Modeling electron and neutrino scattering:

from high to low Q^2

Sergey Alekhin

IHEP Protvino

Sergey Kulagin

INR Moscow

Roberto Petti

University of South Carolina
CERN

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OUTLINE

I *Introduction*

II *Charged lepton scattering*

- *Structure functions (SF) down to* $Q^2 = 0$
- *Evaluation of* $R = \sigma_L/\sigma_T$
- *Comparison with low Q data*
- *Extrapolation to resonance region*

III *Neutrino (antineutrino) scattering*

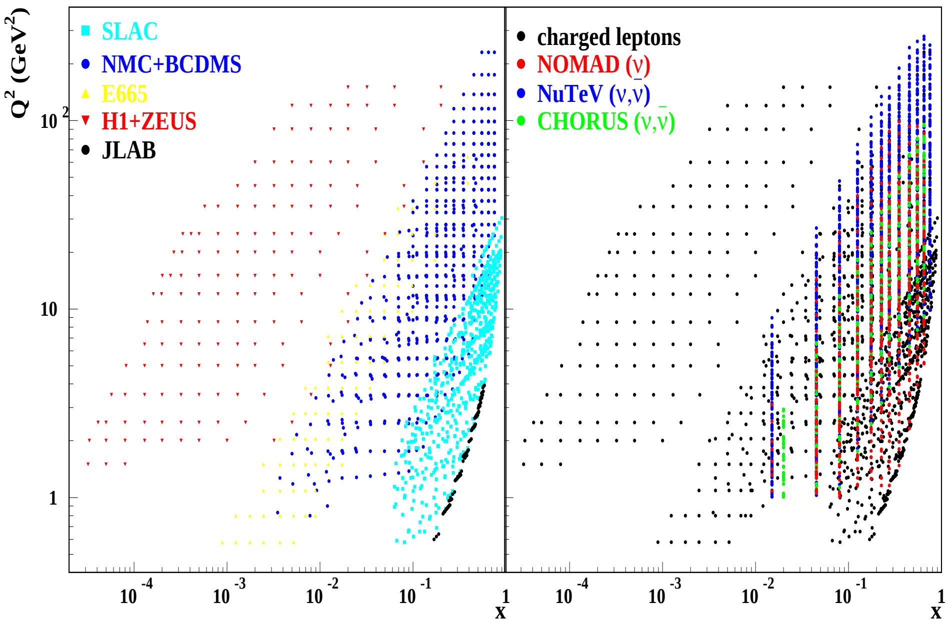
- *Axial-vector current and SF limit for* $Q^2 \rightarrow 0$
- *Comparison with NOMAD, CHORUS and NuTeV cross-section data*
- *Comparison with low Q data*

STRUCTURE FUNCTION PHENOMENOLOGY

❖ NNLO *pQCD approximation is used for parton distributions (PDF) and structure functions (SF) as default. Analysis in the* $\overline{\mathrm{MS}}$ *scheme with number of flavours fixed at 3 (FFS). Parton distributions are evolved from* $Q_0^2 = 9$ *GeV*^{2}.

$$F_i(x,Q^2) = F_i^{\mathrm{LT,TMC}}(x,Q^2) + \frac{H_i^{(4)}(x)}{Q^2} + \frac{H_i^{(6)}(x)}{Q^4} \qquad i=1,2,3$$

- *Electron and muon scattering data on p and D from BCDMS,HERA,JLab,NMC,SLAC*
- *Neutrino (antineutrino) scattering data on C, Fe and Pb from NOMAD, NuTeV and CHORUS*
- *Drell-Yan data on pCu (E605) and pD/pp (E866)*
- *When possible, use cross-section data rather than structure function data*
- *Fit all data with* $Q^2 > 1.0\ GeV^2$ *and center-of-mass energy* $W > 1.9$ *GeV (avoid resonances)*
- *PDF and HT ($H_i(x)$) uncertainties from fits*



TARGET MASS CORRECTIONS

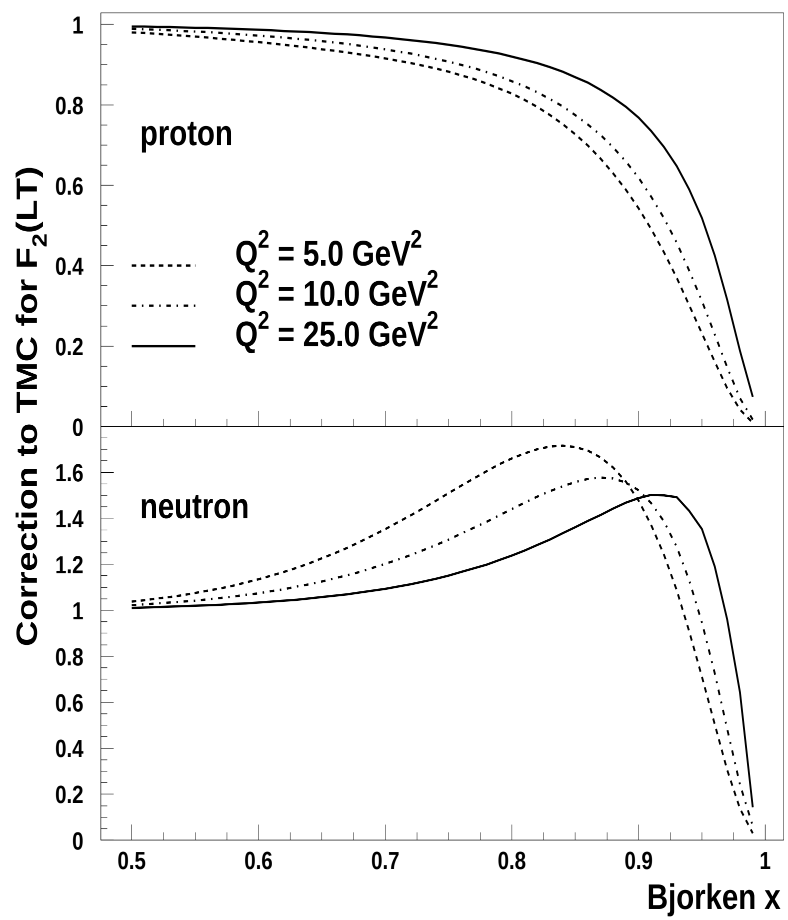
- *Effect of finite mass of target nucleon for small values of x^2M^2/Q^2 can be calculated according to Georgi and Politzer:*

$$F_2^{\rm TMC}(x,Q^2) = \frac{x^2}{\xi^2\gamma^3}F_2^{\rm LT}(\xi,Q^2) + \frac{6x^3M^2}{Q^2\gamma^4}\int_\xi^1 \frac{dz}{z^2}F_2^{\rm LT}(z,Q^2)$$

with $\gamma = (1+4x^2M^2/Q^2)^{1/2}$ *and* $\xi = 2x/(1+\gamma)$

- FOR $x \to 1$ *we cure the thresold problem of previous expression by expanding it in series of* Q^{-2} *(not applied yet in QCD fits, only in nuclear part)*

