Compatibility of Neutrino DIS Data and Its Impact on Nuclear Parton Distribution Functions

Fred Olness
SMU

Thanks for substantial input from my friends & colleagues

nCTEQ
nuclear parton distribution functions

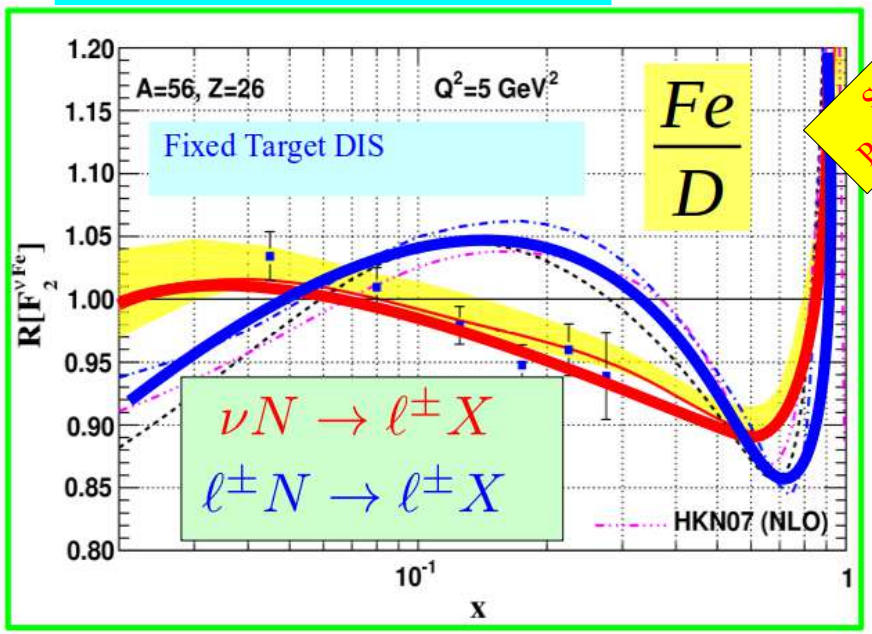
xFitter

SURGE COLLABORATION

C T E Q

GHP
14 April 2023

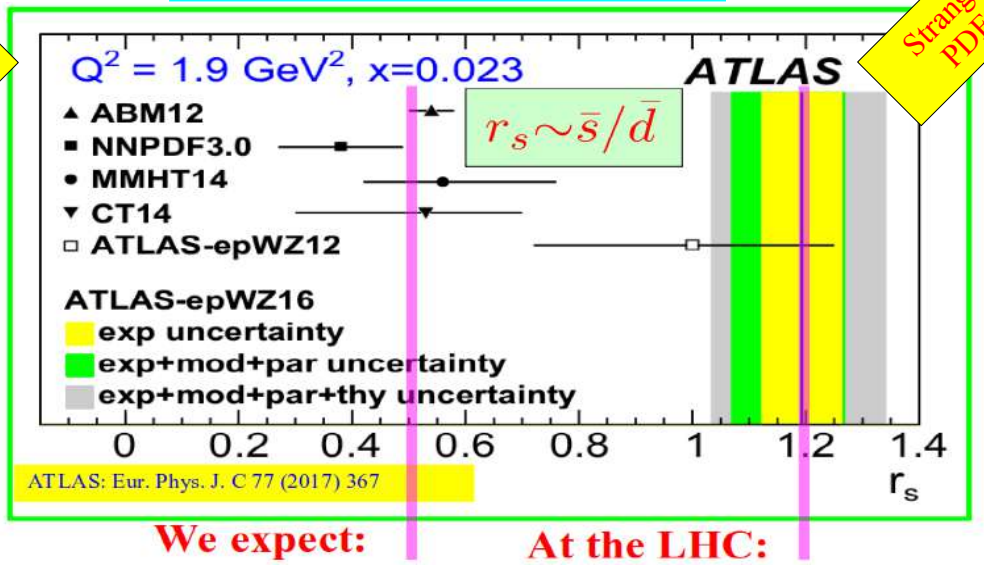
nCTEQ15ν



Split Personality

nCTEQ: F.Muzakka, K.Kovarik, ... **nCTEQ: PRD** 106, 074004 (2022)

