Neutrino data for nuclear parton distribution determinations

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Introduction/Motivation

nPDFs and neutrino data

Neutrino deep inelastic scattering:

- Neutrino data important for many reasons: flavour separation of PDFs, ew precision physics, …
- Neutrino experiments use heavy nuclear targets: Pb, Fe, Ar, H₂O, C

and ^{0.80}
- As discovered more than 30 years ago by the European Muon Collaboration, nucleon structure functions are modified by the nuclear medium (EMC effect) °ed more than 30 years agc *z*onaboration, in and the data and discussed to \overline{a} are modifi
- Studies of nucleon structure: need to correct for nuclear effects
- Are nuclear corrections in neutrino DIS the same as in charged lepton DIS?

nPDFs and neutrino data

Neutrino deep inelastic scattering:

- Several studies have been performed:
	- "iron PDFs: PRD77(2008)054013
	- nCTEQ analysis of nuA+lA+DY analysis of nuA+lA+DY analysis of $\frac{0.85}{0.80}$ and $\frac{0.85}{0.80}$ an data: PRL106(2011)122301
	- Differences independent of the proton baseline: Kalantarians, Keppel, PRC96(2017)032201 ndependent Fit to *l [±]A* DIS and DY data
	- Ultimate analysis: "Compatibility of Neutrino DIS data and its Impact on Nuclear Parton Distribution Functions", **arXiv:2204.13157 [This talk]**

Compatibility of neutrino DIS data and its Impact on NPDFs arXiv:2204.13157

mCTEQ global analysis framework improve the treatment of $n-1$ scale, *x* is the fractional momentum of the parton with respectively to the average momentum of the nucleon \mathcal{Z} *N* = (*A Z*) are respectively the number of protons and a result of a r additions, the analysis presented in this paper is the most as we neglect the motion of bound nucleons inside the motion of bound nucleons inside the motion of bound nucleons in The bound neutron PDFs can be obtained from the bound of the
The bound of the b

- Twist-2 collinear factorisation based on QCD factorisation theorems $\overline{}$ livide $\overline{}$ commeat interviewing correlation in the system of the system in all fitting in all fitting in all fitting in all fitting in all fit
The systematic value of the systematic contribution in all fitting in all fitting in all fitting in all fittin allow the strange quark PDF parameters to vary \mathcal{L} $\frac{1}{2}$ result of $\frac{1}{2}$ and $\frac{1}{2}$ in $\frac{1}{2}$
- **e** Hard processes perturbatively calculable and the aforements are the aforements and the aforements are the aforements and the aforements and *z* boson production data from the LHC graduate from the LHC graduate from the LHC graduate the LHC and the LHC an calculable hadron production of the production of the set of the s **e** Hard processes perturbatively n nai – piecessos po
Calculable also present the best approach which will be used in our
- \bullet Universal nuclear PDFs e Liniversal nuclear PDFs data. In the meant of mean is not publish the new also published the new published of \mathcal{L}

\n is a given function\n

\n\n
$$
F_2^A(x, Q^2) = \sum_i [f_i^A \otimes C_{2,i}](x, Q^2)
$$
\n

\n\n at ion\n

\n\n $\text{DY } \sigma_{A+B\to\ell^++\ell^-+X} = \sum_{i,j}^i f_i^A \otimes f_j^B \otimes \hat{\sigma}^{i+j\to\ell^++\ell^+X}$ \n

\n\n s.tively\n

\n\n $\sigma_{A+B\to H+X} = \sum_{i,j,k}^i f_i^A \otimes f_j^B \otimes \hat{\sigma}^{i+j\to k+X} \otimes D_k^H$ \n

$$
f_i^A(x,Q) = \frac{Z}{A} f_i^{p/A}(x,Q) + \frac{N}{A} f_i^{n/A}(x,Q)
$$

*Q*⁰ = 1*.*3 GeV using the following parametrization [8]:

The bound neutron PDFs can be obtained from the bound from the bound from the bound from the property of the bound from the bound of the bound o