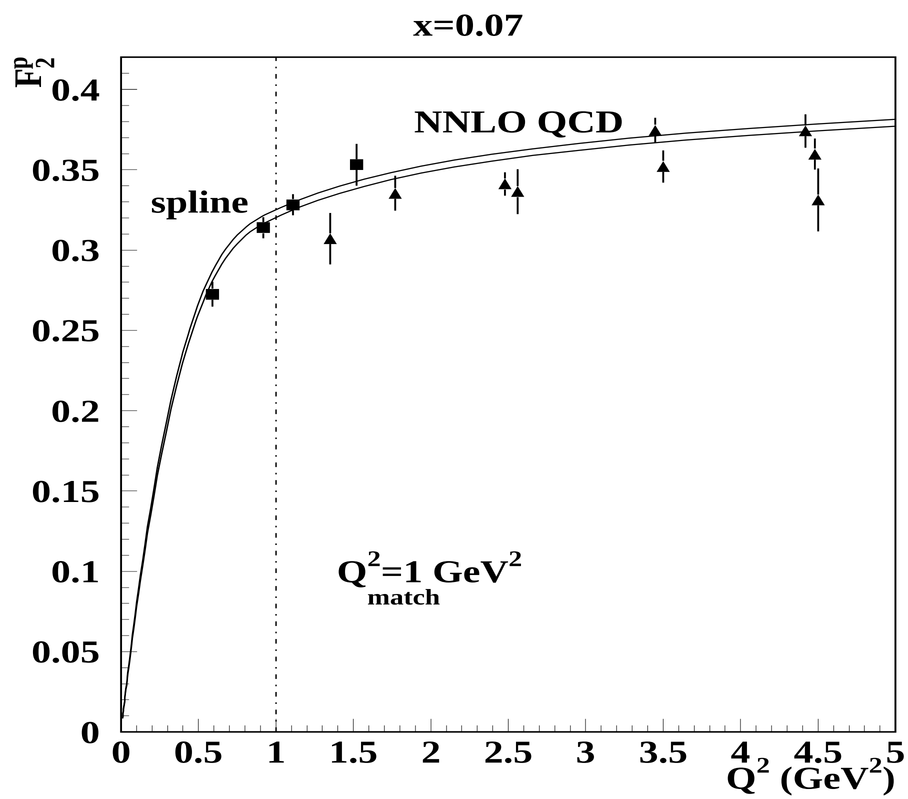
$\Longrightarrow$ *As a result $F_i^{\rm TMC}(x,Q^2)$ are vanishing for $x \to 1$ if both LT and its derivative vanish*



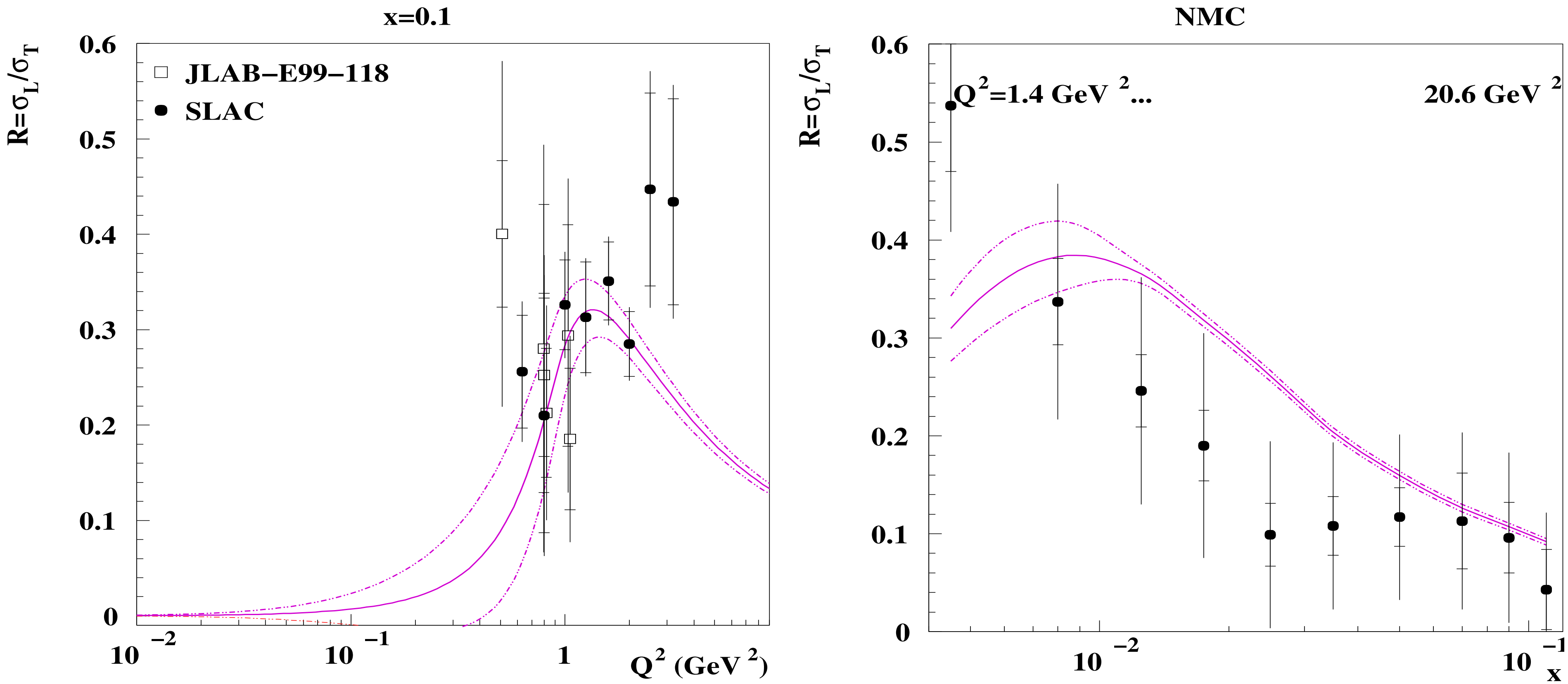
STRUCTURE FUNCTIONS DOWN TO $Q^2 = 0$

✦ LOW Q SF are constructed as smooth interpolation between QCD approach (LT + HT) at high Q^2 and the limit for $Q^2 \to 0$ from current conservation arguments:

