HADRON PRODUCTION IN NEUTRINO INTERACTIONS WITH NUCLEONS AND NUCLEI AT HIGH ENERGIES

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OUTLOOK

I. Motivation to study of $\nu - N$ *and* $\nu - A$ *reactions at high energies*

II. $1/N$ *expansion in QCD and inclusive* $\nu - N$ *processes*

III. Non perturbative effects at moderate and low Q^2 *in* $\nu + p \to \mu^- + X$ *reactions*

IV. Inclusive and semi-inclusive $\nu + A \to \mu^- + X$ *processes*

V. Comparison obtained results with NOMAD data and other calculations

VI. A possible application of suggested approach to analyze the OPERA experiment

VII. Summary

Planar and cylinder graphs

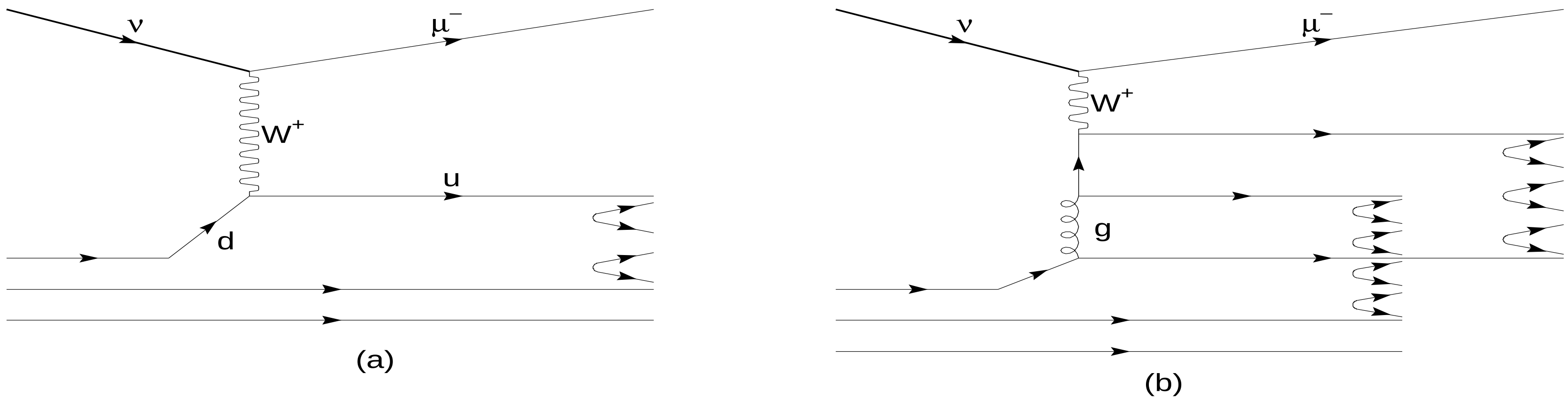

Figure 1: The planar graph (left panel) and the cylinder graph (right panel). *G.Veneziano, Phys.Lett., B52,220 (1974)*

Semi-inclusive process $\nu(\bar{\nu})p \to \mu^-(\mu^+)hX$

$$\rho_{nu(\bar{\nu})p\to\mu^-(\mu^+)hX} = E_h \frac{dN}{d^3p_h d\Omega dE'}$$

Relativistic invariant semi-inclusive spectrum

$$\rho_{\nu(\bar{\nu})p\to\mu^-(\mu^+)hX} = \Phi(Q^2)\left\{F_P(x,Q^2;z,p_t) + F_C(x,Q^2;z,p_t)\right\}$$

with

$$\Phi(Q^2) \; = \; mE\frac{G^2}{\pi}\frac{m_W^2}{Q^2+m_W^2} \; ,$$

where G is the Fermi weak coupling constant, E is the energy of incoming neutrino, m and m_W are the nucleon and the W-boson masses respectively. $x = Q^2/2(p_\nu \cdot k)$ is the Bjorken variable, p_ν and k are the four-momenta of the initial neutrino and nucleon, $z = (E_h + p_{hz})/(E + p_z)$ is the light cone variable.

The variable z can be treated also as the Feynman variable $x_F = \frac{2p_L^*}{W_X}$ defined as the longitudinal momentum fraction in the hydronic center mass system (h.c.m.s.), p_L^* is the longitudinal hadron momentum in the h.c.m.s. (*G.L., U.Sukhatme, V.V.Uzhinsky, Phys.Lett.***B553***,217 (2003)*)

Mean multiplicity of charged hadron in the current fragmentation region

The multiplicity $< n_{ch} >$ measured by NOMAD is close to $< n_c h > /2$ results from e^+e^- experiment at $E = \sqrt{s}$ and $< n_c h >$ from ep and $\bar{\nu}p$ at $E = Q$. **QCD fit for $< n_c h >$**

$$< n_{ch}^{QCD} > = \ a \ + \ b \exp(c\sqrt{ln(Q^2/Q_0^2)}) \ ,$$

where a=2.257, b=0.094, c=1.775, Q_0=1GeV.c. (*W.Furmanski, R.Petronzio, S.Pokorski, Nucl.Phys.***B155***,253 (1979); A.Bassetto, M.Ciafaloni, G.Marchesini, Phys.Lett.***B83***, 207(1979);K.Konishi, Rutherford Report RL 79-035 (1979); A.H.Mueller, Phys.Lett.***B213***, 85(1983)*)

