# (Anti)-Neutrino DIS Measurements

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# OUTLINE

**I** *Role of the Neutrino Probe*

- *The Ideal Case: Scattering off Free Nucleon;*
- *The Real Case: Existing Data.*

**II** *Understanding (Anti)-Neutrino Deep Inelastic Scattering*

- *The Axial-Vector Current;*
- *High Twist Contributions to Structure Functions;*
- *Nuclear Effects.*

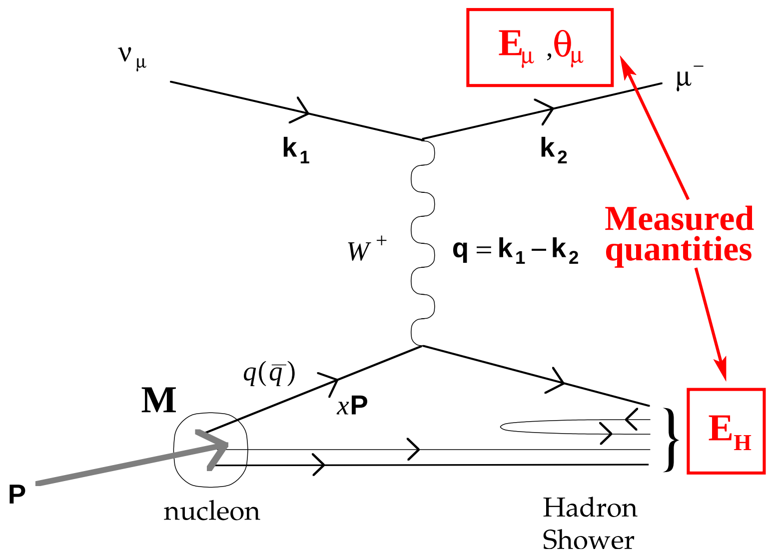
**III** *Determination of Strange Sea Distributions*

- *(Anti)-Neutrino Induced Charm Dimuon Production;*
- *Extraction of the Strange Sea Parameters;*
- *The NOMAD measurements.*

**IV** *Future measurements*

- *The MINER$\nu$A Experiment;*
- *The LBNE Project.*

# THE NEUTRINO PROBE (IDEAL CASE)




$$\begin{aligned} Q^2_{\rm vis} &= 4(E_\mu + E_H)E_\mu \sin^2(\theta_\mu/2) \\ x_{\rm vis} &= Q^2_{\rm vis}/2M(E_H - M) \\ y_{\rm vis} &= E_H/(E_\mu + E_H) \end{aligned}$$

$$\frac{1}{E}\frac{d^2\sigma^{\nu,\bar{\nu}}}{dxdy} = \frac{G_F^2 M}{\pi(1+Q^2/M_W^2)^2}\left[y^2 xF_1 + \left(1 - y - \frac{Mxy}{2E_\nu}\right)F_2 \pm \left(y - \frac{y^2}{2}\right)xF_3\right]$$

- BOTH $\nu$ AND $\bar{\nu}$ DIS *off FREE nucleon ideal probe of nucleon structure:*
  - *Isospin relations* $F_2^{\bar{\nu},p}(x,Q^2) = F_2^{\nu,n}(x,Q^2)$ *(Adler sum rule);*
  - $\sigma^{\nu N} + \sigma^{\bar{\nu}N} \simeq F_2 \sim 2\sum(xq + x\bar{q})$; $\quad \sigma^{\nu N} - \sigma^{\bar{\nu}N} \simeq xF_3 \sim 2\sum(xq - x\bar{q})$
  - *Small radiative corrections.*
- *Complete flavor separation in Charged Current interactions* ($d/u$, $s/\bar{s}$, $\bar{d}/\bar{u}$)
- *Separation of valence* ($xF_3$) *and sea* ($F_2$) *distributions*

$\Longrightarrow$ *We want to measure differential cross-sections and/or structure functions off p,D*

# THE NEUTRINO PROBE (REAL CASE)

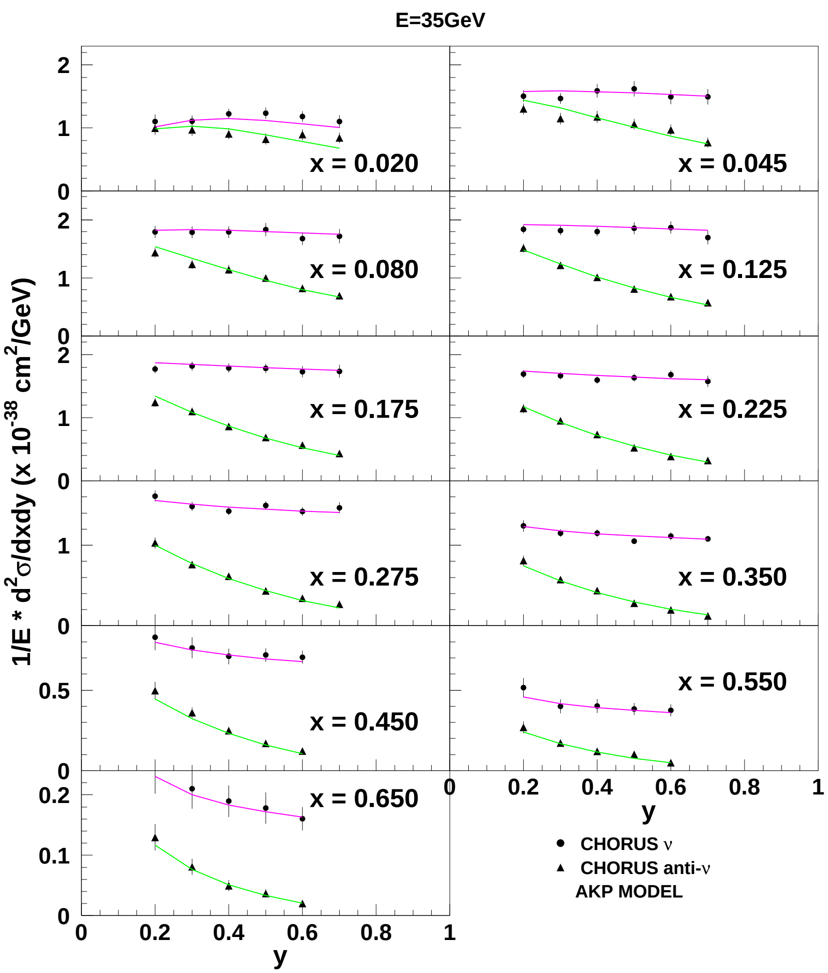
- *Potential of the $\nu(\bar{\nu})$ probe still limited by experimental factors:*
  - BEAM TECHNOLOGY: *beam intensity and knowledge of fluxes;*
  - DETECTOR RESOLUTION: *event reconstruction and energy scales.*

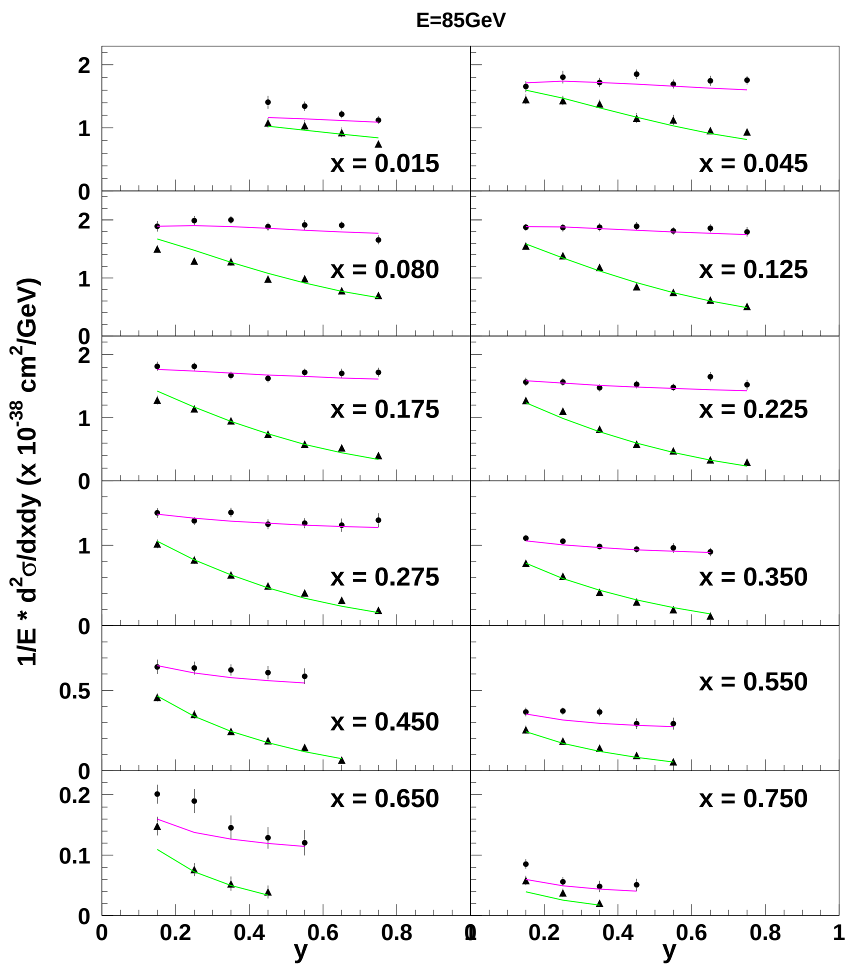
- *Existing measurements of $d^2\sigma/dxdy$ and structure functions use NUCLEAR targets and are significantly affected by systematics on $E_\mu$, $E_{\rm H}$ energy scales and flux*

| Experiment | Mass | $\nu_\mu$ CC Stat. | Target | $E_\nu$ (GeV) | $\Delta E_\mu$ | $\Delta E_{\rm H}$ |
|---|---|---|---|---|---|---|
| CDHS | 750 t | $10^7$ | p,Fe | 20-200 | 2.0% | 2.5% |
| BEBC | various | $5.7\times10^4$ | p,D,Ne | 10-200 | | |
| CCFR | 690 t | $1.0\times10^6$ | Fe | 30-360 | 1.0% | 1.0% |
| NuTeV | 690 t | $1.3\times10^6$ | Fe | 30-360 | 0.7% | 0.43% |
| CHORUS | 100 t | $3.6\times10^6$ | Pb | 10-200 | 2.5% | 5.0% |
| NOMAD | 2.7 t | $1.3\times10^6$ | C | 5-200 | 0.2% | 0.5% |
| | 18 t | $1.2\times10^7$ | Fe | 5-200 | 0.2% | 0.5% |
| MINOS ND | 980 t | $3.6\times10^6$ | Fe | 3-50 | 2-4% | 5.6% |