- QCD matching point $Q^2_{\rm match} = 1.0$ GeV^2
- Conservation of Electromagnetic Current implies $F_2 \sim Q^2$ and $F_L \sim Q^4$ as $Q^2 \to 0$.
- A cubic spline interpolation at fixed x is applied from $Q^2 = 1.0$ GeV^2 to the $Q^2 = 0$ limit predicted by current conservation.
- Functions and derivatives match at $Q^2_{\rm match}$
- The region $0 \leq Q^2 \leq 1$ GeV^2 is determined by the asymptotics at $Q^2 \to 0$ and by the matching conditions at $Q^2 = Q^2_{\rm match}$.

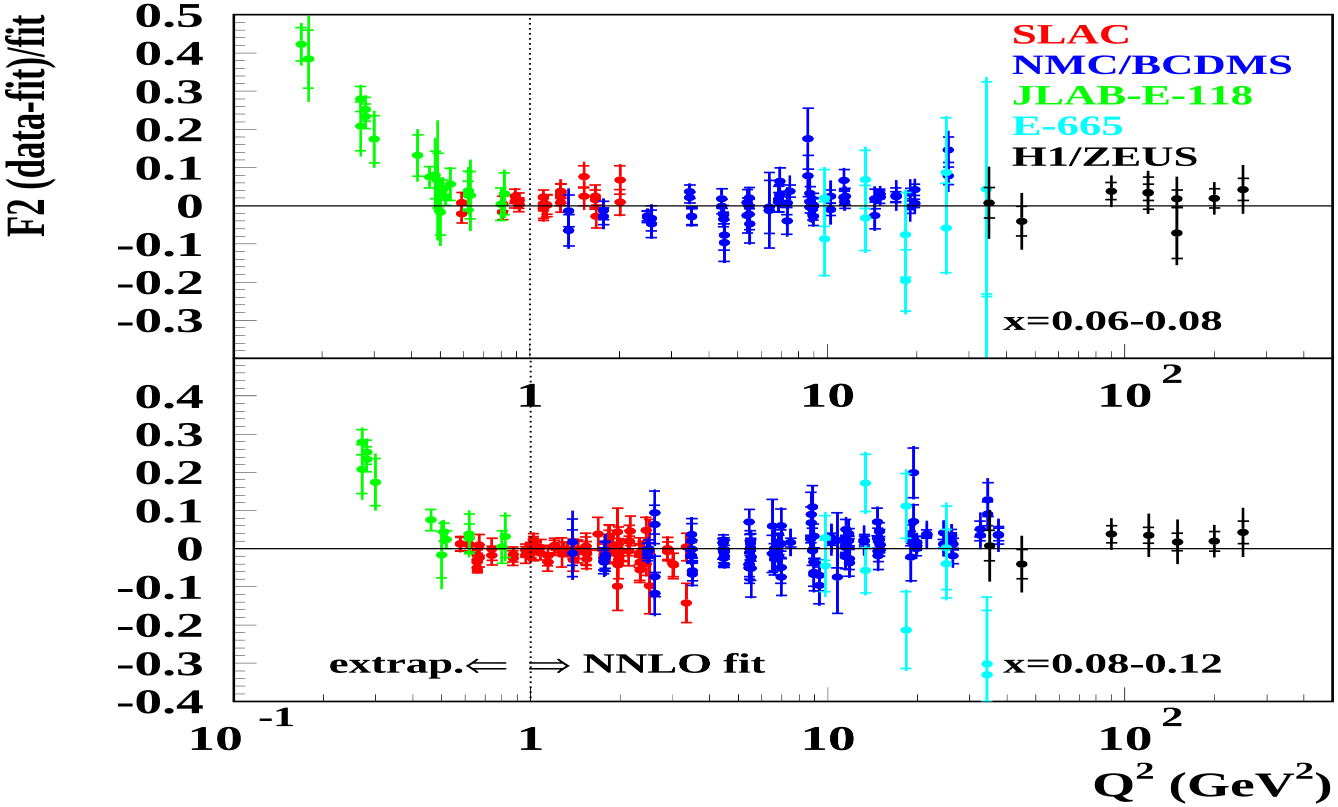


EVALUATION OF $R = \sigma_L/\sigma_T$



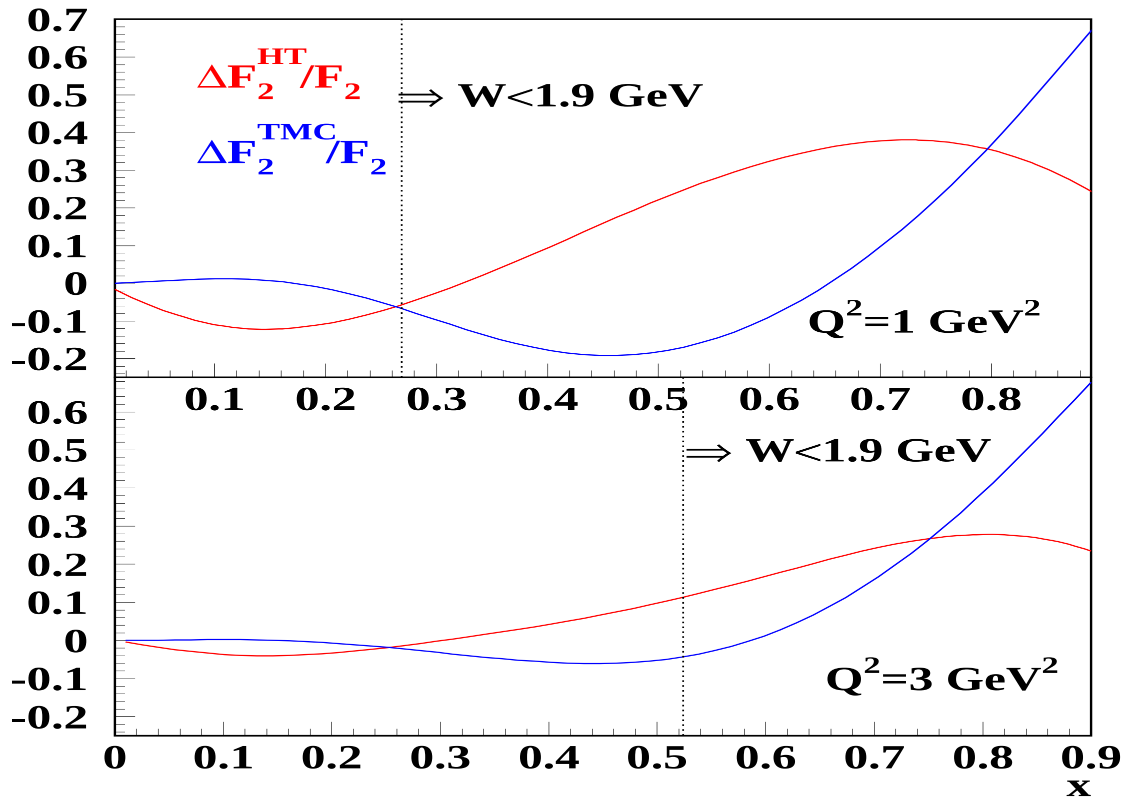
- *Some tension observed between SLAC and NMC data for* $R = \sigma_L/\sigma_T$
- *Impact of N3LO corrections is negligible for relatively large x after re-fitting*

