NNPDF1.2: Unbiased Determination of Electro-Weak Parameters and the Strange Content of the Proton

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Work in collaboration

NNPDF collaboration

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Outline

1. Motivation
2. Data and theoretical input
   - Experimental data
   - Theoretical input
3. The proton strangeness content
   - Strange sea fraction
   - Strange asymmetry
4. Determination of EW parameters
   - NuTeV anomaly
   - $|V_{\rm cs}|$ and $|V_{\rm cd}|$ determination
5. Conclusions

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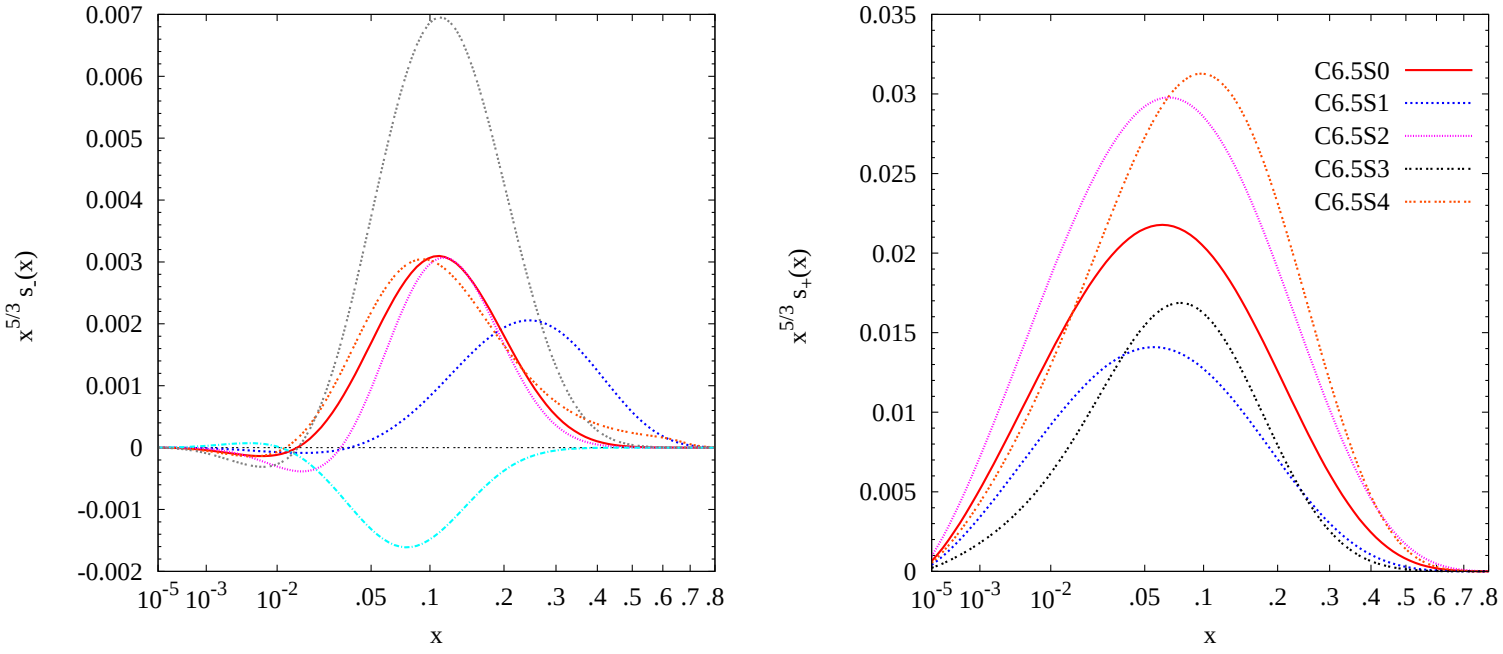
Motivation

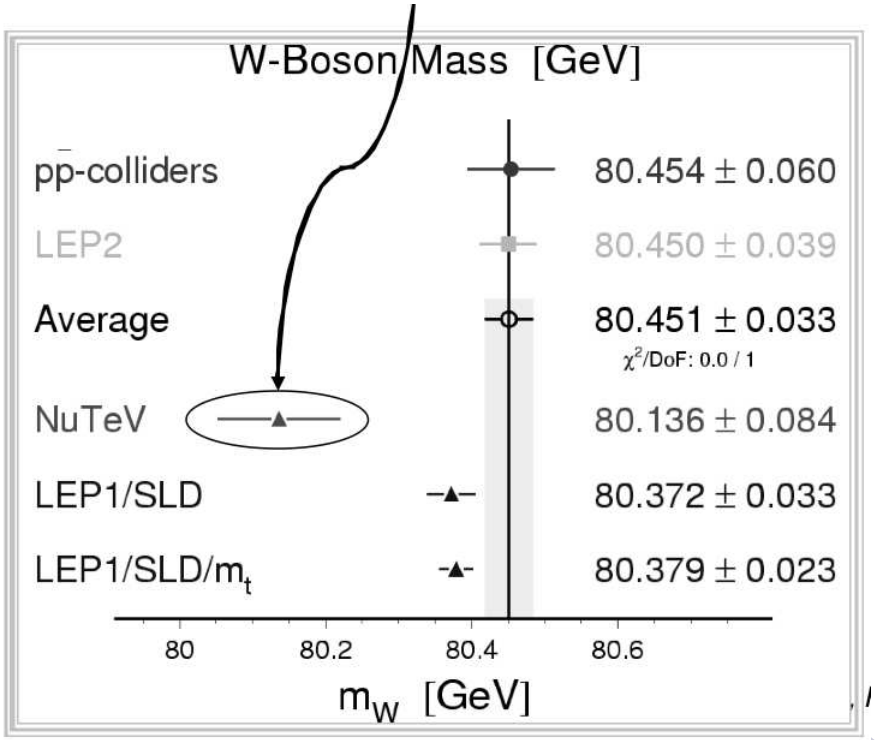
- The strange PDFs are the worse known light quark PDFs
  (CTEQ6.5, MRST2001E $\rightarrow$ $(s+\bar{s}) = \kappa_s\,(\bar{u}+\bar{s})$, $s-\bar{s}=0$)
  $\rightarrow$ Effects of parametrization bias should be dominant
  Lack of precise information forces in standard PDFs restrictive parametrizations for $s^{\pm}(x)$
  Example: Results from the CTEQ6.5S (Lai et al, JHEP 0704:089,2007)