$\Longrightarrow$ *Next generation experiments need high resolution detectors and $\geq 10^7$ CC events*

# RECENT MEASUREMENTS OF $d^2\sigma/dxdy$




CHORUS (Pb) *PLB 632 (2006) 65-75.*

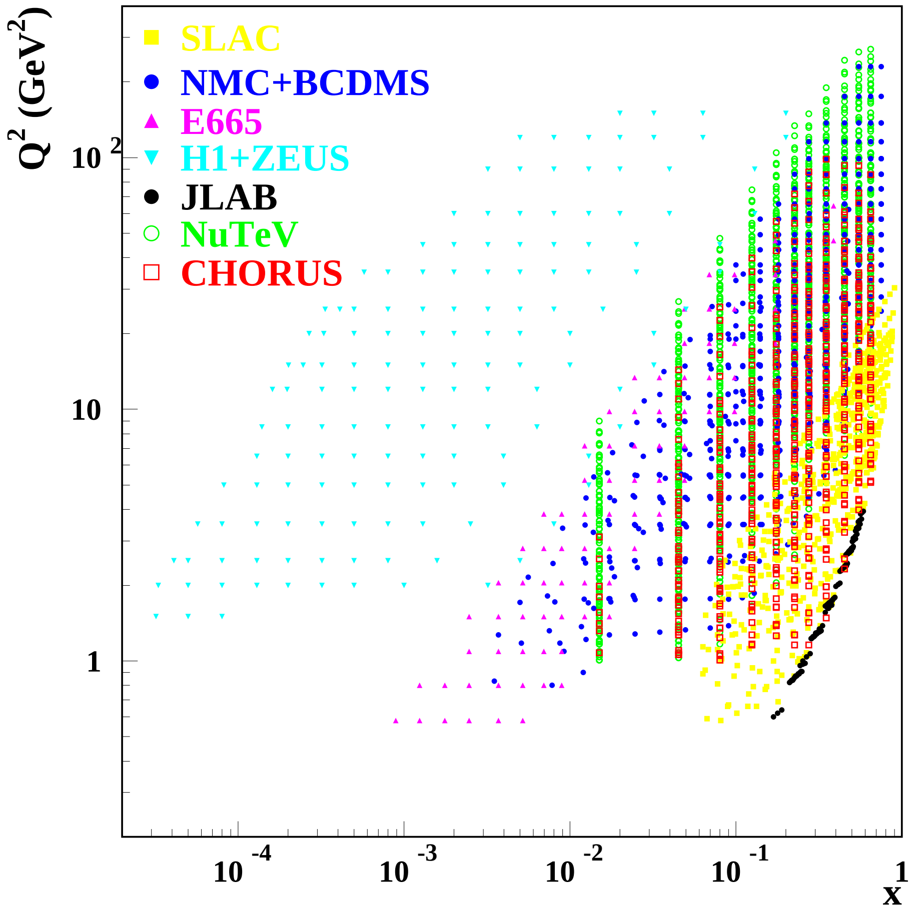
$\Delta E_\mu = 2.5\%, \Delta E_{\rm H} = 5.0\%$

*Selected* $\nu_\mu(\bar{\nu}_\mu)$CC: *870k (146k)*

NuTeV (Fe) *PRD 74 (2006) 012008.*

$\Delta E_\mu = 0.7\%, \Delta E_{\rm H} = 0.42\%$

*Selected* $\nu_\mu(\bar{\nu}_\mu)$CC: *860k (240k)*




- *(Anti)-Neutrino Charged Current (CC) DIS complementary to charged lepton (NC) DIS and Drell-Yan processes*

  $\Longrightarrow$ *Fixed target kinematics*

- *Need to address several model uncertainties in order to benefit from the addition of $\nu(\bar{\nu})$ CC data in global QCD fits:*
  - *Role of the Axial-Vector current;*
  - *High Twist corrections;*
  - *Nuclear effects.*

  $\Longrightarrow$ *Higher complexity with respect to charged lepton scattering off p,D*

# PECULIARITY OF THE WEAK CURRENT

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

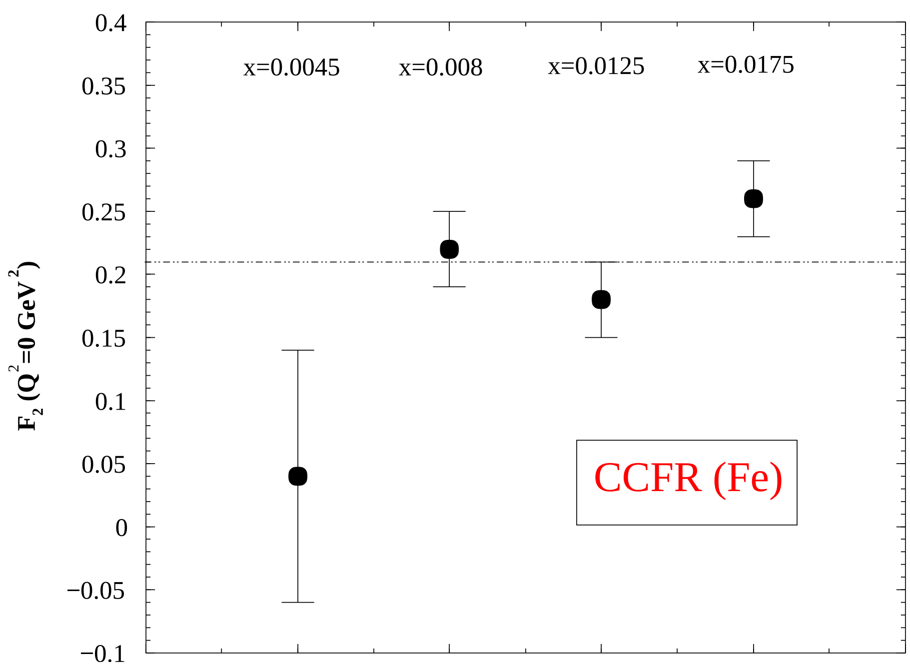
$$VV, AA \implies F_{1,2} \quad (or\ F_L,\ F_T)$$
$$VA \implies F_3$$

- *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 $Q^2$:*

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




- *Transition scale between low and high $Q^2$ is* NOT $m_\pi^2$ *but rather $M_{\mathrm{PCAC}} \sim 1\ GeV^2$, since direct pion contribution $\partial_\mu \varphi$ cancels out. Non vanishing constribution to $F_2$:*

$$F_2 = (F_L + F_T)/(1 + 4x^2M^2/Q^2) \to (f_\pi^2 \sigma_\pi)/\pi \qquad Q^2 \to 0$$

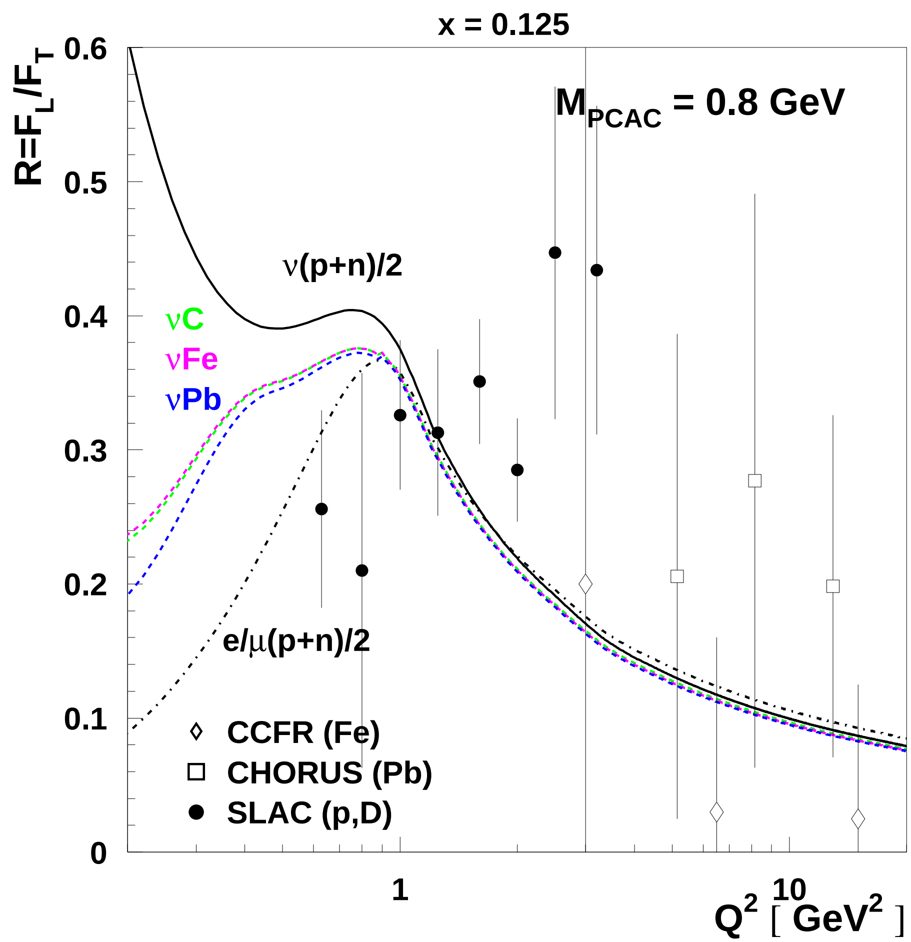
$\implies$ *CCFR determination on $Fe$ target* $0.210 \pm 0.02$ *(CCFR Coll., PRL 86 (2001) 5430).*