COMPARISON WITH LOW Q DATA



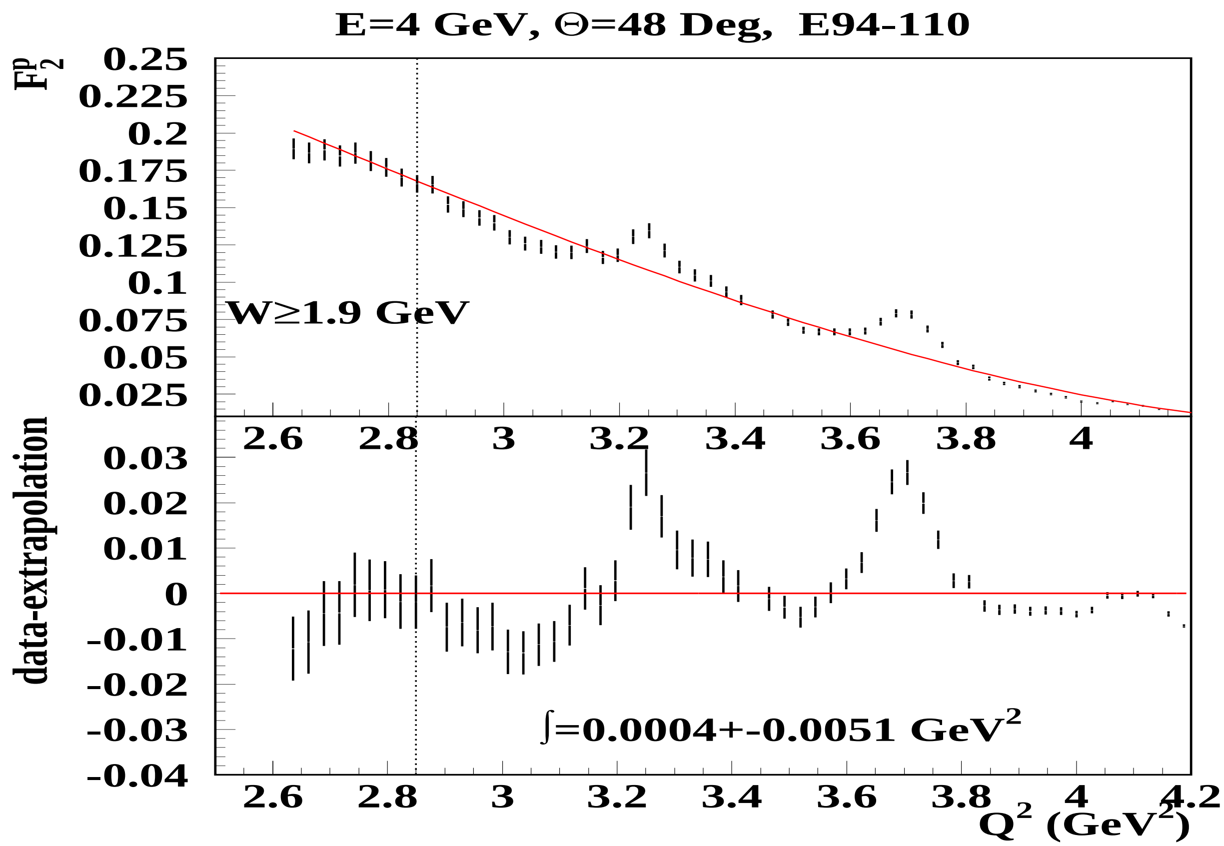
- *Data points with $Q^2 < 1.0$ GeV^2 (JLab, SLAC) are not included in fits*
- *The phenomenological extrapolation of the QCD phenomenology (LT + HT) can provide a good description of charged lepton data down to $Q^2 \sim 0.5$ GeV^2*

IMPACT OF HIGH TWISTS



- *The total High Twist contribution (Twist-4 + Twist-6) is, in general, a small correction to structure functions*
- *The extrapolation of phenomenological HTs provides a sizeable correction in the resonance region ($W < 1.9$ GeV)*

EXTRAPOLATION TO RESONANCE REGION



- *Use data on p and D targets with $W > 1.9$ GeV in fits.*
- *Extrapolation of DIS calculations to the resonance region with $W < 1.9$ GeV (not used in fits) is consistent with duality.*