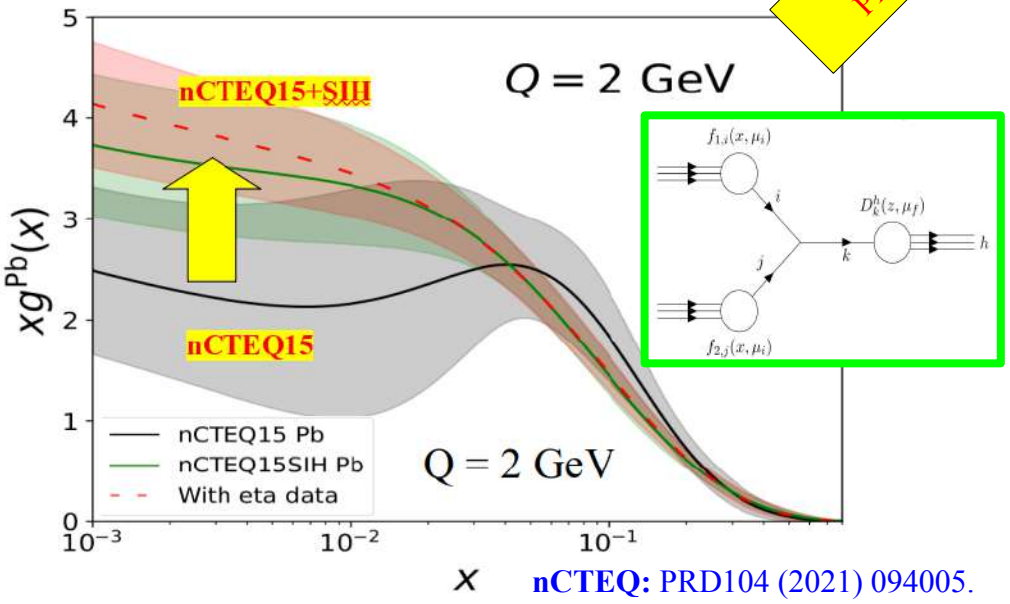
nCTEQ15WZ



Strange PDF

nCTEQ: Phys.Rev.D 104 (2021) 094005

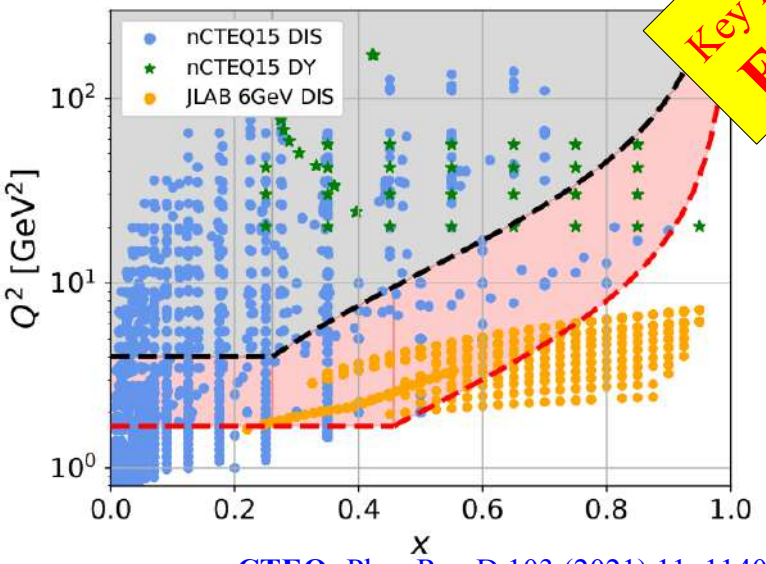
nCTEQ15WZ+SIH



Gluon PDF

nCTEQ: PRD104 (2021) 094005.