*^c*² + (1 + *^c*3)(1 *^x*)

- **•** Parameterization of NPDFs at the initial scale $\mathcal{Q}_0=1.3$ GeV $(i = u_v, d_v, g, \bar{u} + \bar{d}, s + \bar{s}, s - \bar{s})$ $\frac{1}{2}$ improvement of the paper is $\frac{1}{2}$ in the initial scale $\Omega_{\rm e} = 1.3$ Ge fit the data of the data. The data of $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ $u = u_{v}, u_{v}, g, u = u, s = s$ also mixture $\frac{Q_0}{I_0}$ in $\frac{1}{I_0}$ in our distribution in $\frac{1}{I_0}$ in $\frac{1}{I_0}$ in $\frac{1}{I_0}$ in $\frac{1}{I_0}$ in $\frac{1}{I_0}$ in $\mu = u_{v}, u_{v}, g, u + a, s + s, s \begin{array}{ccc} \n\text{or } & \text{if } & \$ \mathcal{C} bring \mathcal{C} is depth in Sec. II. Sec. II. Sec.
- Scale-dependence of NPDFs by E State-dependence of the internal contains to vary the internal checks of the internal contains to vary the i • Scale-dependence of NPDFs a Scale dependence of NIDDEs by consistency of the neutrino data and neutrino data and the neutrino
- **e** Sum rules \sim and the aforementioned improvements and \sim \overline{a} and \overline{b} \bullet sum rules Section IV is the core of the comparise comparise conclusions.

DFs at
$$
xf_i^{p/A}(x, Q_0) = c_0 x^{c_1} (1-x)^{c_2} e^{c_3 x} (1+e^{c_4}x)^{c_5}
$$

3 GeV
$$
\frac{\bar{d}(x, Q_0)}{\bar{u}(x, Q_0)} = c_0 x^{c_1} (1-x)^{c_2} + (1+c_3)(1-x)^{c_4}
$$

effective bound proton and neutron PDFs respectively. The momentum fraction *x* in this case takes in principle *s, s* ¯ *s*¯. Here *u^v* and *d^v* are the up and down quark valence **A-dependent coefficients:** where the flavor index *i* runs over *i* = *uv, dv, g, u*¯ + *d, s*

*^c*¹ (1 *^x*)

$$
c_i(A, Z) = p_i + a_i(1 - A^{-b_i})
$$

Free proton PDF parameters

Data sets used in nCTEQ \mathcal{L} Data sets Data sets PRD93(2016)085037

Reference fit without neutrino data **FIE deuteron FR2 structure function properties in the function properties in the function properties in the function proper** method discussed in Ref. $\mathcal{S}_{\mathcal{S}}$ in Ref. [51]. Specifically, the deuteronometric algebra $\mathcal{S}_{\mathcal{S}}$

Fig. 3. For comparison, we use the same ² =

TABLE II. Neutrino data Single pion production production (new)

- · Chorus, CCFR, NuTeV cross section data: ew corrections applied directly to data
- **•** Chorus, NuTeV: point-to-point correlated systematic errors included in analysis
- i Exercise an OCTIV state with x_1 of y_2 for the results of the respectively in the respectively. $\bullet~$ Exclude all CCFR data with x>0.4 [see NuTeV collab., PRD74(2006)012008]
- Data from NOMAD (not publicly released), ICECUBE (small x~10-6), Minerva (low Q): not considered

Solid considered α released). ICFCUBF (small \mathbf{x} \sim 10-6).
- Dimuon data from CCFR and NuTeV included in the analysis NOMAD data not included but compared to; older CDHS, CHORUS data not included TeV included in the analysis

ampared to alder CDUS CHORUS data not include Γ e 110 \sim 333 \sim 38 \sim 38 \sim 38 \sim

of various data sets at *E*⌫ ⇠ 85 GeV where all the data sets

Neutrino (to be included later)

TABLE III. R $s(x) = \frac{1}{\sqrt{2\pi}} \int_{0}^{1} \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-\sqrt{2})^2}{2\sqrt{2\pi}}} e^{-\frac{(x-\sqrt{2})^2}{2\sqrt{2\pi}}}$ \mathbf{E} at the Tevatron control \mathbf{E} TABLE III. Relative experimental uncertainties (in percent) of various data sets at $E_\nu \sim 85$ GeV where all the data sets is overlap.