APPLICATION TO NEUTRINO SCATTERING

- *Neutrino scattering is characterized by the* **AXIAL-VECTOR CURRENT** *(V-A):*

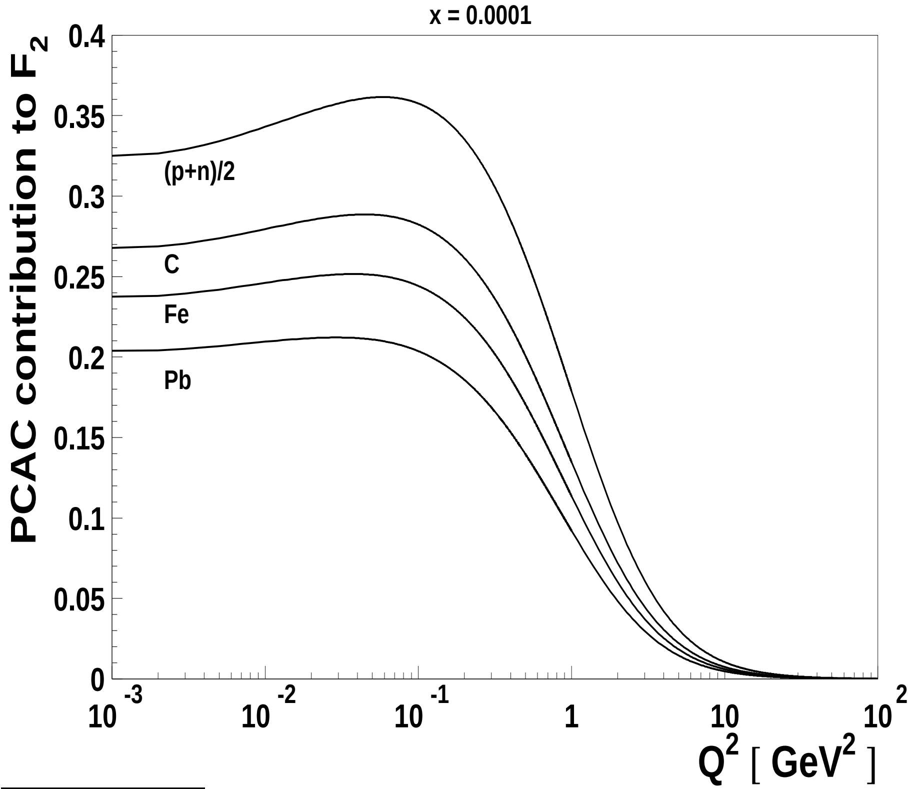
$$VV, AA \implies F_{1,2} \quad (or\ F_L,\ F_T)$$
$$VA \implies F_3$$

- *Conservation of Vector Current (CVC), in analogy to the charged leptons, implies:*

$$F_2, F_T \sim Q^2 \qquad F_L \sim Q^4 \qquad for \quad Q^2 \to 0$$

- *Axial Current is only Partially Conserved (PCAC) and dominates F_L at low Q^2:*

$$\partial A = f_\pi m_\pi^2 \varphi \quad \implies \quad F_L = \frac{f_\pi^2 \sigma_\pi}{\pi}$$



- *Transition scale between low and high Q^2 is* NOT m_π^2 *but rather $m_a \sim 1\ GeV^2$, since direct pion contribution $\partial_\mu \varphi$ cancels out. We use the following model:*

$$F_L = \frac{f_\pi^2 \sigma_\pi}{\pi}(1 + Q^2/m_a^2)^{-2} + \widetilde{F}_L \qquad with \quad \widetilde{F}_L \propto Q^4 \quad for \quad Q^2 \to 0$$

$\implies$ *Non vanishing contribution to $F_2 = (F_L + F_T)/(1 + 4x^2M^2/Q^2)$ for $Q \to 0$.*

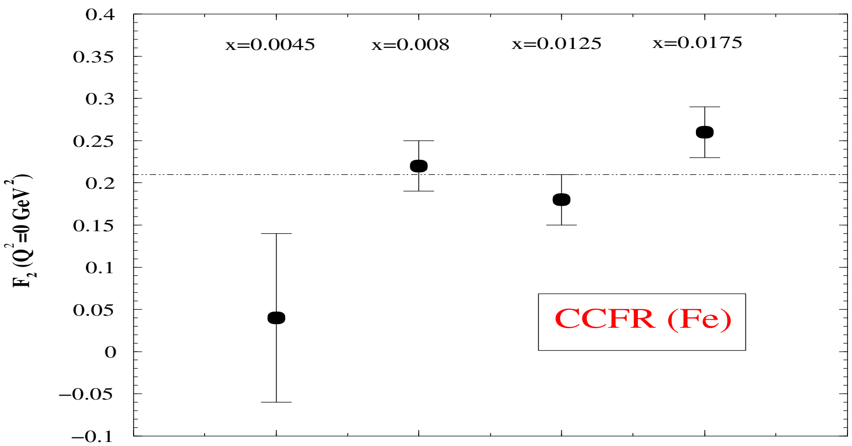
- *Predictions for the asymptotic value $F_2(Q^2 = 0)$ in neutrino CC scattering seem in agreement with the CCFR determination on Fe target 0.210 ± 0.02.*