Motivation

- The strange sea asymmetry $[S^-]$ plays a prominent role in explaining the NuTeV anomaly (PRL **88** (2002) 091802)

$$\sin^2\theta_W\Big|_{\rm EWfit} = 0.2223 \pm 0.0003\ , \quad \sin^2\theta_W\Big|_{\rm NuTeV} = 0.2277 \pm 0.0017$$



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NuTeV result assumes $[S^-] = 0$ but (S. Davidson et al., JHEP 0202:037,2002)

$$\delta_s \sin^2\theta_{\rm W} = -\frac{[S^-]}{[\mathcal{Q}^-]}\,\frac{1}{6}\left[3 - 7\sin^2\theta_{\rm W}\right] \approx -0.240\,\frac{[S^-]}{[\mathcal{Q}^-]}\ .$$

$[S^-] \sim 5\cdot 10^{-3}$ enough to explain NuTeV anomaly

$$[S^-] \equiv \int_0^1 dx\, x s^-(x,Q^2)\ , \quad [\mathcal{Q}^-] = \frac{1}{2}\int_0^1 dx\, x\left(u_V(x,Q^2) + d_v(x,Q^2)\right)$$

Note also isospin violations contributes to decrease the NuTeV anomaly (MRST2004QED, EPJC39:155,2005)

Motivation

- Best direct determination of CKM $|V_{\rm cd}|$ from dimuon data
- Only lower limits for $|V_{\rm cs}|$, large ($\sim 10\%$) uncertainties in other direct determinations
- Existing determinations of $|V_{\rm cd}|, |V_{\rm cs}|$ include several model assumptions
- Example: CDHS, Z.Phys.C15:19,1982 $\rightarrow |V_{\rm cs}| \geq 0.59$
  (Still quoted in PDG, EPJ C15 (2000) 1)
  - Q^2-dependence of PDFs neglected
  - No NLO corrections
  - Vanishing $[S^-]$

$$\frac{|V_{\rm cs}|^2}{|V_{\rm cd}|^2} = \frac{[S^+]}{[\bar{U}+\bar{D}]}$$

Uncertainties in $[S^+]$ prevent accurate $|V_{\rm cs}|$ determination?

Motivation

- The strange PDFs are the less well known light quark PDFs
- The strange sea asymmetry $\left[S^-\right]$ plays a prominent role in explaining the NuTeV anomaly
- Best direct determination of CKM $|V_{\rm cd}|$ from dimuon data, but only lower limits for $|V_{\rm cs}|$
- Motivation for NNPDF1.2 $\rightarrow$ Revisit the determination of precision EW parameters and the proton strange content the improved statistical techniques of the NNPDF approach:
  1. Faithful estimation of PDF uncertainties
  2. Absence of parametrization bias (no theoretical prejudices)
  3. No model assumptions in determination of EW parameters

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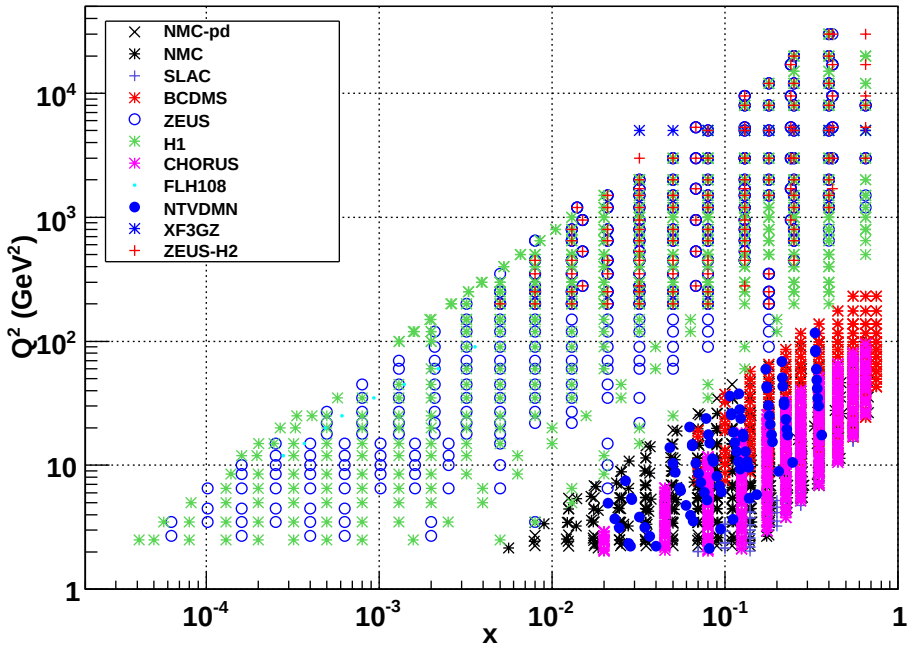
Experimental data