- *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.*




*S. Kulagin and R.P., PRD 76 (2007) 094023*

# HIGH TWIST CONTRIBUTIONS

$$F_{T,2,3}(x,Q^2) = F^{\tau 2}_{T,2,3}(x,Q^2) + \frac{H^{\tau 4}_{T,2,3}}{Q^2} + ..... \qquad \text{(OPE)}$$

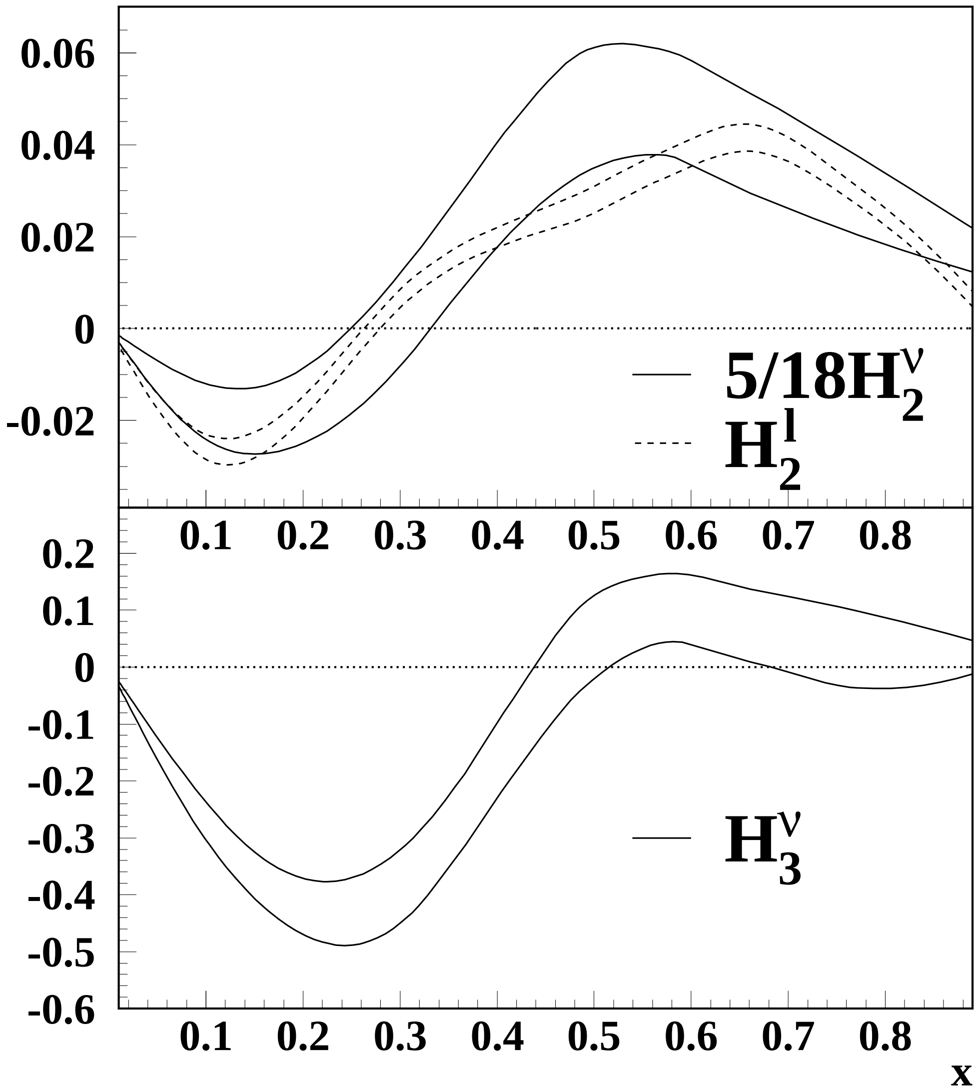
- *High Twists (HT) non-perturbative terms $\tau = 4, 6, ...$ reflecting the strength of the multi-parton correlations ($qq$ and $qg$) and suppressed by powers of $1/Q^2$*
  $\Longrightarrow$ *Important at low and moderate $Q^2$ ($< 10$ GeV$^2$) where most $\nu(\bar{\nu})$ data*

- *Kinematical High Twists associated with finite mass of target nucleon relevant at large $x^2M^2/Q^2$ values. Corrections usually incorporated into the leading twist (LT) term ($\tau = 2$) following Georgi and Politzer (1976):*

$$F^{\rm LT}_{T,2,3}(x,Q^2) \rightarrow F^{\rm LT,TMC}_{T,2,3}(x,Q^2)$$

  *where the calculation involves the Nachtman variable $\xi = 2x/(1+\sqrt{1+4M^2x^2/Q^2})$. Difficulty for $x \rightarrow 1$ due to wrong threshold behaviour ($F^{\rm LT}_i(\xi,Q^2) > 0$).*

- *Dynamical High Twists ($\tau > 2$) related to multi-parton correlations can be determined phenomenologically from data by exploiting their specific $Q^2$ dependence.*




- *No evidence for sizeable twist-6 terms from global fit to $e, \mu$ DIS and DY data (upper limit $\sim 0.02$ well below twist-4)*
- *HT similar in $F_T$ and $F_2$ indicate HT contributions to $F_L$ very small*
- *HT on $F_2$ and $F_T$ from CHORUS $\nu(\bar{\nu})$ cross-section data consistent with charged leptons after charge rescaling.*
- *Simultaneous extraction of HT in $xF_3$ from neutrino data*

*S. Alekhin, S. Kulagin and R.P., arXiv:0710.0124 [hep-ph], arXiv:0810.4893 [hep-ph]*

# EFFECTIVE LEADING ORDER APPROACH

- *Use Leading Order GRV98 PDFs and introduce scaling variable $\xi_w$ and empirical $K$-factors to account for High Twists, missing high order QCD, etc.*

$$x \rightarrow \xi_w = \frac{Q^2 + M_f^2 + B}{M\nu\left[1+\sqrt{1+Q^2/\nu^2}\right] + A}$$

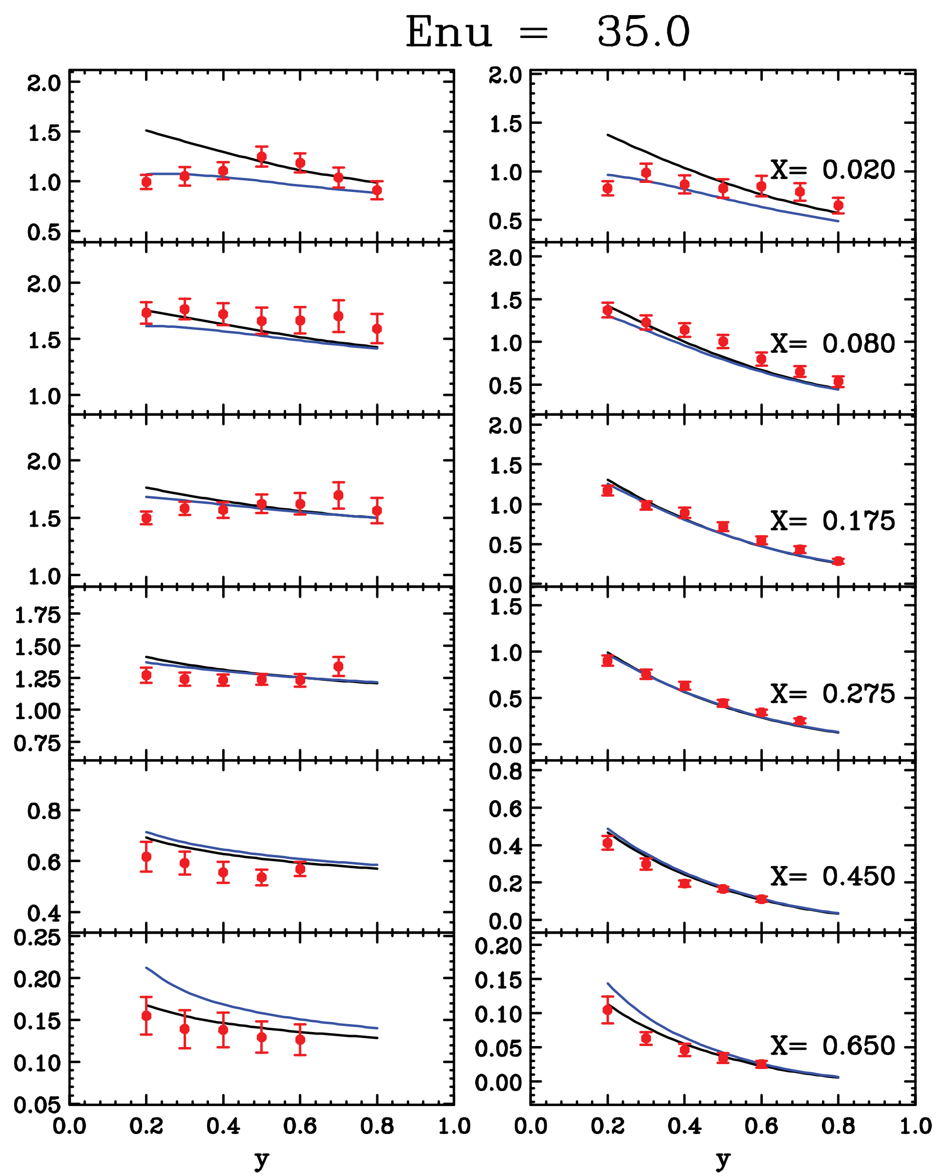
$$f(x, Q^2) \rightarrow K_f \times f(\xi_w, Q^2)$$