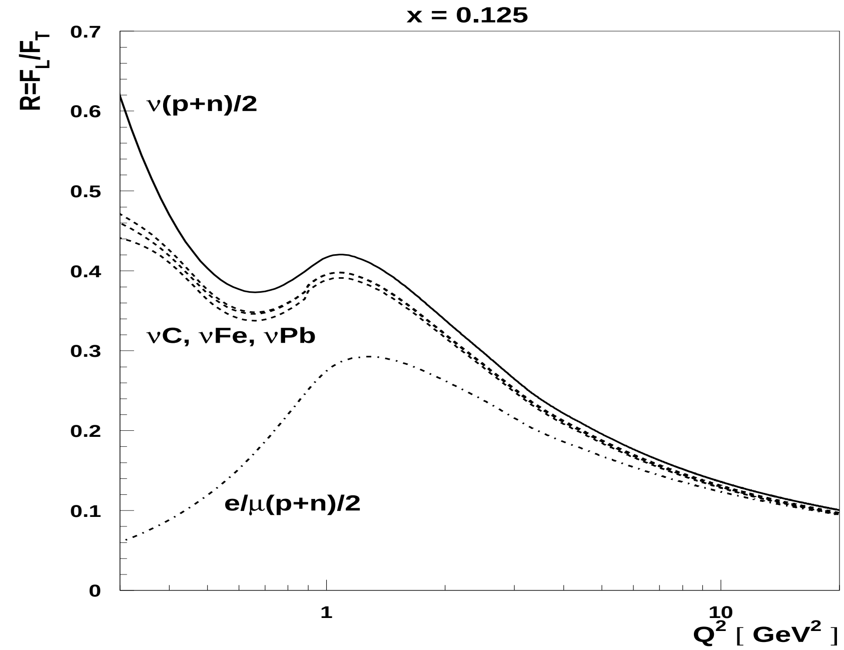
- *The finite PCAC contribution to F_L strongly affects the asymptotic behaviour of $\boxed{R = \sigma_L/\sigma_T}$ for $Q^2 \to 0$:*

$$F_T \sim Q^2$$
$$F_L \sim \frac{f_\pi^2 \sigma_\pi}{\pi} > 0$$

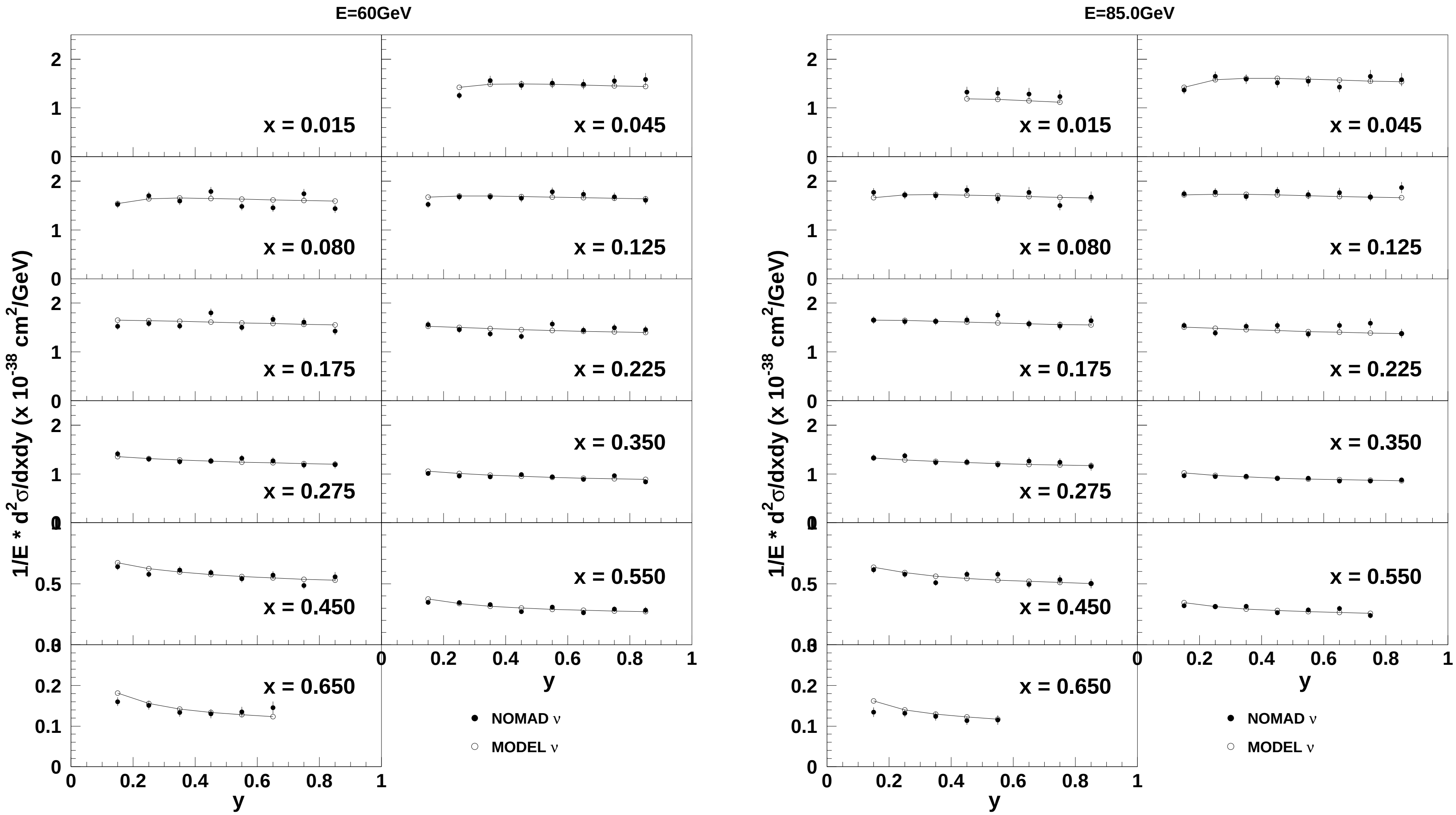
so that R is divergent for vanishing Q^2

$\Longrightarrow$ *Substantial difference with respect to charged lepton scattering.*