- Direct determination of both s and $\bar{s}$ allowed by recent NuTeV data, via

$$\frac{1}{E_\nu}\frac{d^2\sigma^{\nu(\bar{\nu}),2\mu}}{dx\,dy}(x,y,Q^2) \equiv \frac{1}{E_\nu}\frac{d^2\sigma^{\nu(\bar{\nu}),c}}{dx\,dy}(x,y,Q^2)\cdot\langle \mathrm{Br}\,(D\to\mu)\rangle\cdot\mathcal{A}\,(x,y,E_\nu)\ ,$$



$$\tilde{\sigma}^{\nu(\bar{\nu}),c} \propto (F_2^{\nu(\bar{\nu}),c}, F_3^{\nu(\bar{\nu}),c}, F_L^{\nu(\bar{\nu}),c})$$

$$F_2^{\nu,c} = x\left[C_{2,q}\otimes\left(|V_{\rm cd}|^2(u+d)+2|V_{\rm cs}|^2 s\right)+C_{2,g}\otimes g\right]$$

$$F_2^{\bar{\nu},c} = x\left[C_{2,q}\otimes\left(|V_{\rm cd}|^2(\bar{u}+\bar{d})+2|V_{\rm cs}|^2 \bar{s}\right)+C_{2,g}\otimes g\right]$$

Additional data in NNPDF1.2:

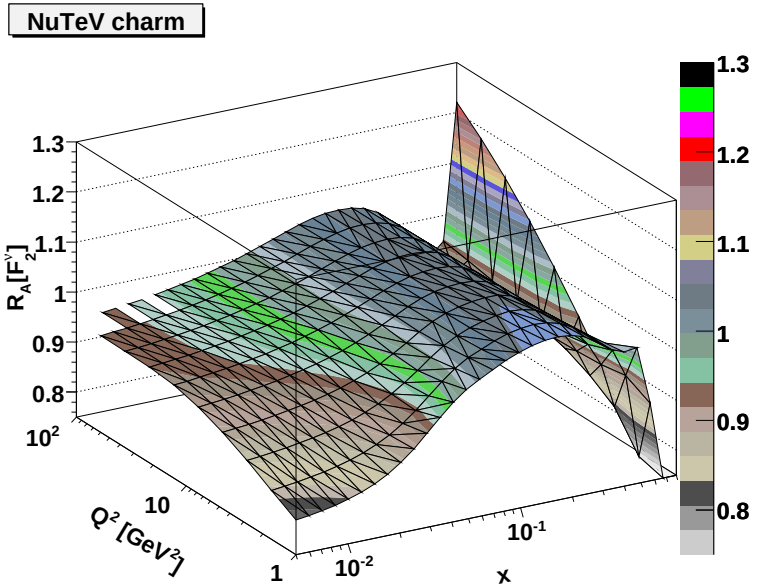
* Neutrino and anti-neutrino dimuon production from NuTeV.
* HERA-II ZEUS data on NC and CC reduced xsec at large-Q^2.
* HERA-II ZEUS data on $xF_3^{\gamma Z}$.

Theoretical input

- Only theoretical constraint on strange PDFs → valence sum rule

$$\int_0^1 dx s^-(x, Q^2) = 0$$

- Charm mass effects for NuTeV dimuon production treated in the Improved ZM-VFN scheme [Thorne, Tung, ArXiv:0809.0714],[Nadolsky, Tung, ArXiv:0903.2667].
- Neutrino data (NuTeV and CHORUS) corrected by (small) nuclear effects from various models [Hirai, Kumano, Nagai - de Florain, Sassot]



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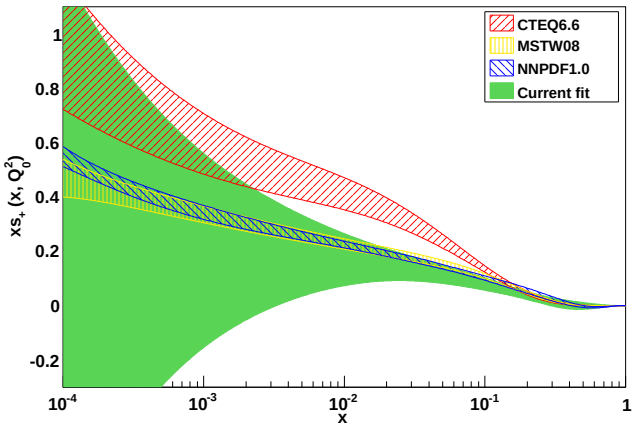
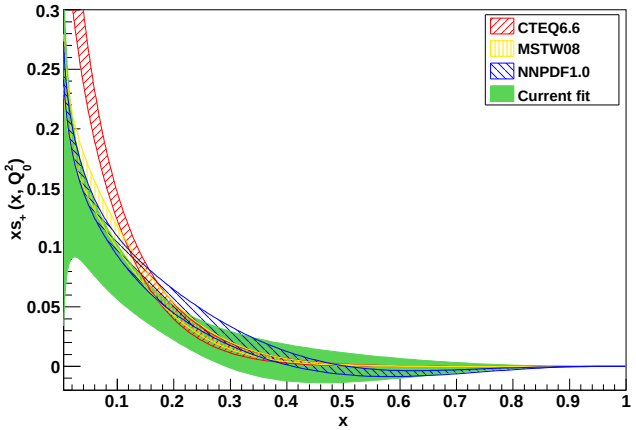
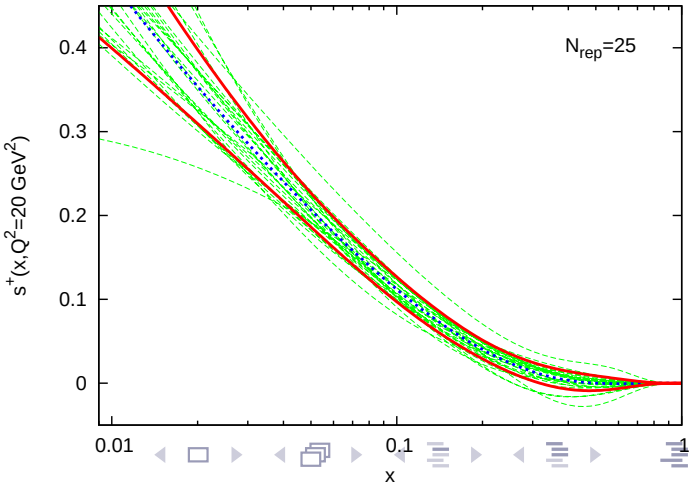
Strange sea PDF: $s^+(x, Q^2)$