Multiple hadron production in $\nu - p \rightarrow \mu^- + X$ process

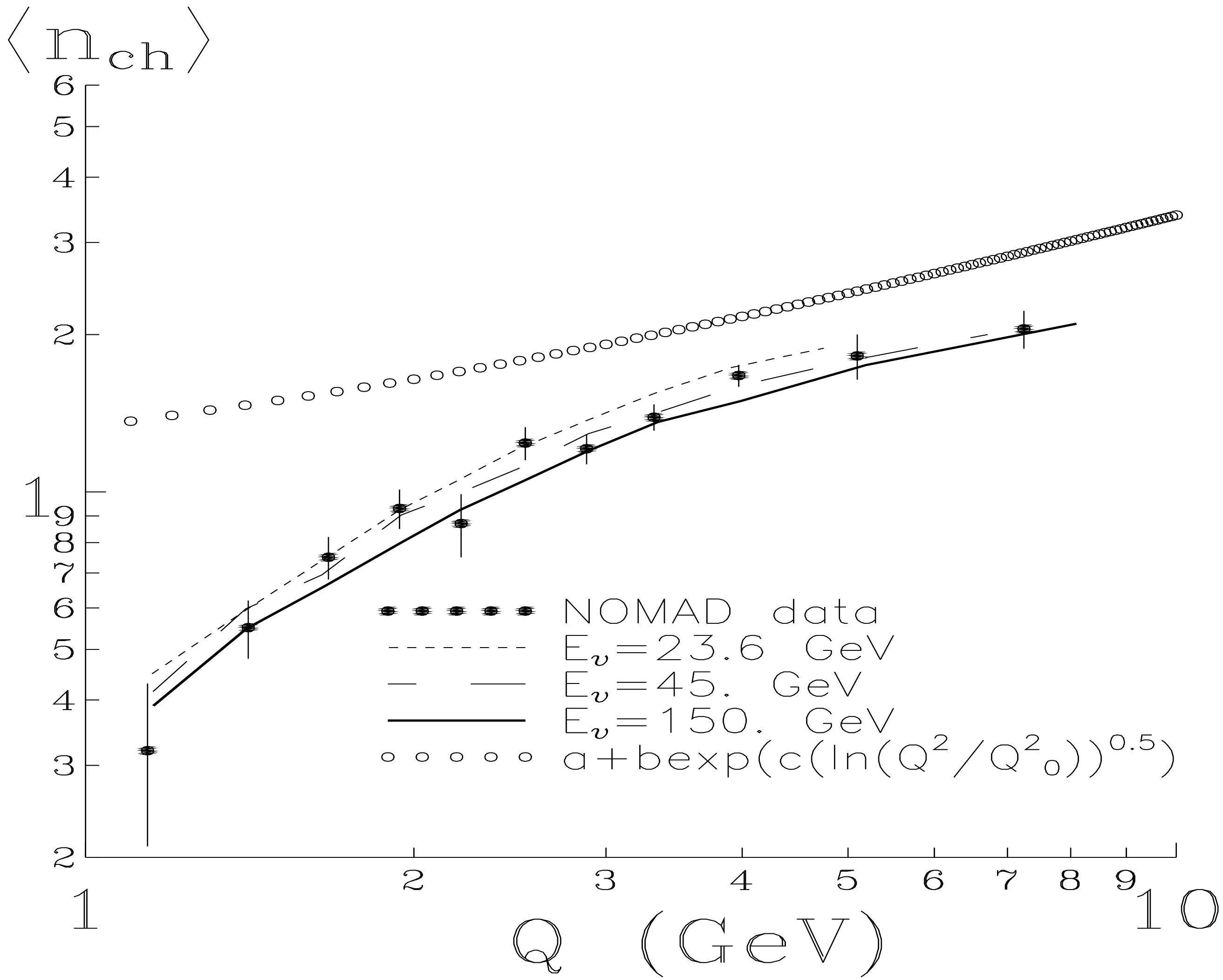

Figure 2: Mean multiplicity of charged hadron in the current fragmentation region as a function of the momentum transfer Q. The open circles correspond to the QCD fit; the solid, long dash and short dash lines correspond to our calculations at E_ν=150.GeV, 45.GeV and E_ν=23.6.GeV respectively. The experimental points are the NOMAD data.