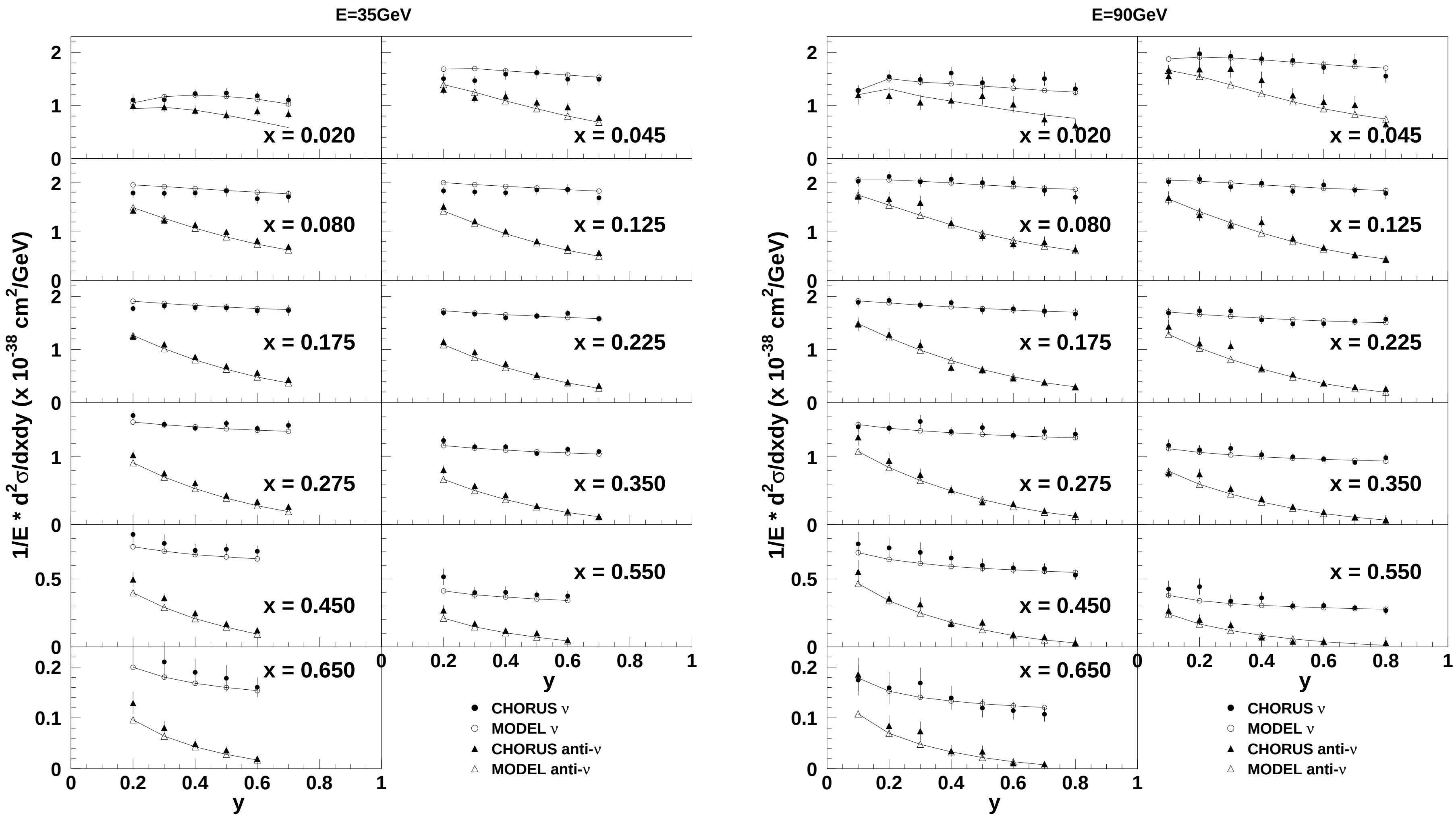


COMPARISON WITH NOMAD νC CROSS-SECTION



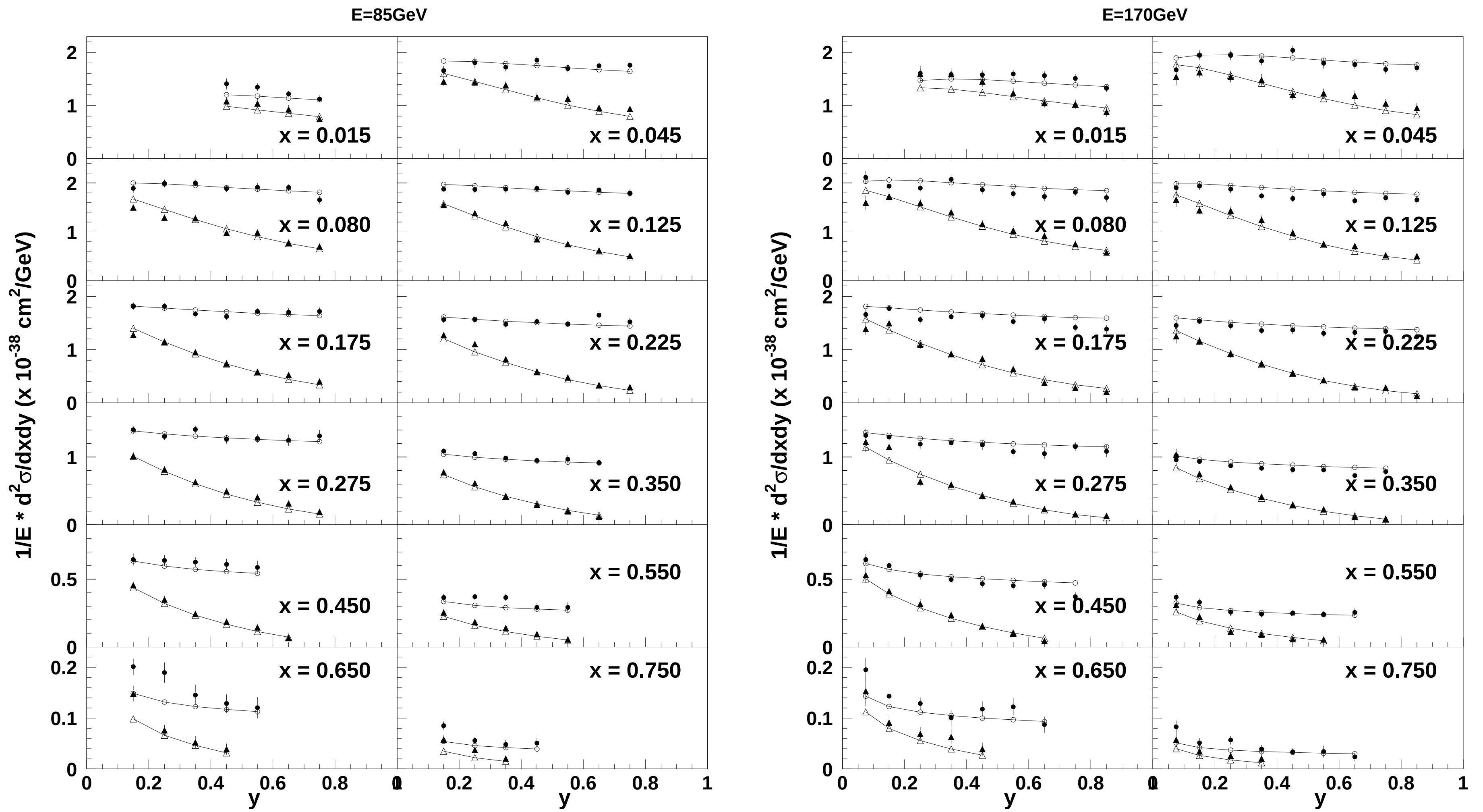
Predictions of our model for differential cross sections of different neutrino energies vs. data (R.P., NuInt 2005)