Total strangeness: log scale ↓, individual reps ↘ Total strangeness: lin scale →





- Data region → Moderate uncertainties, larger than CTEQ6.6/MSTW08
- Extrapolation region → Blow-up of uncertainties due to lack of experimental constraints



Strange sea fraction

Strange sea fraction characterized by $K_S(Q^2)$

$$K_S(Q^2) \equiv \frac{\int_0^1 dx\ x\ s^+\ (x, Q^2)}{\int_0^1 dx\ x\ (\bar{u}\,(x, Q^2) + \bar{d}\,(x, Q^2))}\ .$$

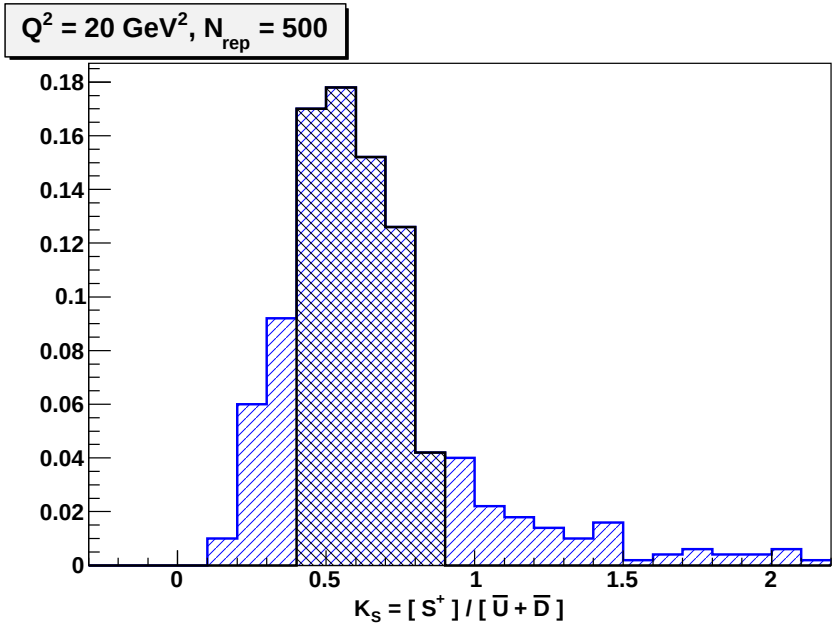
Highly asymmetric distribution $\longrightarrow$ Requires proper treatment of non-gaussian effects
No theoretical prejudice on shape of s^+, unlike other analysis (*Ex.* MSTW08)

$$xS_{\rm mstw08} = x\left(2\,(\bar{u}+\bar{s}) + s^+\right) = A_S x^{\delta_S}\,(1-x)^{\eta_S}\,(1+\epsilon_S\sqrt{s}+\gamma_S x)$$

$$xs^+_{\rm mstw08} = A_+ x^{\delta_S}\,(1-x)^{\eta_+}\,(1+\epsilon_S\sqrt{s}+\gamma_S x)$$

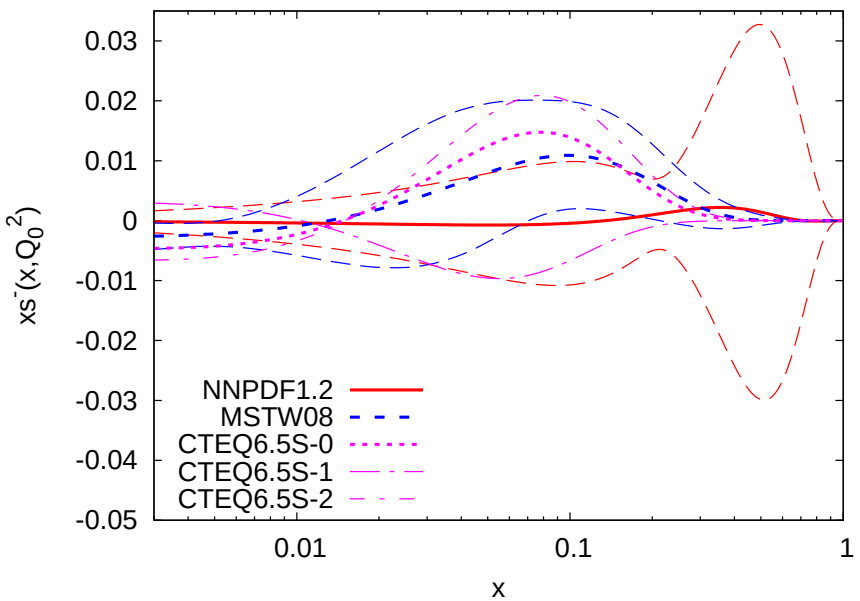
Analysis	$K_S\ (Q^2 = 20\,\mathrm{GeV}^2)$
NNPDF1.2	$0.71^{+0.20}_{-0.31}$
MSTW08	0.56 ± 0.03
CTEQ6.6	0.72 ± 0.05
AKP08	0.59 ± 0.08