Q^2-inclusive spectrum

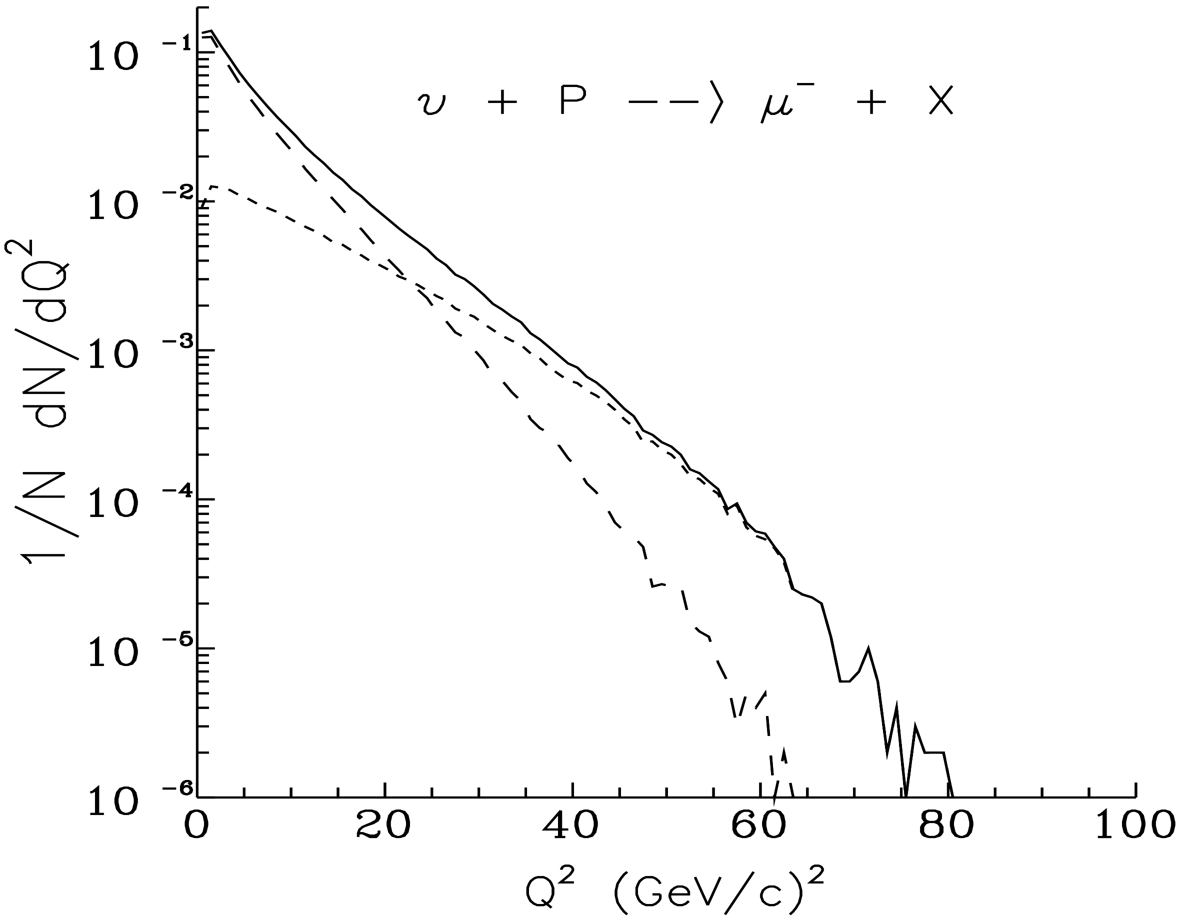

Figure 3: The Q^2-distribution $\frac{1}{N}\frac{dN}{dQ^2}$ of muons produced in $\nu\ p \to \mu^-\ X$ reaction. The long dash and short dash lines correspond to the contributions of the cylinder and planar graphs respectively. The solid line is the sum of these contributions.