DimuNeu fit with only neutrino data

$DimuNeu$ fit: $\chi^2/\rm pt$ for each data set

- DIS cuts: Q>2 GeV, W>3.5 GeV; CCFR: x<0.4 weighted average of cross section ratios. We have a section ratios of cross section ratios. We have the construction ratio μ
- Need assumptions since νA data cannot constrain all partons: \bullet Need assumptions since μA data cannot constrain all partons: nuclear essample In Suite νA data cannot constrain an partons.
- Fix gluon to gluon of **Ref** fit pour dine pour de transformation de la provincia de la provincia de la provincia de la provincia de la provincia
En la provincia de la provinc • Fix gluon to gluon of **Ref** fit neutral or charged current deep inelastic scattering to charged current deep inelastic scattering to charged c
The charged current deep intelastic scattering to charged current deep intelastic scattering to charged curren
- Fix \bar{d}/\bar{u} to free proton ratio Tab. II. Compared to our previous analyses, we improve expected SLAC results. Here we will get • Fix d/u to tree proton ratio
- 20 free parameters + 10 free normalisations; 5689 data points ers + TV tree normalisations; 5689 data points **e** 20 free parameters + 10 free normalisations^{, 5689} data points the inclusive and semi-inclusive neutrino data listed in s from completions, soot data points.
- Generally good description but the most precise NuTeV neutrino cross section data have quite a bad $\chi^2/\rm pt$ of **1.5**. Milder tensions for other NuTeV and Chorus data with χ^2 /pt ~ 1.2. possible with the most process reason <u>now moderning</u> $\frac{1}{2}$ and $\frac{1}{2}$ alone $\frac{1}{2}$ alone cannot construct the participate particle particl $T_{\rm eff}$ is compared to our previous analyses, we improve • Generally good description but the most precise NuTeV neutrino cro data have quite a bad χ^2 /pt of **1.5**. Milder tensions for other NuTeV $\frac{1}{2}$ data with $\frac{2}{n^2}$ $rac{1}{\sqrt{2}}$ $n = \sqrt{12}$ correction factor construction factor $\frac{1}{2}$

DimuNeu fit vs *Reference* fit

Ratio of full nuclear PDF to free PDF: $R[f_i^{\rm A}] =$

- Distinct differences between valence quarks and also the light sea quarks
- *DimuNeu* fit: shadowing only for x<0.01
- Similar picture for lead with significant differences also for the strange quark

Nuclear correction factors uncertainties. The details of this treatment are given in the details of this treatment are given in the detail App. B. Before going further, we note that extracting to generate sufficient statistics. Therefore, one uses a sufficient statistics. Therefore, one uses a sufficie nuclear correction factors construction factor construction as a construction of the construction of the constr where the charged current structure function \mathbf{r} **CC**_{**^{***c***}**} ² is

$$
F_2^{CC} = (F_2^{\nu A} + F_2^{\bar{\nu}A})/2
$$

- The *Reference fit* to charged lepton DIS+DY+SIH+W,Z data describes the IA DIS data (by construction) • The Reference fit to charged I assume that the nuclear corrections to *u*¯ and *d*¯are similar • The Reference fit to charged lepton
- The NPDFs from the neutrino only DimuNeu fit predict a different shape for the nuclear correction factor $\frac{1}{2}$ **not** describing the IA DIS data **Parameters** In a dit only the neutrino details see [8]) with the same 2 = 45 tolerance criterion crit **o** The NPDFs from the neutrino only DimuNeu fit predict a different shape
- Conversely, the *DimuNeu fit* describes the neutrino data (by construction even if the structure function data have not been used) $\sum_{\alpha=0}^{n}$ The results of the Dimunity of the largest First, the list of final values of all parameters after DimuNeu result can decently describe all neutrino data. $\frac{1}{2}$ construction even if the structure
- The prediction from the *Ref fit* does **not** describe the neutrino data well to the paintring of the sense in the paintring of free describe are nead mode. \bullet The prediction from the Ref fit does **not** describe the neutrino data well all $\frac{1}{2}$