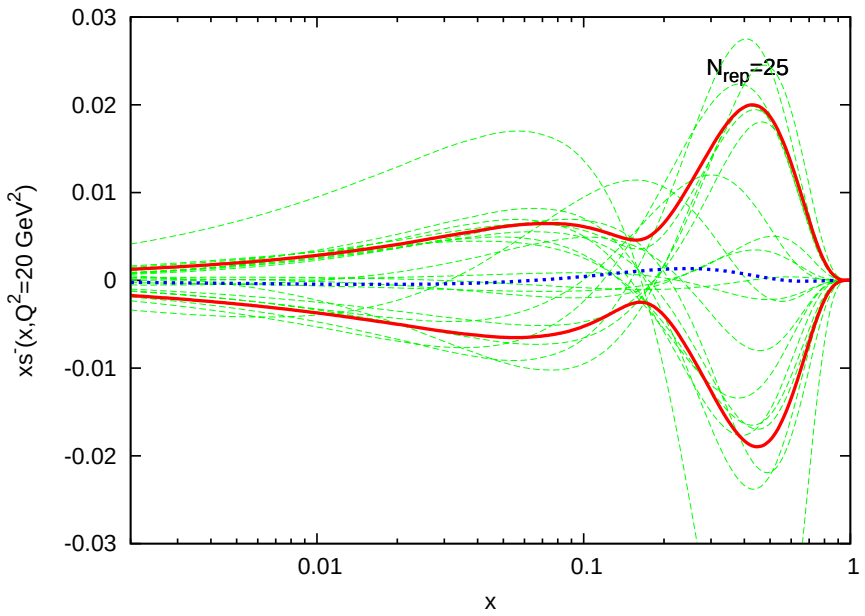
Central value for K_S in perfect agreement with CTEQ6.6, uncertainties larger by factor 4



Strange asymmetry PDF: $s^-(x, Q^2)$

Strange asymm: log scale ↓, individual reps ↘



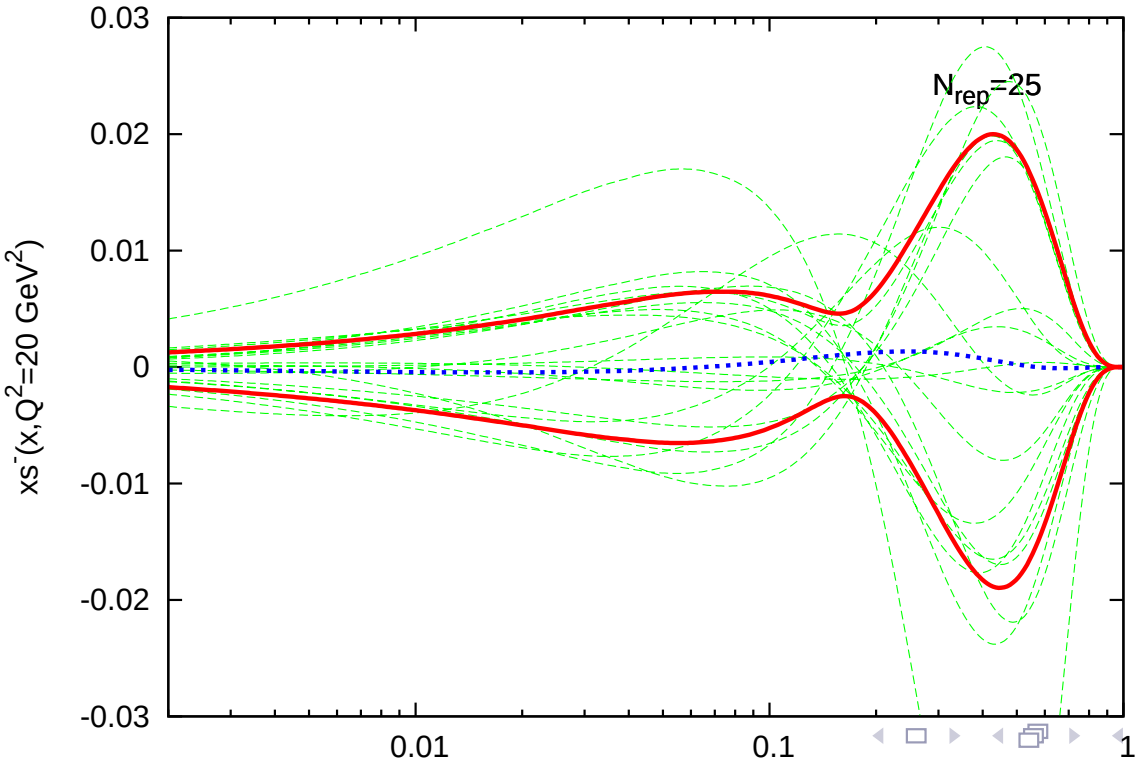


Analysis	$[S^-]\ (Q^2 = 20\,\mathrm{GeV}^2) \cdot 10^3$
NNPDF1.2	0 ± 9
MSTW08	1.4 ± 1.2
CTEQ6.5s	1.2 ± 1.1
AKP08	1.0 ± 1.3
NuTeV07	1.3 ± 0.8

Strange asymmetry PDF: $s^-(x, Q^2)$

- No theoretical constraints on $s^-(x, Q_0^2)$ apart from valence sum rule
- At least one crossing required by sum rule, but some replicas have two crossings
- Compare with more restrictive parametrizations