*(A. Bodek and U. Yang, arXiv hep-ex/0308007; 1011.6592 [hep-ph] )*

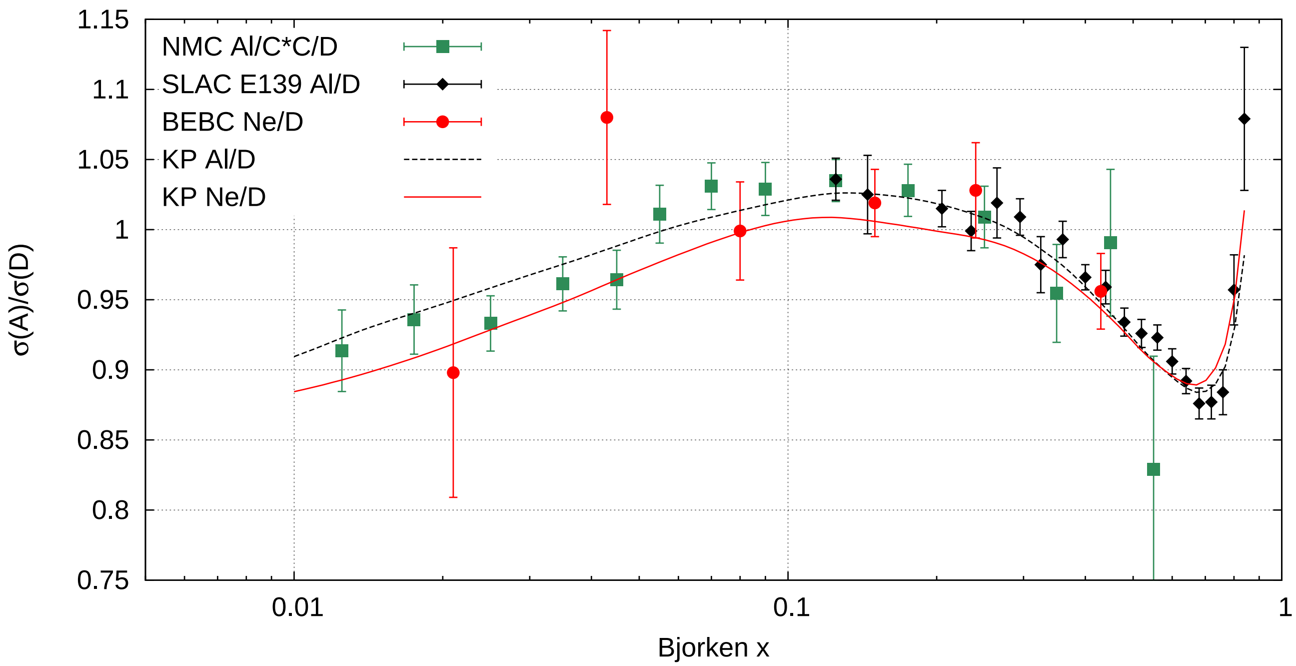
- *For $\nu(\bar{\nu})$ interactions use separate Vector and Axial $K$-factors*
  - *Vector $K_f$ same as for $e, \mu$ data;*
  - *Axial $K_f$ constrained by Adler sum rule.*

- *Results show significant contributions from effective HT*

$\Longrightarrow$ *See talk by U. Yang in parallel session*



# NUCLEAR EFFECTS



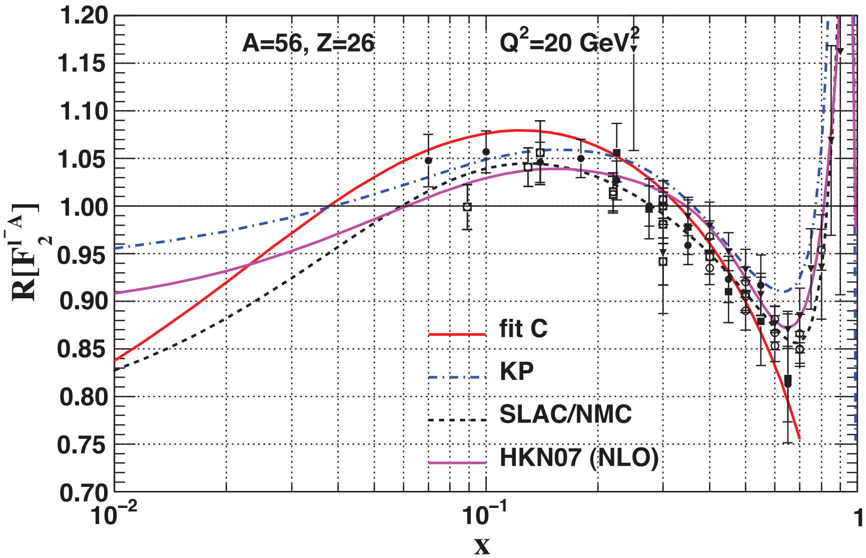

*BEBC Coll., ZPC 36 (1987) 337; PLB 232 (1989) 417.*

- *Nuclear corrections are crucial in order to use $\nu(\bar{\nu})$ data in global QCD fits since virtually all existing data on heavy targets*
  $\Longrightarrow$ *Significant uncertainties on nuclear corrections in $\nu(\bar{\nu})$ interactions*

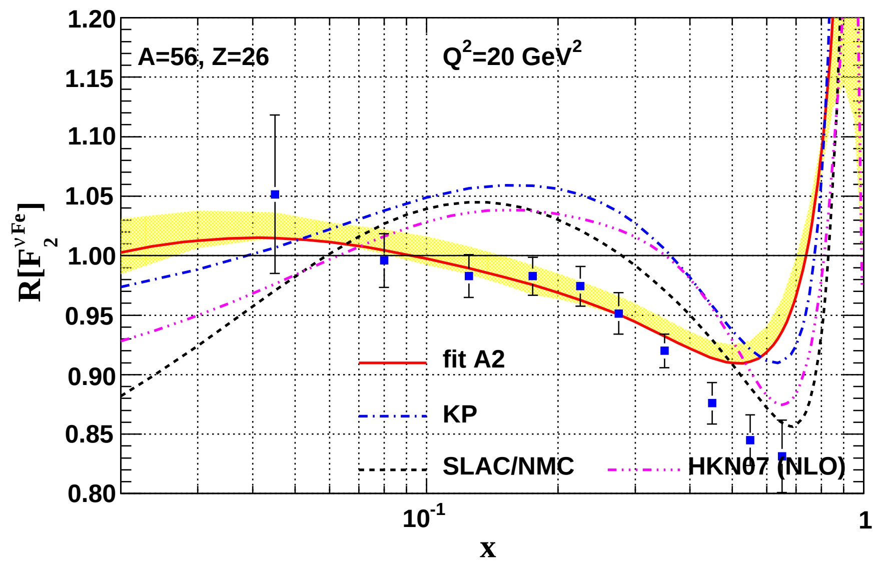
- *Only DIRECT measurement of nuclear effects in $\nu(\bar{\nu})$ SFs from ratio $^{20}$Ne/D in BEBC*
  - *Consistent with shadowing at small $x_{Bj}$ but large uncertainties;*
  - *Consistent with the EMC effect measured from $e, \mu$ DIS.*

- *Differences with respect to $e, \mu$ DIS expected due to the axial-vector current and to the flavor selection*

# CTEQ FITS TO $\nu(\bar{\nu})$ DATA




*Fit to $e, \mu$ DIS + DY*




*Fit to $\nu + \bar{\nu}$ DIS*

- *Within the CTEQ analysis introduce nuclear PDFs as modifications of nucleon PDFs:*

$$xf(x, Q_0) = f(x, c_0, c_1, .....c_n); \qquad c_k \rightarrow c_k(A)$$

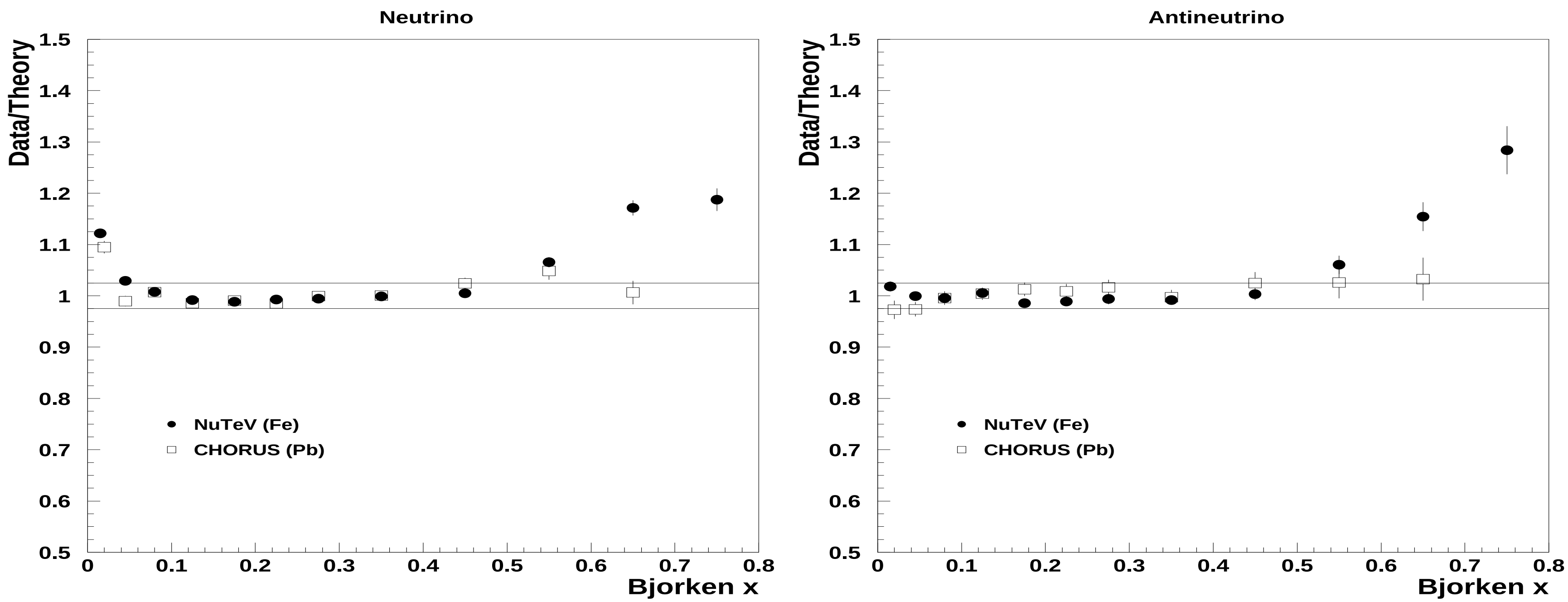
*(I. Schienbein at al., PRD 80 (2009) 094004; PRL 106 (2011) 122301).*