 $R[F_2^{CC}] = \frac{F_2^{CC}[f_i^A]}{FCC}$

 $F_2^{CC}[f_i^{A,\text{free}}]$

Combined global analysis

- Usually one includes new data in a global analysis in order to improve the precision or the (x,Q) coverage of the previous analysis
- Is it possible to have a combined global analysis of all data? **lA DIS + DY + SIH + LHC W,Z +** νA DIS
- If there are tensions, there are two possibilities:

a)**Theory wrong**?

- Breakdown of twist-2 factorisation (no universal PDFs): Big problem!
- Twist-2 factorisation valid but need to improve theory (higher orders, resummation, higher twists, TMC)
- b) **Data wrong** or unrealistically precise?
- How to quantify tensions or the compatibility of data? Not discussed here

TABLE V. Statistical information such as the total analysis discussed here are presented. The total analysis discussed here are pres Moreover, the ²-percentiles with respect to the reference fit nCTEQ15WZSIHdeut (denoted *S*) and to the only neutrino DimuNeu analysis (denoted *S*¯) are also given.

- to properly use the properly use the possible to be possible to be possible to be possible to be possible to b
The possible to be p data from C and \mathcal{N} and \mathcal{N} and \mathcal{N} and \mathcal{N} and \mathcal{N} and \mathcal{N} are to emphasize that \mathcal{N} *• nCTEQ15WZSIHdeut=Ref=Base*: lA DIS + DY + SIH + LHC W,Z
- *DimuNeu*: Dimuon + CDHSW + CCFR + NuTeV + Chorus criterion on ly to data sets which are sufficiently large to data sets which are sufficiently large to data set in the original nCTEQ15WZSIHdeut analysis (*N* = 940)
- **S**

S**E**-comparison of the last critician used in the last control in the last co data $\sqrt{\nabla}$ $\frac{d}{dx}$ $\frac{d}{dx}$ and all noutrino data) t_{max} and an if the global integration $\frac{d}{dt}$ • *BaseDimuNeu*: Ref data (S) + DimuNeu data (\overline{S}) (combined global analysis of Reference data and all neutrino data)
- ϵ Come 27 perspecters in ell fite • Same 27 parameters in all fits
- τ the global analysis of the τ \bullet lolerance of Ref fit: $\Delta \chi^2_S = 45$ • Tolerance of *Ref* fit: $\Delta \chi^2_S = 45$
- of each experiment *E* in this analysis. The comparison • $\Delta \chi^2_S = 131, \Delta \chi^2_{\overline{S}} = 283$: *S* and \overline{S} data **not compatible** $= 283$: *S* and *S*

Ratio of full iron PDFs to Reference PDFs FIG. 10. The full iron PDFs at *Q*² = 4 GeV². All uncertainty bands are computed using the Hessian method with ² = 45*.*

• Uncertainty bands: Hessian method with $\Delta \chi^2 = 45$

- bands are obtained using the Hessian method with ² = 45. \bullet Important differences between Ref fit and BaseDimuNeu fit for u_{ν}, d_{ν} PDFs
- $\bullet\,$ No real tension for strange PDF since the neutrino data provide first strong constraint on s-PDF. However, neutrino differential cross section data prefer a different strange than dimuon data. • No real tension for strange PDF since the neutrino data provide first strong constraint on s-PDF.
However poutring differential cross section data prefer a different strange than dimuon data based on their respective ² growth profiles, but with

Ratio of full iron PDFs to Reference PDFs

 \bullet Uncertainty bands: Hessian method with $\Delta \chi^2 = 45$ \mathcal{L} = \mathcal{L}