$$xs^-_{\rm mstw} = A_- x^{0.2} (1-x)^{\eta_-} (1 - x/x_0)$$



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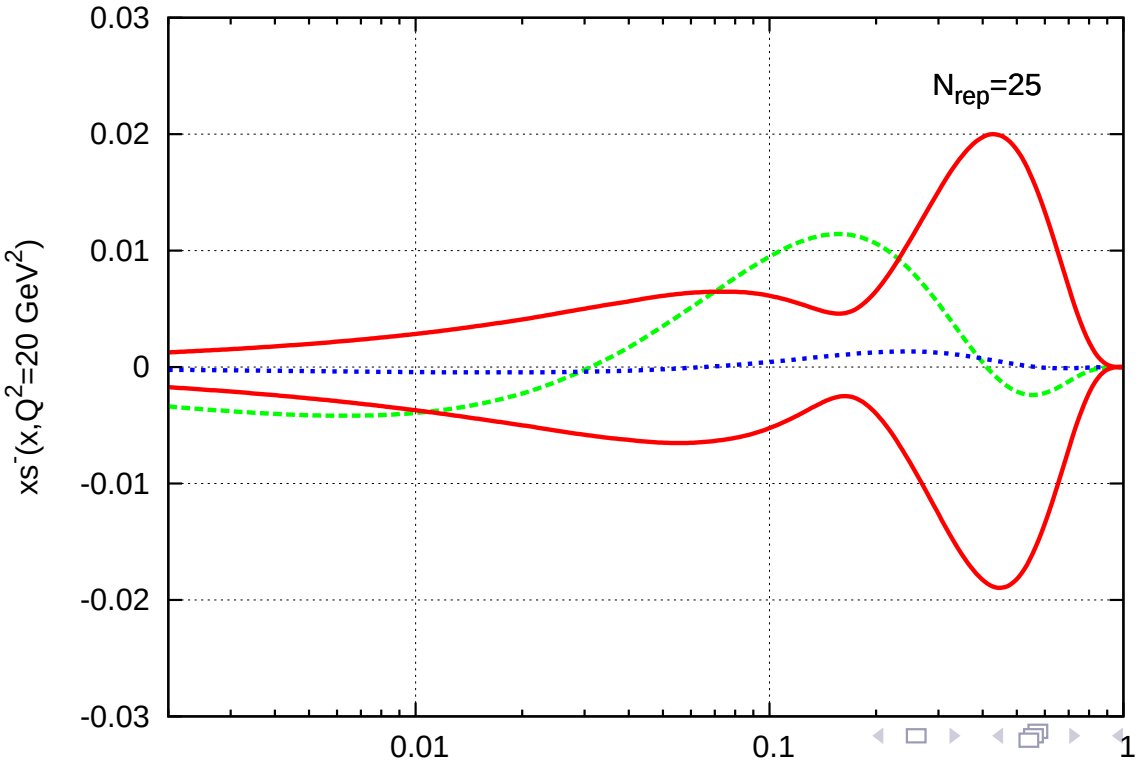

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Impact on NuTeV anomaly

- NuTeV anomaly: Discrepancy ($\geq 3\sigma$) between indirect (global fit)and direct (NuTeV neutrino scattering) determinations of $\sin^2\theta_W$

EW fit

$\sin^2\theta_W = 0.2223 \pm 0.0003$

NuTeV

$\sin^2\theta_W = 0.2277 \pm 0.0017$

$$\sin^2\theta_W\Big|_{\rm NuTeV} - \sin^2\theta_W\Big|_{\rm EWfit} = (5.4 \pm 1.7)\cdot 10^{-3}$$

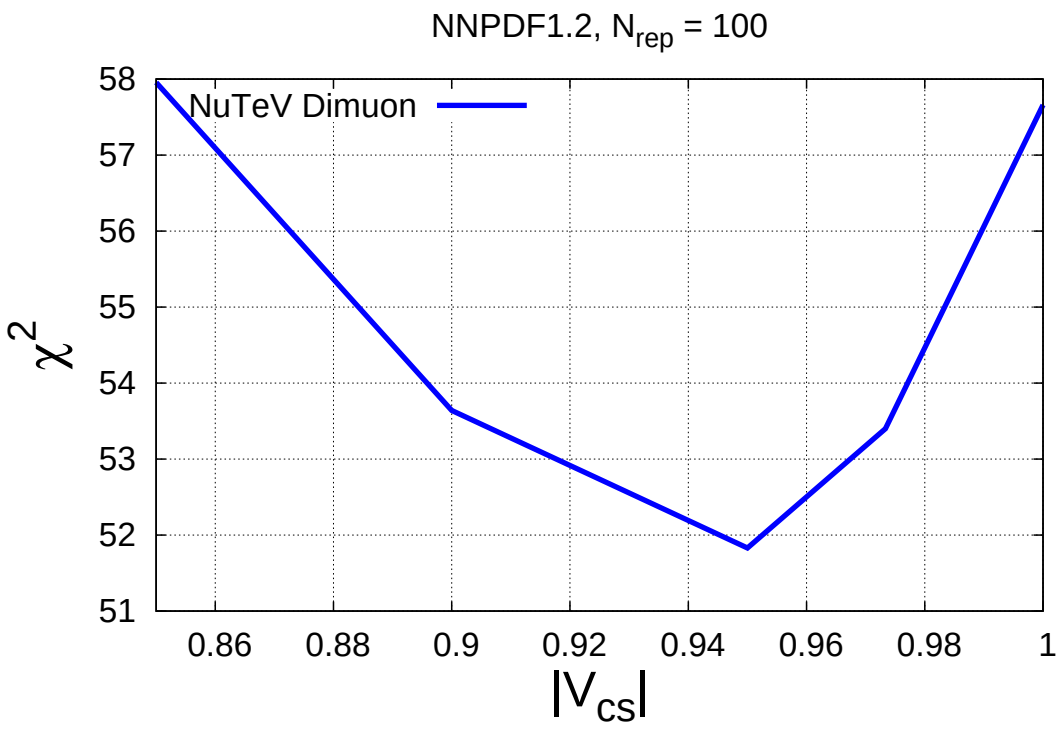
- NuTeV assumes $[S^-] = 0$. Releasing this assumption

$$\delta_s \sin^2\theta_W \sim -0.240\frac{[S^-]}{[\mathcal{Q}^-]}$$

$$\text{NNPDF1.2} \longrightarrow \delta_s \sin^2\theta_W = \left(0 \pm 9^{\rm PDFs} \pm 3^{\rm theo}\right)\cdot 10^{-3}$$