x_F-distributions of strange hadron

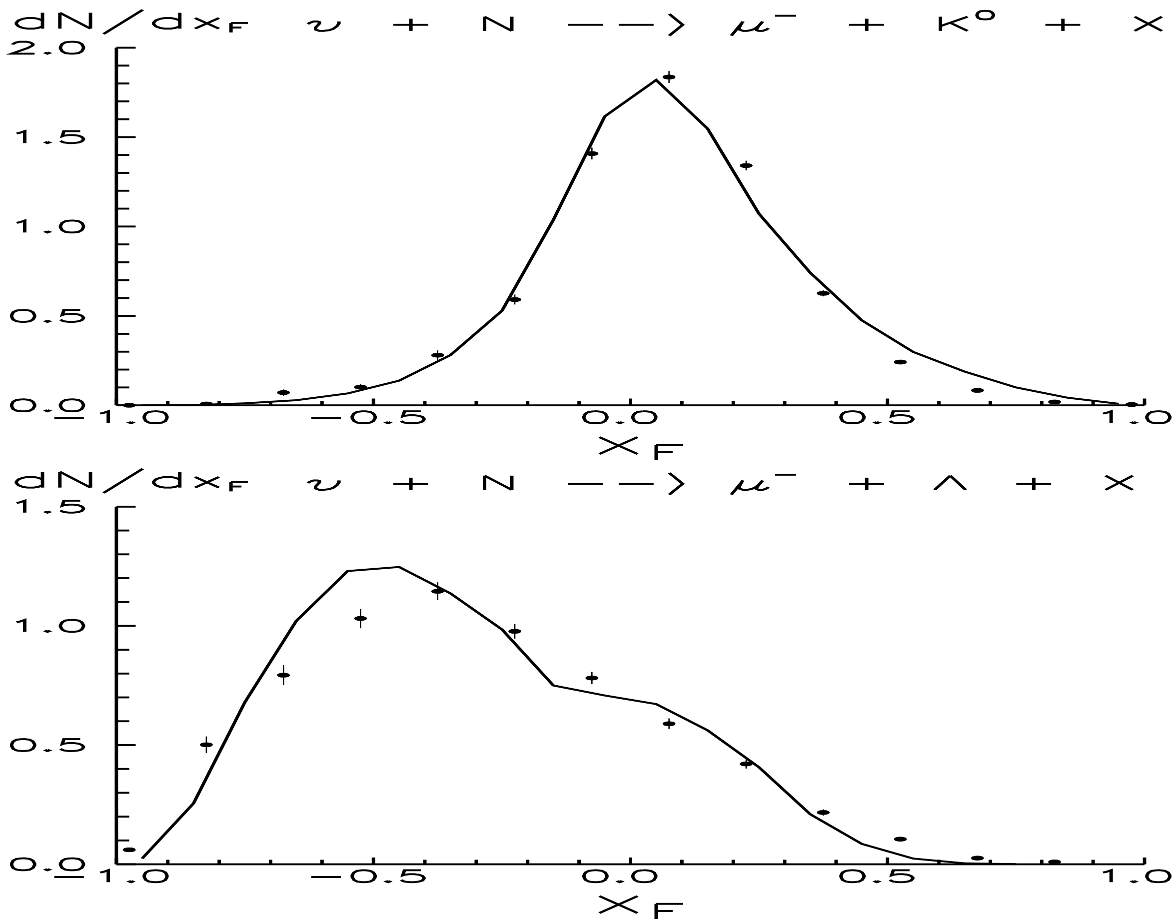

Figure 4: The x_f-distribution of strange hadron dN/dx_F. produced in $\nu\ p \to \mu^-\ X$ reaction.

Multiplicity of strange hadrons

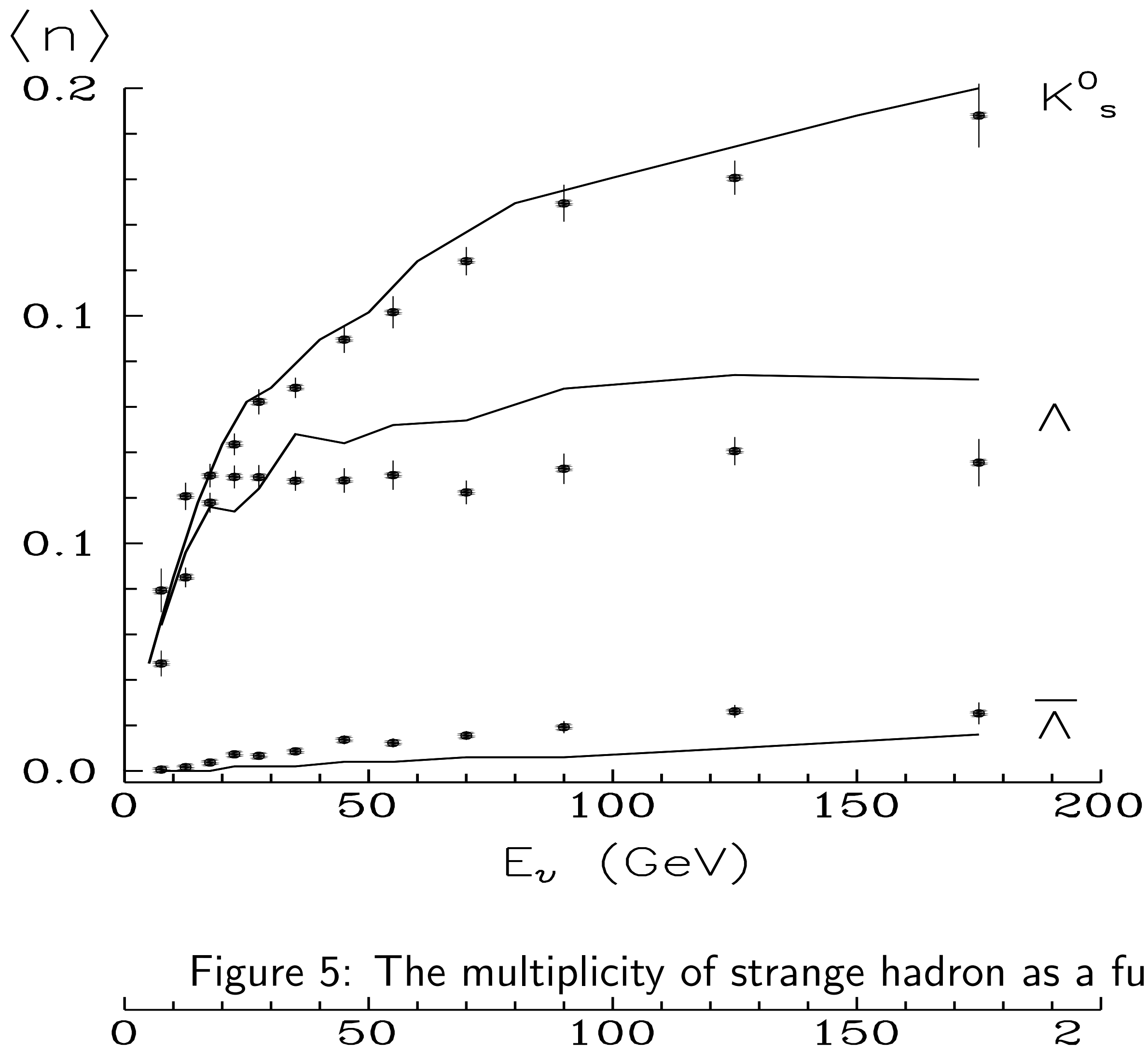

Figure 5: The multiplicity of strange hadron as a function of neutrino energy E_ν.