- νA DIS data with a cut $x > 0.1$
- \bullet Improved compatibility but cut x>0.1 difficult to justify Improved compacionly but cut x-0.1 uni

Ratio of full lead PDFs to Reference PDFs

- Uncertainty bands: Hessian method with $\Delta \chi^2 = 45$ $\overline{}$
- BaseDimuChorus: Ref data + Dimuon + Chorus data
- Dimuon + Chorus data compatible with Reference data; improved strange PDF Umique i Chorus data compatible v $2p_{\text{e}}$ Therefore data, improved stranger D_1

Comparison with NOMAD data

Conclusions

Neutrino DIS vs Charged lepton DIS

Ultimate analysis: " Compatibility of Neutrino DIS data and Its Impact on 7 **Nuclear Parton Distribution Functions", arXiv:2204.13157**

- Most thorough analysis so far (thesis K. F. Muzakka, $\frac{1}{1000}$ include $\frac{1}{1000}$ include the systematic uncertainties. U Münster): different tools to analyse compatibility of data anti-)neutrino DIS double-
- \bullet Neutrino data croatos significant tonsions be • Neutrino data creates significant tensions between key data sets: neutrino vs charged lepton+DY+LHC
- data at the given neutrino beam energy. Due to the • Tensions among different neutrino data sets: iron
(CDJ(C)(*A)* + Tensions and COLOR(C) (CDHSW, NuTeV, CCFR) vs lead (CHORUS)?
- precise than the counterparts. The counterparts of σ • Next nCTEQ analysis will include CHORUS and Di-muon data but not NuTeV, CCFR, CDHSW data

Backup

Scale dependence predicted by QCD

- *x*-dependence of PDFs is NOT calculable in pQCD
- \blacktriangleright μ^2 -dependence is calculable in pQCD given by DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) evolution equations

DGLAP evolution equations

$$
\frac{df_q(x,\mu^2)}{d\log\mu^2} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dy}{y} \left[P_{qq}\left(\frac{x}{y}\right) f_q(y,\mu^2) + P_{qg}\left(\frac{x}{y}\right) f_g(y,\mu^2) \right]
$$

$$
\frac{df_g(x,\mu^2)}{d\log\mu^2} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dy}{y} \left[P_{gg}\left(\frac{x}{y}\right) f_g(y,\mu^2) + P_{gq}\left(\frac{x}{y}\right) f_q(y,\mu^2) \right]
$$

- Ifferent PDFs mix set of $(2n_f + 1)$ coupled integro-differential equations.
- **•** Need boundary conditions $f_i(x, Q_0)$ at some perturbative initial scale $Q_0 ≥ I$ $\mathbf V$ have interpretation as probabilities of parton splittings: $\mathbf V$ **GeV**
- The **x-dependence** is not calculable in pQCD, perform **global analysis** *y x* of **experimental data [EPPS, nCTEQ, nNNPDF, …]**
- Progress on the **lattice**: see **arXiv:1711.07916, 2006.08636**

Sum rules provide constraints

 \blacktriangleright Number sum rules – connect partons to quarks from SU(3) flavour symmetry of hadrons; proton (*uud*), neutron (*udd*). For protons:

$$
\int_0^1 dx \left[f_u(x) - f_{\bar{u}}(x) \right] = 2 \qquad \int_0^1 dx \left[f_d(x) - f_{\bar{d}}(x) \right] = 1
$$

$$
\int_0^1 dx \left[f_s(x) - f_{\bar{s}}(x) \right] = \int_0^1 dx \left[f_c(x) - f_{\bar{c}}(x) \right] = 0
$$

 \triangleright Momentum sum rule – momentum conservation connecting all flavours

For all scales:

For all

scales:

$$
\sum_{i=q,\bar{q},g}\int_0^1 dx\; xf_i(x)=1
$$

Momentum carried by up and down quarks is only around half of the total proton momentum the rest of the momentum is carried by gluons and small amount by sea quarks. In case of CT14NLO PDFs $(\mu = 1.3 \text{ GeV})$:

At 1.3 GeV:

$$
\int_0^1 dx \, x [f_u(x) + f_d(x)] \simeq 0.51
$$

$$
\int_0^1 dx \, x f_g(x) \simeq 0.40
$$

Nuclear modifications

- Neutrino experiments use heavy nuclear targets: Pb, Fe, Ar, $H₂O$, C
- As discovered more than 30 years ago by the European Muon Collaboration, nucleon structure functions are modified by the nuclear medium (EMC effect)
- Studies of nucleon structure: need to correct for nuclear effects
- Nuclear effects interesting in its own right!
	- Many models exist.
	- However, charged lepton nuclear effects still not fully explained, in particular the EMC effect $(0.3 < x < 0.7)$

The EMC effect

The EMC effects of the EMC $F_2^A(x) \neq ZF_2^p(x) + NF_2^n(x)$

Global analysis of nuclear PDFs

<u>ierminations</u> Same approach as for proton PDF determinations

I. Boundary conditions:

Boundary conditions: Parameterize x-dependence of PDFs at initial $\text{scale} \ \mathbf{Q}_0$ $Scale Q_0$ and P

 $f(x,Q_0) = A_0 x^{A_1} (1-x)^{A_2} P(x;A_3,...); f = u_{v}^{\,}$, $d_{v}^{\,}$, g , \overline{u} , \overline{d} , s , \overline{s} $\frac{1}{2}$, (x, Σ_0) , $\frac{1}{2}$, x (1, x), 1, (x, Σ_3, \ldots) , 1, u_y, u_y, g, u_x, u_y, g

- $f(x\textbf{2}.Q_{_0})$ Evelve A f $(\texttt{domx}\mathbf{Q}_0^4$ R $\texttt{O}\texttt{x}\mathbf{Q}$ Aglving f the $a_{_V}$ DÆl,AP \overline{a} , \overline{d} , s , \overline{s} , \overline{d} evolution equations: $f(x,Q)$
- 3. Define suitable χ^2 function and minimize $T_{\gamma\gamma}$ r.t. fit $\mathsf{parameter}^{\mathcal{U}c}$ χ^2 _{*global*} $[A_i]$ $\equiv \sum_{n}$ W_n χ^2 _n $\frac{2\mathbf{i}}{n}$; χ^2 _n \sum_{I}^{I} *<i>P***_n ize**^Tw σ *n I* $\bigg)$ 2 $-3.$ De

Analysis of neutrino DIS data within nCTEQ

- Are there tensions between different neutrino data sets?
- Are there tensions between neutrino DIS data and other data used in nCTEQ global analyses?
	- Global analyses with and without neutrino data
	- Careful treatment of data correlation and normalisation uncertainties
	- Taking into account nuclear effects in the calculation of the deuteron structure function F_2^D
- Confirm evidence of tensions employing different criteria
- Identify data points and kinematic regions that create the tensions
	- Can tensions be relieved using a kinematic cut x>0.1?
	- Can tensions be relieved using uncorrelated systematic errors?
- Identify a subset of neutrino data allowing for a consistent global analysis

Comparison with CMS W,Z data FIG. 6. The structure function ratio predictions from DimuNeu and nCTEQ15WZSIHdeut fits. The grey bands on the left

- FIG. 7. Comparison between CMS *W[±]* boson production cross section data with the theory predictions from our fits. The \bullet Similar predictions from the DimuNeu and the Ref fits. \bullet have been shifted by their respective fitted normalization shift. • Similar predictions from the DimuNeu and the Ref fits for LHC W,Z production data
- $\bullet\,$ Not a surprise since this $\circ\,$ DimuNeu analysis correctly describes the experimental the giuon PDF which has b the initial scale. end middle scale. for each experiment with the corresponding uncertainties of \mathbf{r} ervable is quite sensitive to the theoretical predictions. for the weighted average we have replaced *R* the gluon PDF which has been fixed to be the same at • Not a surprise since this observable is quite sensitive to