- *Perform separate global fits to $\nu(\bar{\nu})$ DIS data and $e, \mu$ DIS + Drell-Yan nuclear data*

- *Results show CHORUS+NuTeV $\nu(\bar{\nu})$ data not consistent with $e, \mu$ DIS:*
  - *No shadowing observed at small $x_{\rm Bj}$;*
  - *Different EMC slope.*

$\Longrightarrow$ *See talk by K. Kovarik in parallel session*

# KP PREDICTIONS FOR CHORUS AND NuTeV




- *Detailed phenomenological model including Fermi motion and binding energy, off-shell effect of bound nucleons, nuclear pion excess and shadowing correction* (*S. Kulagin and R.P., NPA 765 (2006) 126; PRD 76 (2007) 094023, PRC 82 (2010) 054614*).
- *Comparison with NuTeV (Fe) and CHORUS (Pb) cross-section data (band $\pm 2.5\%$):*
  - *Systematic excess observed for $x > 0.5$ in both $\nu$ and $\bar{\nu}$ NuTeV data on Fe*
  - *CHORUS data on Pb target consistent with predictions at large x;*
  - *Discrepancy between NuTeV and old CCFR data at large $x$ on Fe target.*

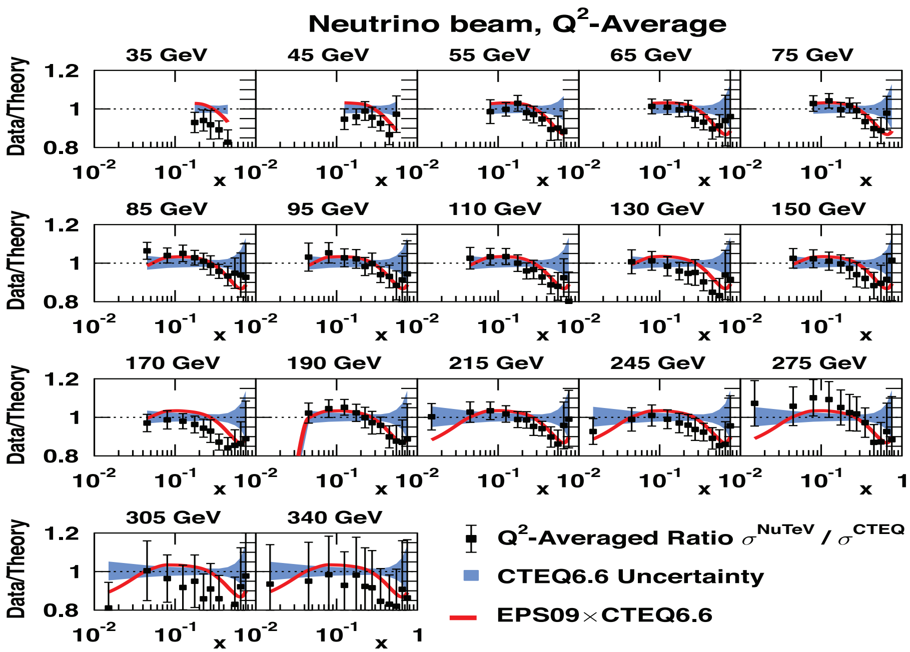
| Cut | # of points Neutrino | # of points Antineutrino | $\chi^2/dof$ Neutrino | $\chi^2/dof$ Antineutrino |
|---|---|---|---|---|
| NuTeV (Fe) | | | | |
| No cut | 1423 | 1195 | 1.36 | 1.10 |
| $x > 0.015$ | 1324 | 1100 | 1.15 | 1.08 |
| $x < 0.55$ | 738 | 671 | 1.16 | 1.02 |
| $0.015 < x < 0.55$ | **686** | **620** | **0.97** | **1.01** |
| CHORUS (Pb) | | | | |
| **No cut** | **607** | **607** | **0.68** | **0.84** |
| $x > 0.02$ | 550 | 546 | 0.55 | 0.83 |
| $x < 0.55$ | 506 | 507 | 0.74 | 0.83 |
| $0.02 < x < 0.55$ | 449 | 447 | 0.60 | 0.83 |

*Fully independent model predictions, NOT FIT*

- *Good agreement of predictions with the CHORUS differential cross-sections on Pb in the whole kinematic range*
- *Good agreement of predictions with the NuTeV differential cross-sections on Fe in the main kinematic region* $0.015 < x < 0.55$

$\Longrightarrow$ *See talk by S. Kulagin in parallel session*

# RESULTS BY EPS




| Experiment | $\chi^2/dof$ | |
|---|---|---|
| | CTEQ6.6 | CTEQ×EPS09 |
| NuTeV | 1.51 | **1.05** |
| CHORUS | 1.15 | **0.79** |
| CDHSW | 1.10 | 0.71 |

- *Use nuclear corrections to PDFs from EPS09 fit to nuclear $e, \mu$ DIS and Drell-Yan (K. Eskola, H. Paukkunen and C. Salgado, JHEP 0904 (2009) 065; JHEP 1007 (2010) 032).*

- *Analysis of CHORUS, NuTeV and CDHSW $\nu(\bar{\nu})$ differential cross-sections and comparison with calculations based upon CTEQ6.6 + EPS09*

- *Results indicate CHORUS and CDHSW data are in agreement with calculations, but in disagreement with NuTeV data*

  $\Longrightarrow$ *Anomalous $E_\nu$-dependent fluctuations in NuTeV data*

# NEW MEASUREMENT FROM NOMAD

- *High resolution spectrometer with low density tracking,* $\rho \sim 0.1 g/cm^3$ *and* $B = 0.4\ T$
  - *Momentum calibration from* $K^0_S$ *mass constraint;*
  - $\Delta E_\mu = 0.2\%$, $\Delta E_{\rm H} = 0.5\%$.

- *Measurement of* $d^2\sigma/dxdy$ *cross-section on Carbon in the energy range* $5 < E_\nu < 200$ *GeV*

  $\Longrightarrow$ *First measurement on C target*

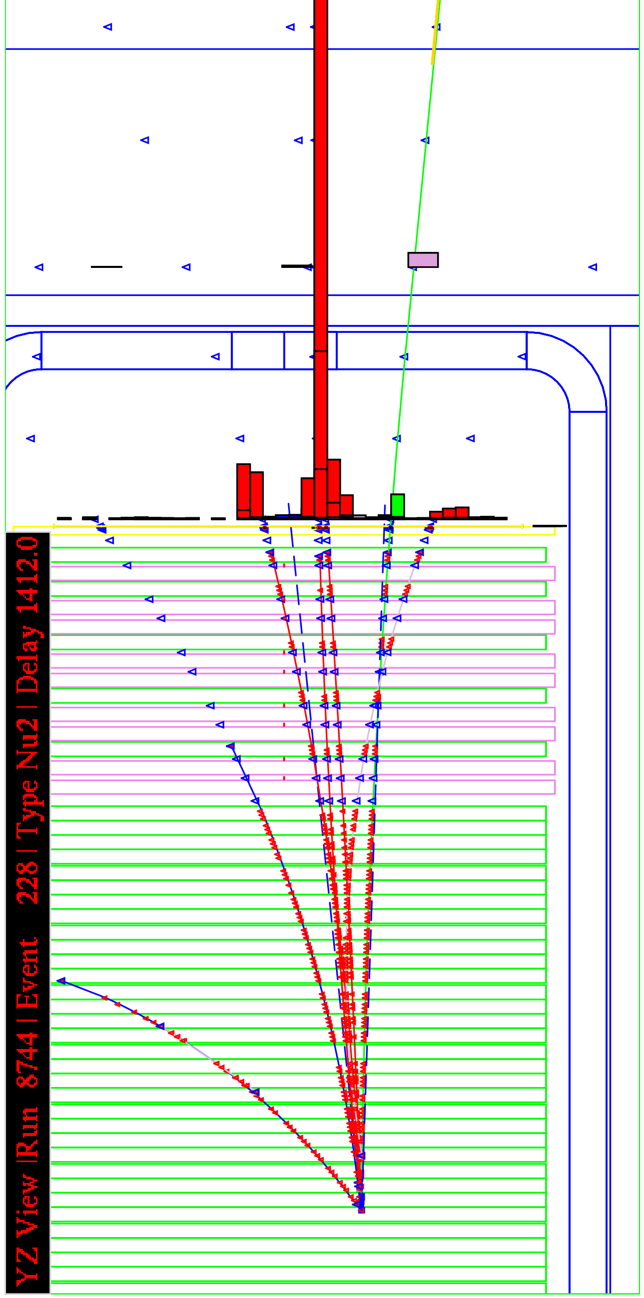
- *Absolute cross-section normalization to the world average value on isoscalar target:*

$$\sigma^\nu/E_\nu \; = \; 0.677 \pm 0.014 \times 10^{-38} \, \frac{cm^2}{GeV}$$

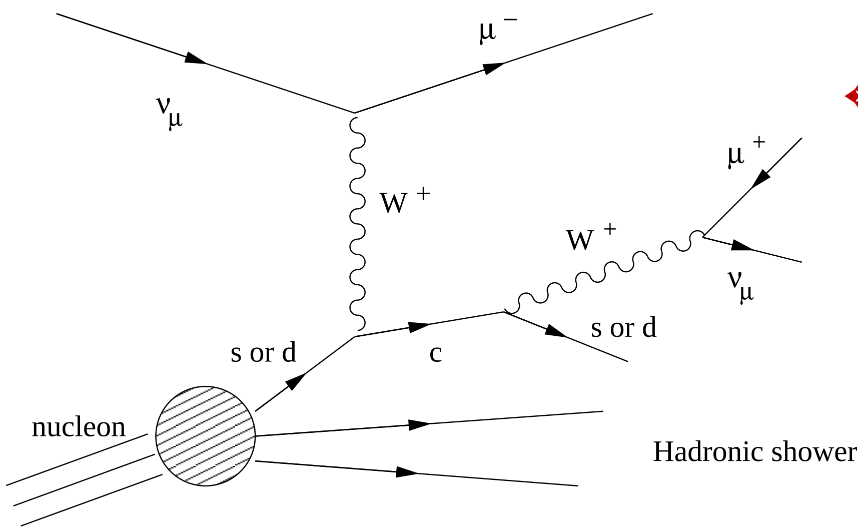
  *in the energy range* $40 < E_\nu < 80$ *GeV.*