MC calculation of K_S^0-spectra

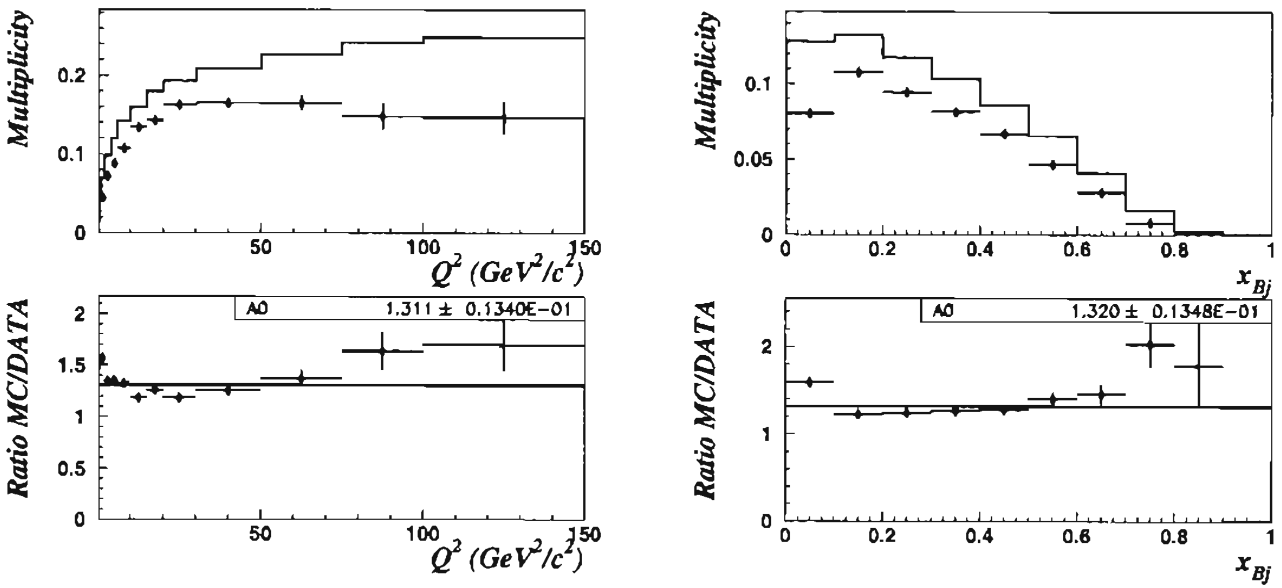

Fig. 6. *Yields in the default MC (histogram) and in the data (points with error bars) for* K_S^0 *as a function of* E_ν, W^2, Q^2 *and* x_{Bj}. *The MC/Data ratios and their fit to a constant are also shown.*

Figure 6: The multiplicity of K_S^0 and ratio MC/DATA as a function of Q^2 and x_B, MC(hystogram) calculation and th NOMAD data (points with errorbars).

(*P.Astier (NOMAD Coll.), Nucl.Phys.***B621***, (2002)*)