COMPARISON WITH CHORUS $\nu(\bar{\nu})Pb$ CROSS-SECTIONS



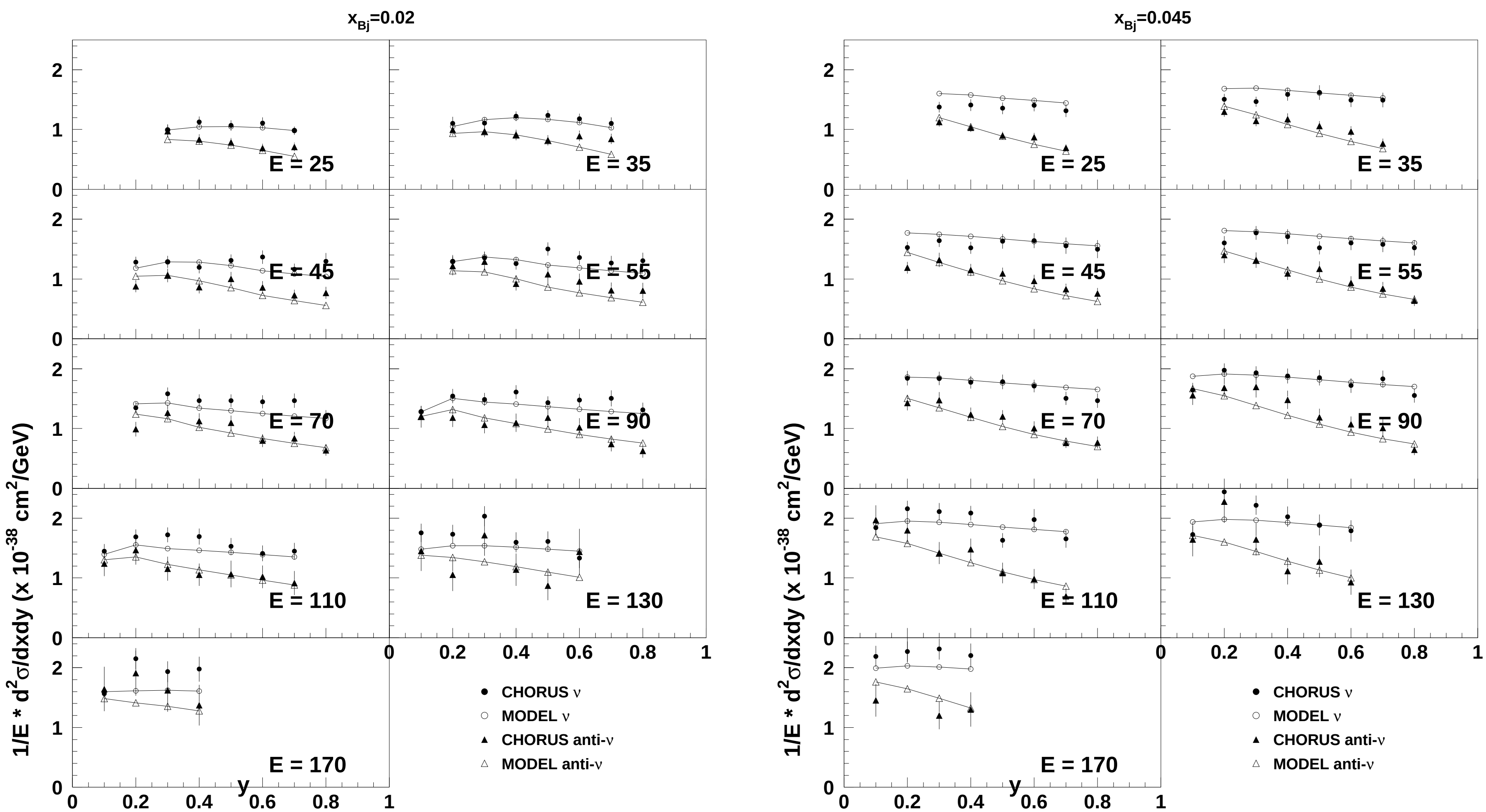
Predictions of our model for differential cross sections
of different neutrino energies vs. data (G. Önengüt et al., Phys. Lett. B. 632 (2006) 65.)

COMPARISON WITH NuTeV $\nu(\bar{\nu})Fe$ CROSS-SECTIONS



Predictions of our model for differential cross sections of different neutrino energies vs. data (M. Tzanov, hep-ex/0507040)

COMPARISON WITH LOW Q DATA



Low x (< 0.05) CHORUS data on Pb target reach $Q^2 \sim 0.25$ GeV^2
and can be used for qualitative checks of PCAC contribution

SUMMARY

- *A smooth interpolation between QCD phenomenology (Leading Twist + High Twists) at large Q^2 and limits for $Q^2 \to 0$ from current conservation arguments has been used to parameterize low Q^2 structure functions.*

  $\Longrightarrow$ *Good description of data from charged lepton DIS down to $Q^2 \sim 0.5$ GeV^2.*

- *Contributions from High Twist terms are important for $Q^2 \sim 1$ GeV^2, in particular for the ratio R of longitudinal to transverse cross-sections.*

- *Once the effect of the axial-vector current is taken into account, (anti)neutrino charged-current data are, in general, consistent with charged lepton scattering data and with universality of parton distributions:*
  - *Significant effect of nuclear and electroweak corrections;*
  - *Agreement of calculations with CHORUS, NOMAD and NuTeV data for $x > 0.02$;*
  - *Excess observed in NuTeV data at large x values ($x > 0.5$) with respect to calculations.*