- *Independent cross-check of NuTeV and CHORUS measurements*

  $\Longrightarrow$ *Preliminary results on C do not show the NuTeV excess at large* $x_{\rm Bj}$



# A DIRECT PROBE OF STRANGE SEA




- *Charm dimuon production in $\nu(\bar{\nu})$ DIS*

$$\frac{d^2\sigma_{\mu\mu}}{dxdydz} = \frac{d^2\sigma_c}{dxdy} D_c(z) B_\mu; \qquad z = \frac{P_L(h_c)}{P_L^{\max}}$$

$$B_\mu = \sum_h f_h Br(h \to \mu^+ X); \; h = D^0, D^+, D_s^+, \Lambda_c^+$$

$D_c(z)$ *average fragmentation function*

- *Charm production in $\nu$ and $\bar{\nu}$ DIS provides a clean and direct access to $s(x)$ and $\bar{s}(x)$*

$$F_{2,c}(x, Q) = 2\xi \left[ |V_{cs}|^2 s(\xi, \mu) + |V_{cd}|^2 \frac{u(\xi, \mu) + d(\xi, \mu)}{2} \right]$$

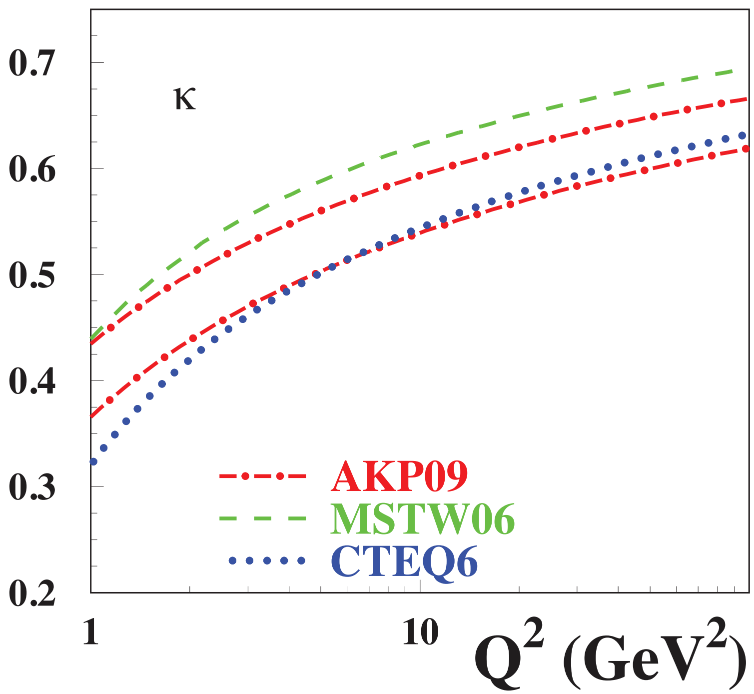
$$\xi = x\left(1 + m_c^2/Q^2\right), \; \mu = \sqrt{Q^2 + m_c^2}$$

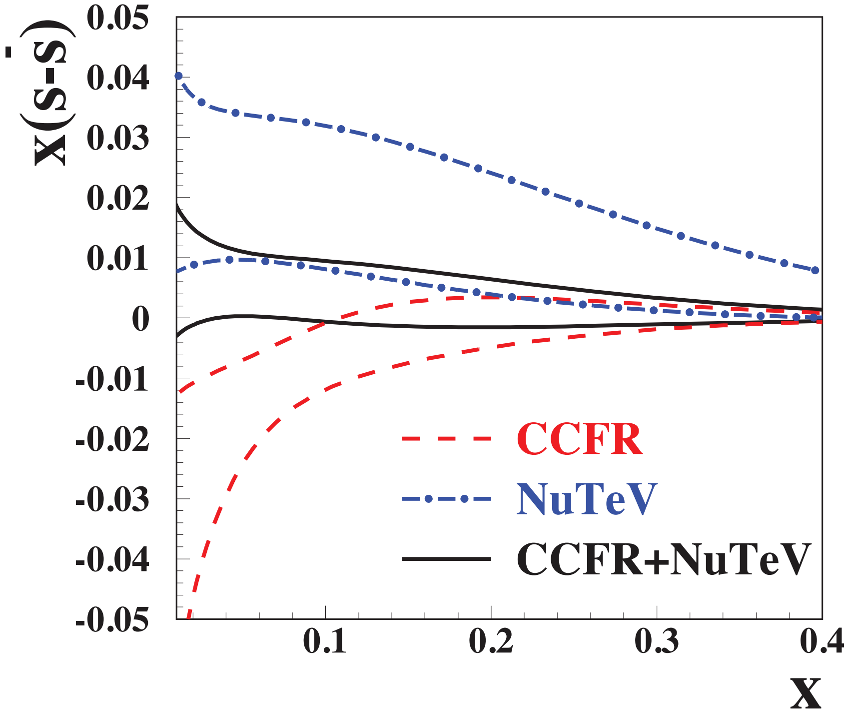
*where simple LO approximations are given for illustration purpose*

$$\begin{cases} \nu: & s/(d_v + d_s) \to c & \simeq 50\% \\ \bar{\nu}: & \bar{s}/\bar{d}_s \to \bar{c} & \simeq 90\% \end{cases}$$

| *Exp.* | *Publ.* | *Stat.* $(N_{\mu\mu})$ | $E_\nu$ *(GeV)* |
|---|---|---|---|
| *Charm dimuons in* $\nu N$ | | | |
| *CDHS* | *1982* | 9922 | $30-250$ *(20)* |
| *CHARM II* | *1999* | 3100 | $35-300$ *(24)* |
| *NuTeV* | *2001* | 5102 | $20-400$ *(157.8)* |
| *CCFR* | *2001* | 5030 | $30-400$ *(150)* |
| *CHORUS* | *2008* | 8910 | $15-240$ *(27)* |
| *NOMAD* | *2011* | 15344 | $6-300$ *(27)* |
| *Charm dimuons in* $\bar{\nu} N$ | | | |
| *CDHS* | *1982* | 2123 | $30-250$ |
| *CHARM II* | *1999* | 700 | $35-300$ |
| *NuTeV* | *2001* | 1458 | $20-400$ |
| *CCFR* | *2001* | 1060 | $30-600$ |
| *CHORUS* | *2008* | 430 | $15-240$ |

- *The NuTeV and CCFR data are used in global QCD fits and provide the only information about* $\bar{\nu}$*-induced charm dimuons*
- *The new NOMAD measurement has the largest sample of* $\nu$*-induced charm dimuons and can reach energies closer to the charm production threshold*




- *Global PDF fits with NuTeV and CCFR dimuon data:*

$\kappa_s = \frac{\int_0^1 x[s(x,Q^2)+\bar{s}(x,Q^2)]dx}{\int_0^1 x[\bar{u}(x,Q^2)+\bar{d}(x,Q^2)]dx} = 0.62 \pm 0.04 \pm 0.03(\text{QCD})$ *(AKP09, PLB 675 (2009) 433 )*

$S^- = \int_0^1 x\,[s(x) - \bar{s}(x)]\,dx = 0.0013 \pm 0.0009 \pm 0.0002(\text{QCD})$ *(AKP09, PLB 675 (2009) 433 )*

$S^- = 0.0016^{+0.0011}_{-0.0009}$ *(MSTW, EPJC 63 (2009) 189 )*

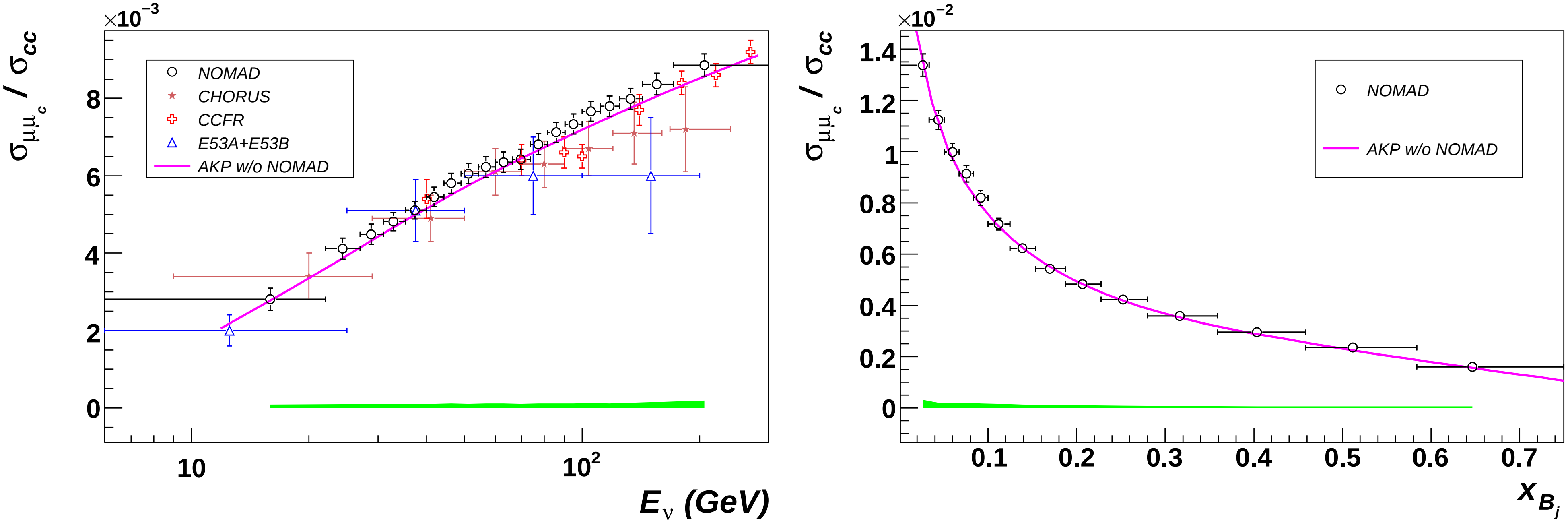
$S^- = 0.0018 \pm 0.0016$ *(CTEQ, JHEP 0704 (2007) 089 )*