- Central value for $[S^-]$ consistent with vanishing strange asymmetry $\longrightarrow$ Not enough information from NuTeV dimuons to pin down $[S^-]$
- PDF uncertainties more than enough to completely remove the NuTeV anomaly

Direct $|V_{cs}|$ determination (preliminary)



CKM global fit

$$V_{cs} = 0.97334 \pm 0.00023, \ \Delta V_{cs} \sim 0.02\%$$

Direct determination-D and B decays

$$V_{cs} = 1.04 \pm 0.06, \qquad \Delta V_{cs} \sim 6\%$$

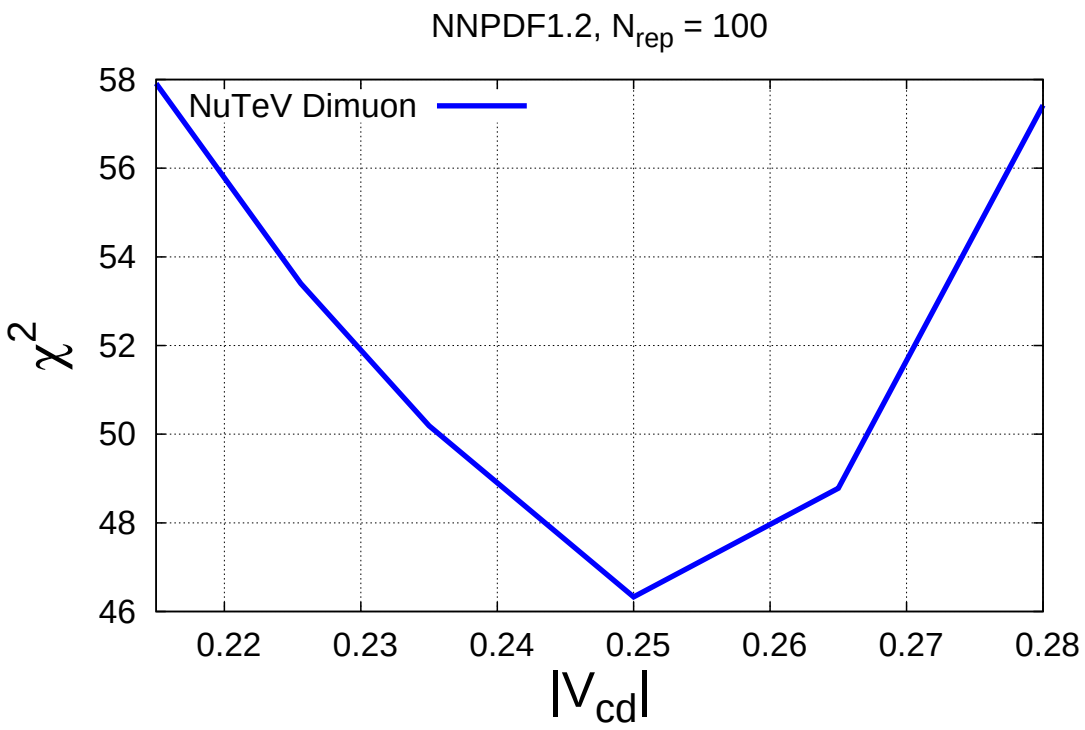
Direct det from $\nu-$DIS (CDHS)

$$V_{cs} \geq 0.59 \quad (90\%\mathrm{CL})$$

[PDG, Amsler et al, Phys. Lett. B67(2008) 1.]

- $|V_{cs}|$ determination from neutrino DIS affected by $s^+(x)$ uncertainties
- Unbiased parametrizations for PDFs allow to discriminate variations in $s^+(x)$ from variations in CKM matrix elements

Direct $|V_{cd}|$ determination (preliminary)



CKM global fit

$$V_{cd} = 0.2256 \pm 0.0010, \ \Delta V_{cd} \sim 0.5\%$$

Direct det - $\nu-$DIS (CDHS)

$$V_{cs} = 0.24 \pm 0.03 \ , \qquad \Delta V_{cd} \sim 12\%$$

Direct det - PDG average

$$V_{cd} = 0.230 \pm 0.011 \ , \qquad \Delta V_{cd} \sim 5\%$$

[PDG, Amsler et al, Phys. Lett. B67(2008) 1.]

- Unbiased parametrizations for PDFs allow to discriminate variations in light-quark PDFs from variations in CKM matrix elements
- NNPDF1.2 direct determination of $|V_{cd}|$ comparable uncertainties with PDG
- Work in progress: correlation between $|V_{cd}|$ and $|V_{cs}|$

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Conclusions

- NNPDF1.2: Unbiased determination of strange PDFs from NuTeV data without theoretical prejudices
- In particular, no fixed number of nodes imposed for $s^-(x)$
- Uncertainties in $\left[S^-\right]$ large enough to completely cancel the NuTeV anomaly
- Most precise direct determination of the $|V_{\rm cs}|$ CKM matrix element from neutrino DIS
- Uncertainty in $|V_{\rm cd}|$ determination comparable to PDG average
- The NNPDF approach faithfully disentangles between strange PDF uncertainties (large) and $|V_{\rm cs}|$, $|V_{\rm cd}|$ uncertainties (small)

Thanks for your attention!