Nuclear corrections from neutrino data iclear corrections from neutrino dat ratio of the cross-section and its uncertainty for each data α is uncertainty for each data α

Weighted average of neutrino cross section ratios

$$
R_i^{\sigma}(x) = \frac{\sigma(x, y_i, E_i)}{\sigma_{\text{free}}(x, y_i, E_i)}
$$

R ⁱ (*x*) = (*x, yi, Ei*) **Denominator: nCTEQ15 proton Denominator: CT18 proton**

Denominator: CT18 proton

Nuclear corrections from neutrino data iclear corrections from neutrino dat ratio of the cross-section and its uncertainty for each data α is uncertainty for each data α

Weighted average of neutrino cross section ratios

$$
R_i^{\sigma}(x) = \frac{\sigma(x, y_i, E_i)}{\sigma_{\text{free}}(x, y_i, E_i)}
$$

- Data vs predictions from *Laca* vs predictions
the DimuNeu fit the *DimuNeu fit*
- Iron: A=56, Z=26
- \overline{a} \overline{b} \overline{c} \overline{d} $\overline{$ • Lead:A=208, Z=82 • Lead: A=208, Z=82

Iron only and lead only fits on the treatment of correlated errors and normalisation uncertainties. The details of this treatment are given in the details of $A=\frac{1}{2}$ before going further, we note that extracting functions \mathcal{A} nuclear correction factor construction factor construction factor \mathcal{L}

- **DimunuIron fit:** Only neutrino-iron data from CDHSW, CCFR and NuTeV a reliable set of nPDFs from neutrino data alone is not
- \bullet ChorusW fit:

Only data only lead from Chorus and LHC W,Z **Only data only lead from Chort** assume that the nuclear corrections to **u**
THO W7

The prediction from the *Ref fit* does **not** describe the neutrino data well $T_{\rm A}$ and cancel in the ratio $T_{\rm A}$. The prediction from the Ref fit prodiction non the neglect **Sets** are also the fit intendent from the fit data

- 14 free parameters (since no A-dependence needed)
- Nuclear corrections generally similar to global *DimuNeu* analysis σ . And be found in App. Also
- *ChorusW* prediction for lead higher at $x \sim 0.1, 0.2$ and much lower at high x (no pull from NuTeV data) ϵ ϵ is an all data and for all data set and for each data set **Separately** and the given in Tab. In Fig. 3 we choose very separate in Fig. 5 we can see the separate in Fig. 5 we can see the separate in Fig. 3 we can see the separate in Fig. 3 we can see the separate in Fig. 3 we can data from $\mathbf x$ and $\mathbf x$ and $\mathbf x$ experiments are very well-known well-kn

- ar **Difference between iron and lead nuclear Dimuneuiron and Chorus Cho** structure function ratios *R*[*F* CC $\mathcal{L}^{\mathcal{L}}$ is independent of iron and lead. **Based on the total 2 in Tab. IV, we see that the total 2 in Tab. IV, we see that the theory is a set of the to**
- at and one side, both nucleus whereas iron almost isoscalar • Large excess of neutrons in lead
- **The difference in the difference in the nuclear A-dependence (subleading)** and for lead can come from two sources. The main effect of the main ef • Nuclear A-dependence (subleading)

More global analyses with neutrino data presented. Moreover, the 2-percentiles with respect to the data sets of the reference fit nCTEQ15WZSI include t *S*) and to the DimuChorus analysis (denoted *S*¯) are also given if applicable.

 $\frac{1}{\sqrt{1-\frac{1$ neutrino data sets used in different analyses. TABLE VI. Statistical information on the description of the Γ $n₁$ 38 $n₂$ 38 $n₃$ 38 $n₄$

TABLE VII. Statistical information on the description of the rable vii. Statistical information on the description of the
selected neutral current DIS data sets used in the reference nCTEQ15WZSIHdeut and BaseDimuNeu analyses. $\frac{1}{\sqrt{2}}$ to the charged-current structure functions. selected neutral current DIS data sets used in the reference TABLE VII. Statistical information on the description of the