$S^- = 0.0005 \pm 0.0086$ *(NNPDF, NPB 823 (2009) 195 )*

$S^- = 0.00196 \pm 0.00046^{+0.00155}_{-0.00116}(syst)$ *(NuTeV, PRL 99 (2007) 192001 )*

$S^- = 0.0018 \pm 0.0038$ *(BPPZ, JHEP 0601 (2006) 006 )*

# CHARM DIMUON PRODUCTION FROM NOMAD




- *Measure* **RATIO** *of cross-sections to reduce systematics:*

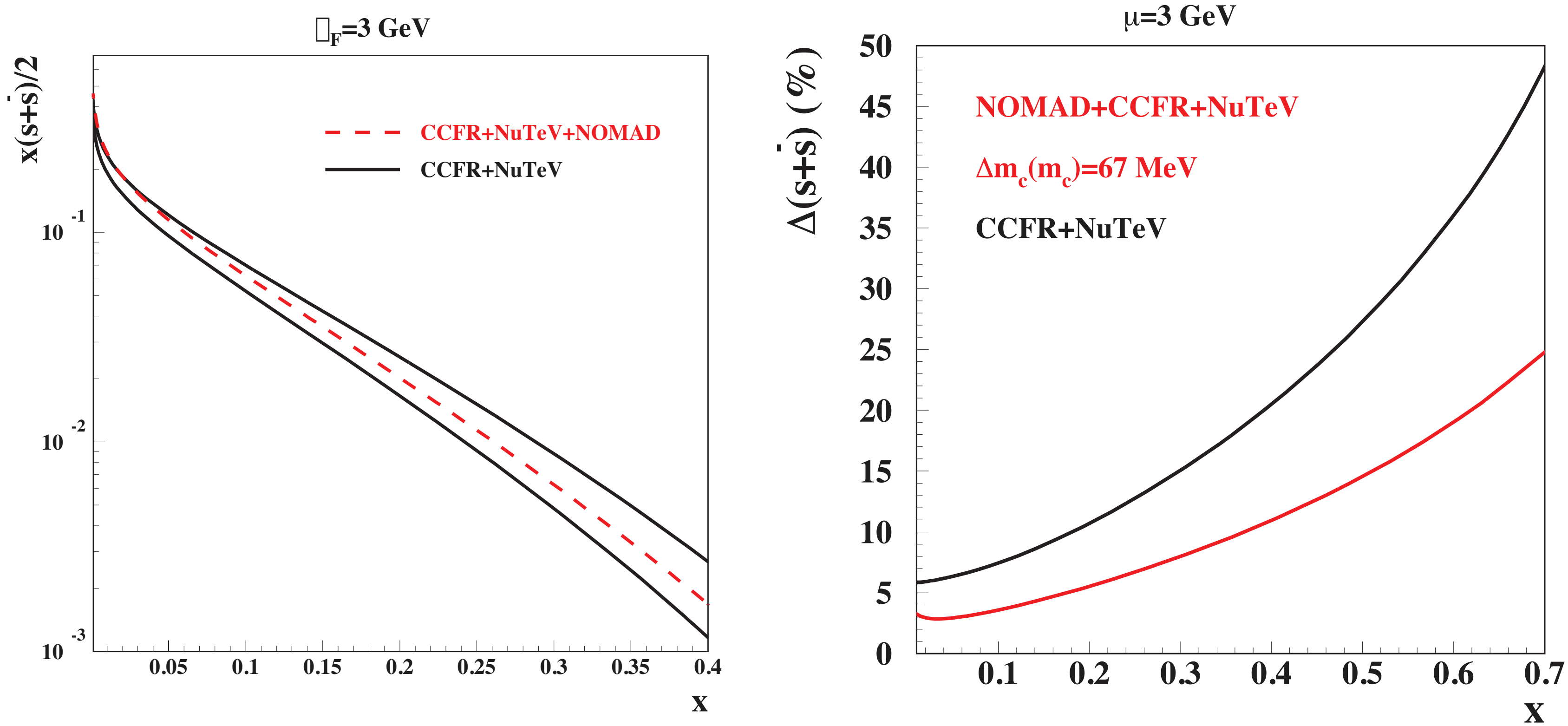
$$\mathcal{R}_{\mu\mu} \equiv \sigma_{\mu\mu_c}/\sigma_{cc} \simeq N_{\mu\mu_c}/N_{cc}(x); \quad x = E_\nu, x_{B_j}, \sqrt{\hat{s}}$$

- *Require leading $\mu^-$ and $Q^2 \geq 1$ GeV$^2$*

$$\int \sigma_{\mu\mu_c}\phi \, dx \, dy \, dE_\nu \quad = \quad 5.15 \pm 0.05 \times 10^{-3} \; \nu_\mu \mathrm{CC}$$

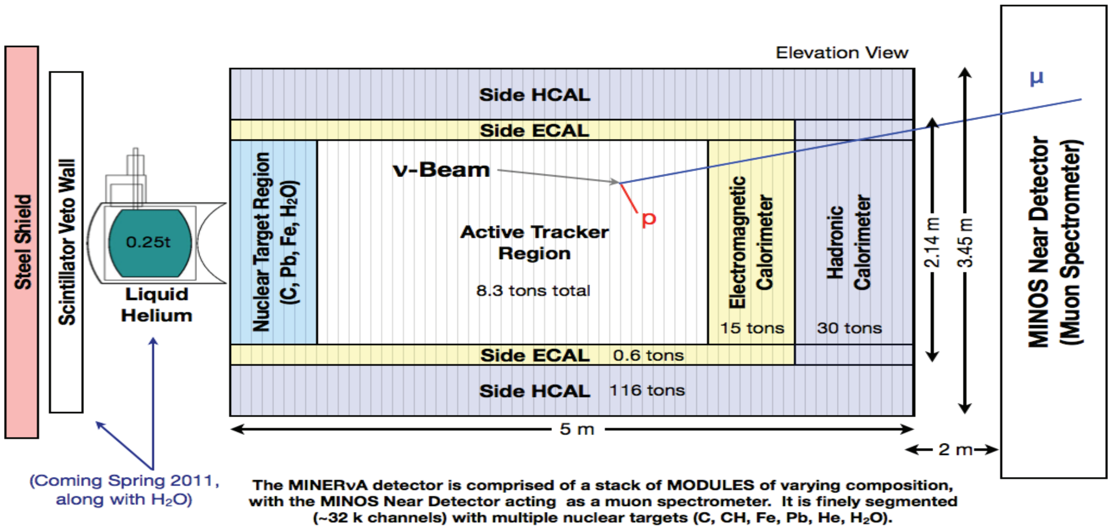
- *Total systematic uncertainty (17 different sources) $\sim 2\%$*

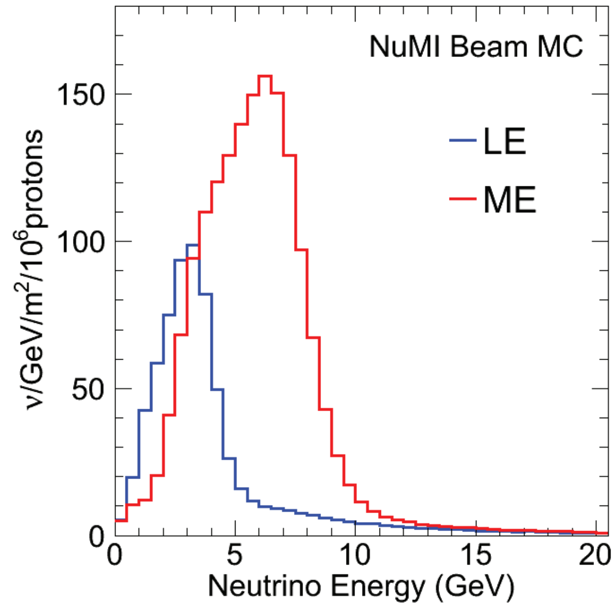
- *Agreement with model calculation based upon global fits with NuTeV+CCFR only*



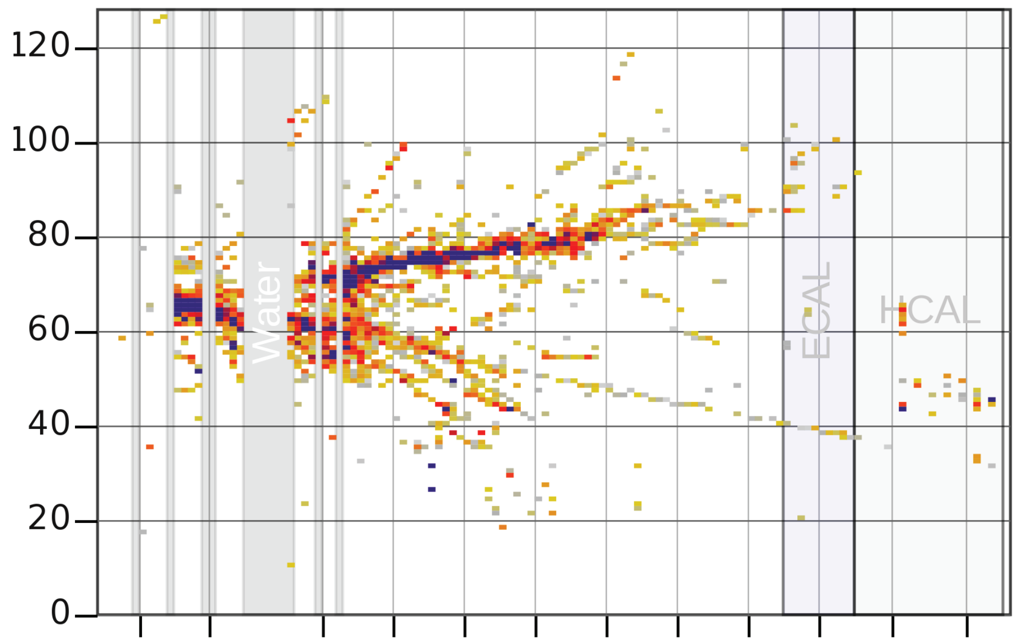

- *Add NOMAD $\sigma_{\mu\mu}/\sigma_{\rm CC}$ data to global PDF fit with NuTeV and CCFR dimuon data* (*S. Alekhin, S. Kulagin and R.P.; PLB 675 (2009) 433*)
- *Consistency of central values*
- *Reduction of $s(x)$ uncertainty by a factor 2 down to $\sim 3\%$: $\kappa_s = 0.61 \pm 0.02$*
- *Improved determination of the $\overline{\rm MS}$ mass* (*S. Alekhin, S. Moch; arXiv:1011.5790 [hep-ph]*)
  $m_c(m_c) = 1.070 \pm 0.067 \pm 0.050({\rm QCD})$