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EXTRA MATERIAL

NNPDF1.2: Normalization and Sum Rules

$$
\begin{aligned}
\Sigma(x,Q_0^2) &= (1-x)^{m_\Sigma} x^{-n_\Sigma} \mathrm{NN}_\Sigma(x) \ , \\
V(x,Q_0^2) &= A_V (1-x)^{m_V} x^{-n_V} \mathrm{NN}_V(x) \ , \\
T_3(x,Q_0^2) &= (1-x)^{m_{T_3}} x^{-n_{T_3}} \mathrm{NN}_{T_3}(x) \ , \\
\Delta_S(x,Q_0^2) &= A_{\Delta_S} (1-x)^{m_{\Delta_S}} x^{-n_{\Delta_S}} \mathrm{NN}_{\Delta_S}(x) \ , \\
g(x,Q_0^2) &= A_g (1-x)^{m_g} x^{-n_g} \mathrm{NN}_g(x) \\
s^+(x,Q_0^2) &= (1-x)^{m_s^+} x^{-n_s^+} NN_{s^+}(x) \\
s^-(x,Q_0^2) &= (1-x)^{m_s^-} x^{-n_s^-} NN_{s^-}(x) - A_{s^-}[x^{r_{s^-}}(1-x)^{m_{t^-}}]
\end{aligned}
$$

Normalization $\longrightarrow$ Fixed by valence and momentum sum rules

$$
\begin{aligned}
\int_0^1 dx\ x\,(\Sigma(x)+g(x)) &= 1 \\
\int_0^1 dx\ (u(x)-\bar{u}(x)) &= 2 \\
\int_0^1 dx\ (d(x)-\bar{d}(x)) &= 1 \\
\int_0^1 dx\ (s(x)-\bar{s}(x)) &= 0
\end{aligned}
$$

NNPDF1.2: Sum Rules

- For instance

$$A_V = \frac{3}{\int_0^1 dx \left((1-x)^{m_V} x^{-n_V} \mathrm{NN}_V(x)\right)}$$

- For the strange sum rule it is slightly different:

$$A_{s^-} = \frac{\Gamma\left(r_{s^-} + t_{s^-} + 2\right)}{\Gamma\left(r_{s^-} + 1\right)\Gamma\left(t_{s^-} + 1\right)} \int_0^1 dx \left((1-x)^{m_{s^-}} x^{-n_{s^-}} \mathrm{NN}_{s^-}(x)\right)$$

- When $A_{s^-} = 0$ the valence sum rule constraint is removed.

Preprocessing exponents

- Polynomial preprocessing functions are introduced in order to speed up the training but should not affect final results.
- Default values for the preprocessing exponents, $\chi^2 = 1.34$.

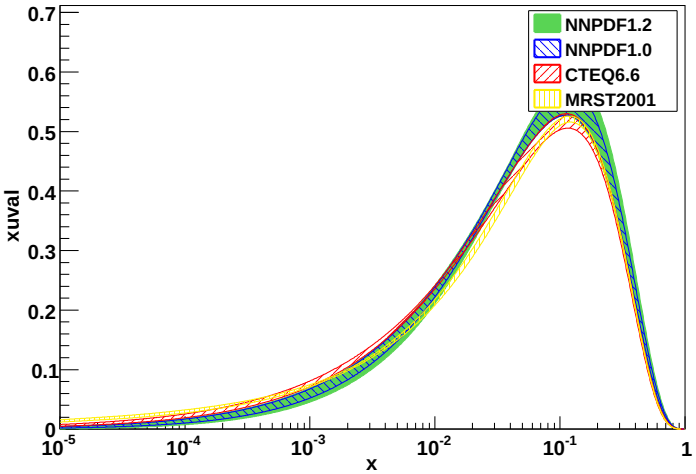
	m	n
Σ	3	1.2
g	4	1.2
T_3	3	0.3
V	3	0.3
Δ_S	3	0.

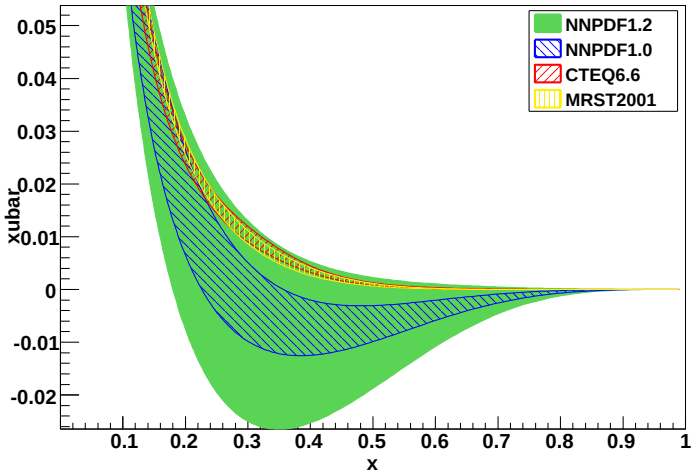
- Stability checks under variation of exponents:

Valence sector		Singlet sector	
	χ^2		χ^2
$n_{T_3} = n_V = 0.1$	1.38	$n_\Sigma = n_g = 0.8$	1.39
$n_{T_3} = n_V = 0.5$	1.34	$n_\Sigma = n_g = 1.6$	1.52
$m_{T_3} = m_V = 2$	1.55	$m_\Sigma = m_g - 1 = 2$	1.37
$m_{T_3} = m_V = 4$	1.28	$m_\Sigma = m_g - 1 = 4$	1.41

NNPDF1.2: Randomized preprocessing

- Remarkable stability: in most cases variations are within 90% C.L.
- Exception given by valence and triplet: deviation $\sim 1.4\sigma$ from central value when varying exponents.
- Uncertainty on V and T_3 underestimated by factor between 1 and 2.
- Note that we have full control on that!
- NNPDF1.2: Randomized preprocessing!





- Bigger uncertainty on $\bar{u}$ and u_v! Will be reduced by DY data.

NNPDF1.2: Strangeness determination

- Individual replicas for strange an anti-strange.
- Bigger uncertainty for $\bar{s}$ due to larger uncertainties of anti-neutrino data.