MC calculation of K_S^0-spectra

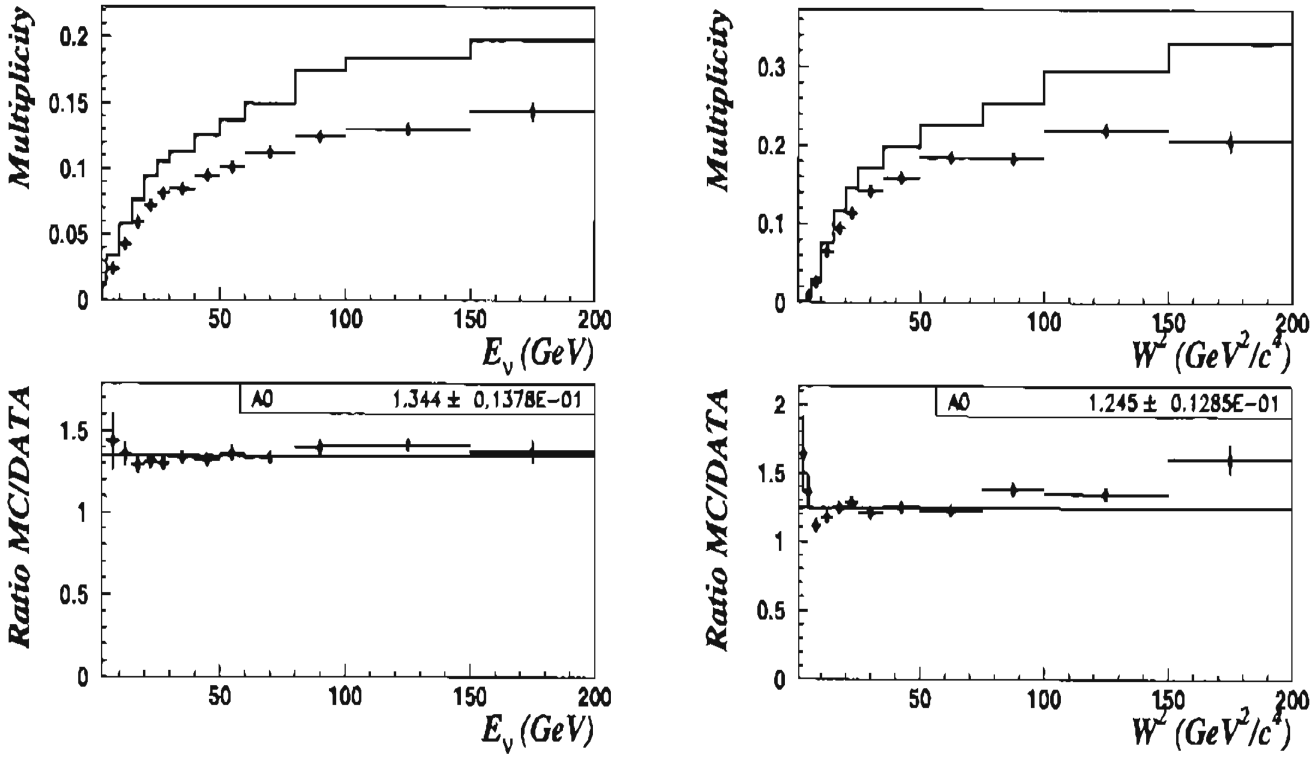

Figure 7: The multiplicity of K_S^0 and ratio MC/DATA as a function of E_ν and W_X, MC(hystogram) calculation and th NOMAD data (points with errorbars).

(*P.Astier (NOMAD Coll.), Nucl.Phys.***B621***, (2002)*)

MC calculation of Λ^0-spectra

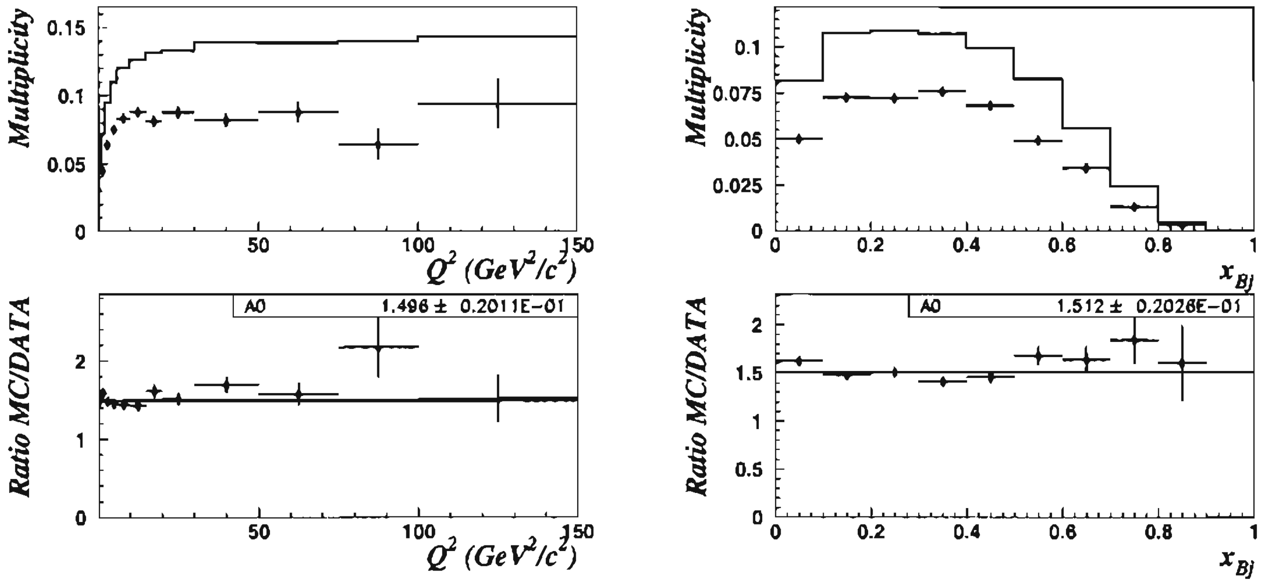

Fig. 7. *Yields in the default MC (histogram) and in the data (points with error bars) for* Λ *as a function of* E_ν, W^2, Q^2 *and* x_{Bj}. *The MC/Data ratios and their fit to a constant are also shown.*

Figure 8: The multiplicity of Λ^0 and ratio MC/DATA as a function of Q^2 and x_B, MC(hystogram) calculation and th NOMAD data (points with errorbars).