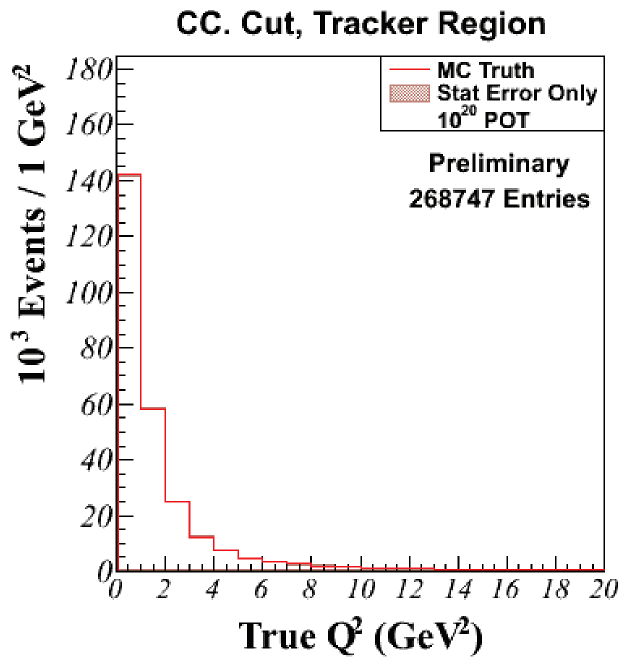
# THE MINER$\nu$A EXPERIMENT




- *New neutrino scattering experiment currently taking data, with plastic scintillator tracker followed by the MINOS Near Detector as Muon spectrometer*
- *Nuclear targets of $CH_2$ (5 t), Fe (1 t), Pb (1 t), $H_2O$ (0.35 t), He (0.25 t) and C (0.17 t) provide many $A$-dependent physics measurements*
- *Movable target and horns in NuMI beam line allow runs with Low (LE) and Medium (ME) energy spectrum:*
  - *Target esposure $4 \times 10^{20}$ pot $(\nu + \bar{\nu})$ with LE, $12 \times 10^{20}$ pot $(\nu + \bar{\nu})$ with ME (from 2012)*
  - *Collected exposure (so far) $1.2 \times 10^{20}$ pot with LE for each $\nu$ and $\bar{\nu}$*




- *Charged Current events with resolvable muon track and characteristic hadron shower*

  $\Longrightarrow$ *Definition of DIS interactions: $Q^2 > 1$ GeV$^2$ and $W > 2$ GeV*

- *Beam studies and MIPP hadro-production measurements provide fluxes with a precision between 5% and 10% ($E$-dependent)*

- *Measure differential cross-sections and structure functions on different nuclear targets*
  - *Expect a total of $1.76 \times 10^6$ CC events and $460k$ DIS events in LE beam run (sum of all targets)*
  - *Expect one order of magnitude more DIS events in ME beam run*

  $\Longrightarrow$ *See talk by J. Mousseau in parallel session*

# THE LBNE PROJECT

- *The Long-Baseline Neutrino Experiment (LBNE) designed for high sensitivity measurements of $\nu_\mu(\bar{\nu}_\mu) \to \nu_e(\bar{\nu}_e)$ with $\nu_e(\bar{\nu})$ appearance and $\nu_\mu(\bar{\nu}_\mu)$ disappearance*
  $\Longrightarrow$ *Next generation after MINOS and NO$\nu$A*

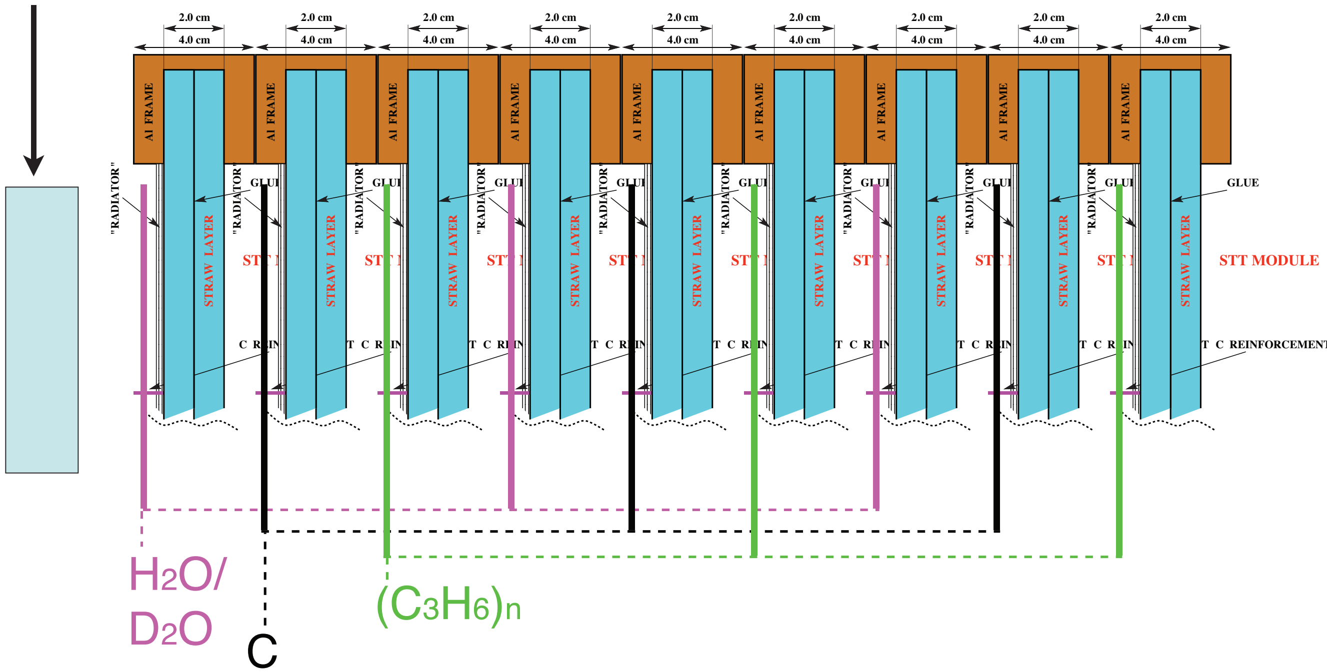
- *High intensity $\nu$ and $\bar{\nu}$ beams from Fermilab to Homestake mine in SD ($L \sim 1300$ km)*
  - *Default configuration with NuMI 700 kW proton beam;*
  - *Potential upgrade with new 8 GeV Linac (Project-X) up to 2.3 MW proton beam;*
  - *Different options for beam spectra considered (with new focusing).*

- NEAR DETECTOR *complex at $\sim 500$ m from target with fine-grained detectors*
  - *Service measurements (fluxes, backgrounds, cross-sections, etc.) for LBL studies*
  - *Precision measurements of neutrino interactions*

  $\Longrightarrow$ *Complementary physics programs*

- *One of the reference ND configurations includes a high resolution tracker in $B$ field*
  - $\Delta E_\mu < 0.2\%$, $\Delta E_{\rm H} < 0.5\%$;
  - *Fiducial mass $\sim 7$ tons, run 5 year $\nu$ + 5 year $\bar{\nu}$;*
  - *Expect about $4.5 \times 10^7$ CC events with 700 kW beam ($\sim 1.8 \times 10^8$ with Project-X)*

Possible to have additional external target




- Possible to install *multiple nuclear targets in the fine-grained ND tracker*
- In-situ determination of fluxes to $\sim 2\%$
- *Subtraction of C target from polypropylene* $(C_3H_6)_n$ target provides *free proton*
  - *Collect $\mathcal{O}(10^6)$ $\nu$ CC events and $\mathcal{O}(10^6)$ $\bar{\nu}$ CC events with the 700 kW NuMI beam*
  - *Complete flavor and valence/sea separation (d/u at large $x$)*
  - *Precision test of Adler sum rule (current algebra)*

$$S_A = \int_0^1 \frac{dx}{x} \left( F_2^{\bar{\nu}p} - F_2^{\nu p} \right) = 2$$

- Subtraction of $H_2O$ target from $D_2O$ target gives interactions on neutron (in D)

# SUMMARY

- *Power of $\nu + \bar{\nu}$ DIS as a probe of nucleon structure still limited by the beam technology and by the resolution of detectors*

  $\Longrightarrow$ *Some inconsistencies among existing data samples*

- *Recent progress in understanding $\nu(\bar{\nu})$ interactions to include $\nu(\bar{\nu})$ DIS into global QCD fits (Axial-Vector current, High Twists, nuclear corrections)*

- *New NOMAD measurement of $\nu$-induced charm dimuon production allows a substantial reduction of the uncertainties on the strange sea distribution*

- *Many new results from neutrino scattering experiments are expected in the near future (NOMAD, MINER$\nu$A)*

  $\Longrightarrow$ *Stay tuned!*

- *The future LBNE project coupled with high intensity neutrino beams (Project X) would finally allow to exploit the physics potential of the (ideal) $\nu(\bar{\nu})$ probe*