(*P.Astier (NOMAD Coll.), Nucl.Phys.***B621***, (2002)*)

MC calculation of Λ^0-spectra

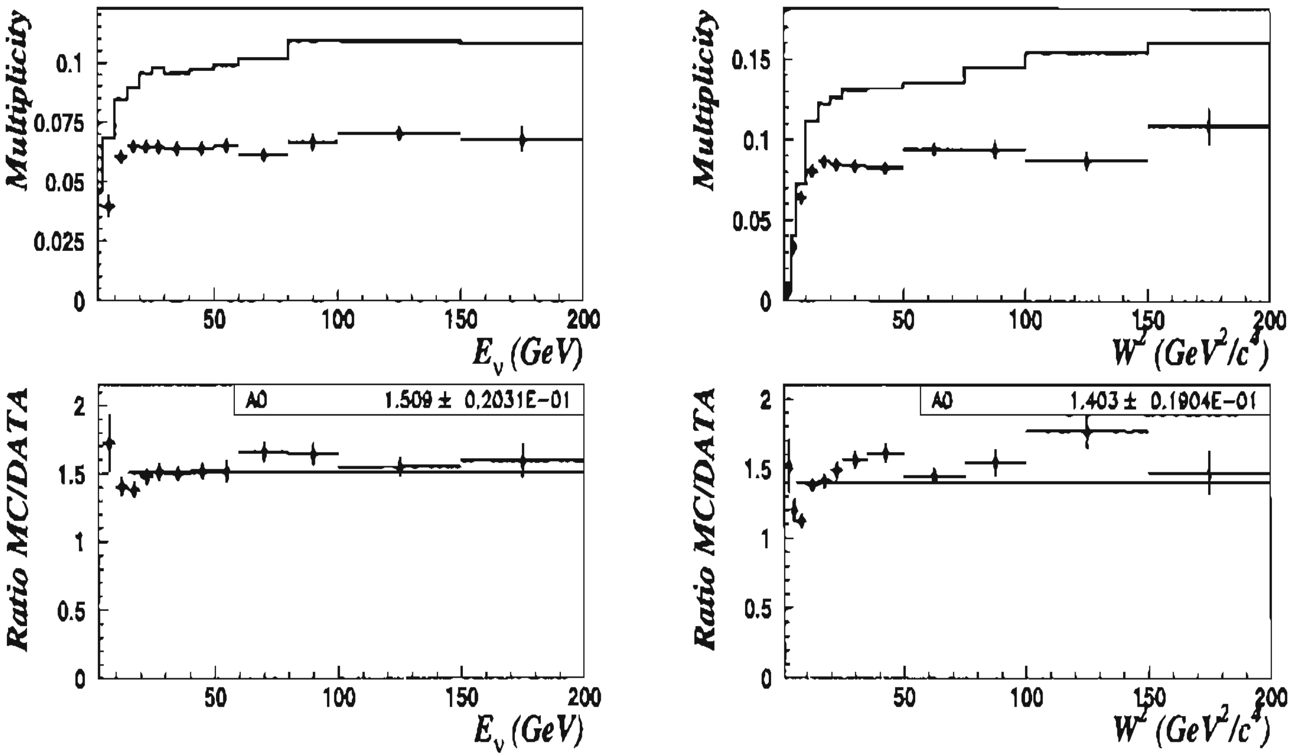

Figure 9: The multiplicity of Λ^0 and ratio MC/DATA as a function of E_ν and W_X, MC(hystogram) calculation and th NOMAD data (points with errorbars).

(*P.Astier (NOMAD Coll.), Nucl.Phys.***B621***, (2002)*)

Theoretical framework

$$\rho_{lA\to l'hX} \equiv E_h \frac{d\sigma}{d^3p_h d\Omega dE'}(x,Q^2;z,p_t) \ ,$$

$$\rho_{lA\to l'hX}(x,Q^2;z,p_t) = \int_{z\leq y} dy d^2k_t f_A(y,Q^2,k_t) \times$$

$$[\frac{Z}{A}\rho_{lp\to l'hX}(\frac{x}{y},Q^2;\frac{z}{y},p_t-k_t) + \rho_{ln\to l'hX}(\frac{x}{y},Q^2;\frac{z}{y},p_t-k_)] \ ,$$

where Z, N and A are the numbers of nucleons, protons and neutrons in the nucleus;

$$f_A(y,k_t) = \int dk_0 dk_z S(k) y\delta(y - \frac{M_A}{m}\frac{(kq)}{(P_A q)}$$

Here $q^2 = -Q^2$, $S(k)$ is the relativistic invariant function describing the nuclear vertex with an outgoing virtual nucleon; $y = \frac{M_A}{m}\frac{(kp_\nu)}{(P_A q)}$
(*O.Benhar,S.Fantoni, G.L., N.V.Slavin, Phys.Rev.***C57***,1532 (1998)*)

Multiplicity of backward going charged pions

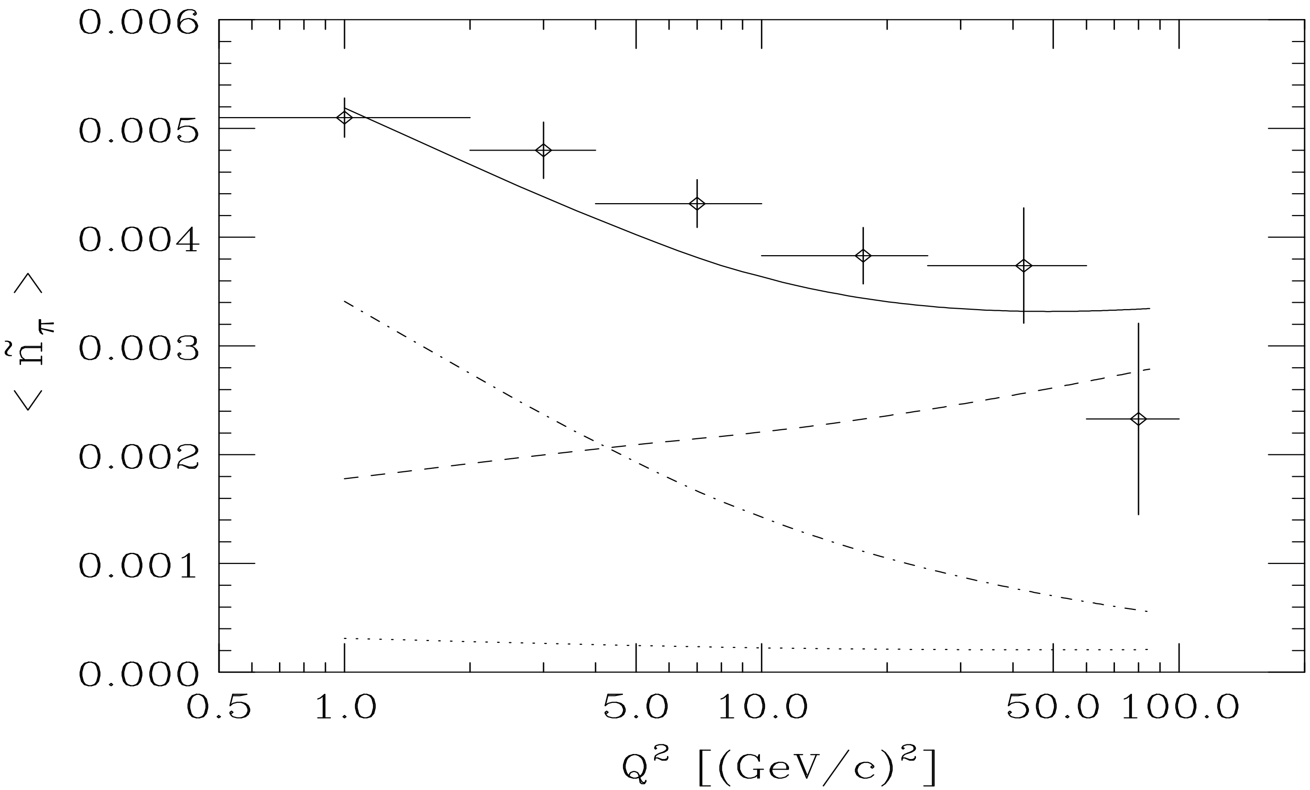

Figure 10: Mean multiplicity of charged pions produced in backward semi-sphere in $\nu^{12}C \to \mu^-\pi X$ process

(*P.Astier, et al., (NOMAD Coll.) Nucl.Phys..***B609***,255 (2001)*)

Our calculations

(*O.Benhar,S.Fantoni, G.L., U.Sukhatme, Phys.Lett.***B527***,73 (2002)*)

Semi-inclusive $\nu^{12}C \rightarrow \mu^{-}\pi^{-}X$ process

Backward going pions

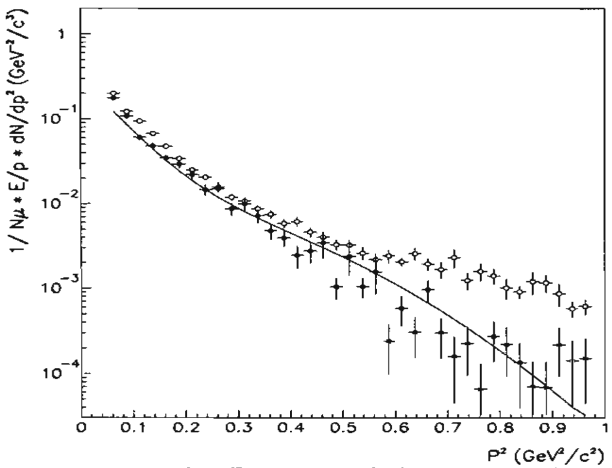

Fig. 13. *Invariant spectrum for $B\pi^{-}$ in MC (open circles) and data (full circles). The solid line is the curve of Ref. [43] superimposed with an arbitrary normalization.*

Figure 11: Comparison of our calculations (solid line) with the NOMAD data (full circles) and the MC calculation (open circles)

MC calculation and NOMAD data

(*P.Astier, et al., (NOMAD Coll.) Nucl.Phys..***B609***,255 (2001)*)

Our calculations

(*O.Benhar,S.Fantoni, G.L., Eur.Phys.J.***A7***,415 (2000);*
O.Benhar,S.Fantoni, G.L., U.Sukhatme, V.V.Uzhinsky,
*Eur.Phys.J.***A19***,147 (2004)*)

SUMMARY

I. The standard QCD model analyzing the multiple hadron production in lepton-proton interactions has to be corrected at $Q^2 < 10(GeV/c)^2$.

II. The non perturbative corrections can be included applying the $1/N$ *expansion in QCD.*

III. The inclusion of cylinder graphs or one-Pomeron exchange diagrams leads to satisfactory description of existing experimental data.

IV. Application of suggested approach and assuming an existence of non nucleon degrees of freedom in nuclei allows us to describe the NOMAD data on pion production in backward semi-sphere in $\nu - A$ *semi-inclusive processes.*

V. The suggested approach can be applied to analyze experiments like OPERA performed at the LNGS.