nCTEQ15HIX



Key for EIC

nCTEQ: Phys.Rev.D 103 (2021) 11, 114015

precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,\sigma)$

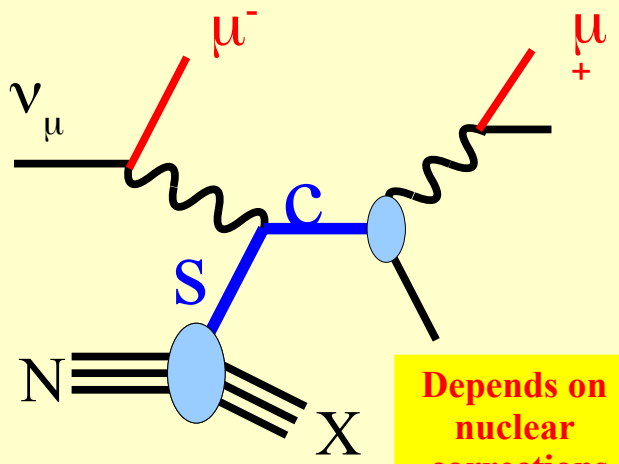
Neutrino Data are ESSENTIAL for PDFs

neutrino DIS

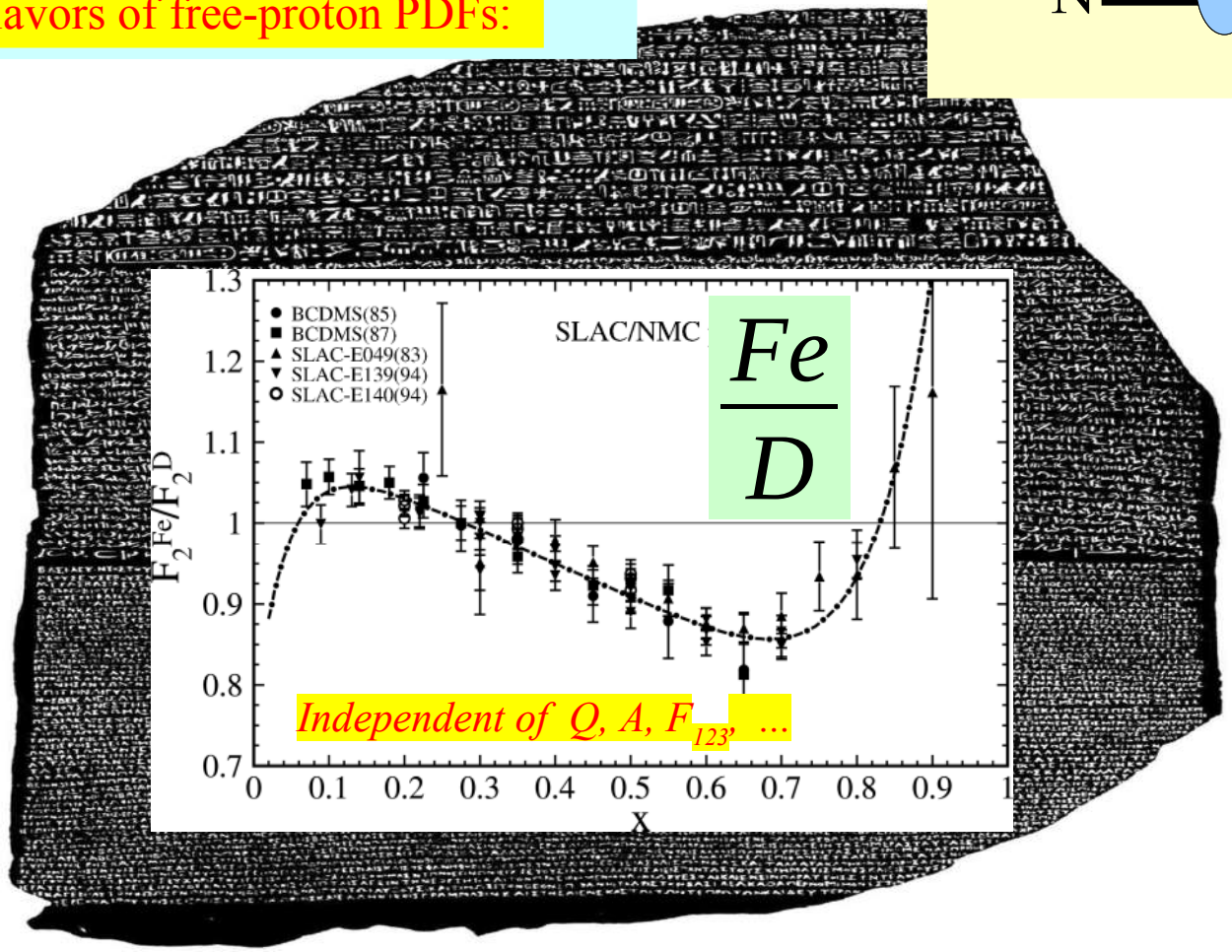
$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
$$F_3^{\nu} \sim 2\left[d + s - \bar{u} - \bar{c}\right]$$
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

Differentiate flavors of free-proton PDFs:

Neutrino DIS



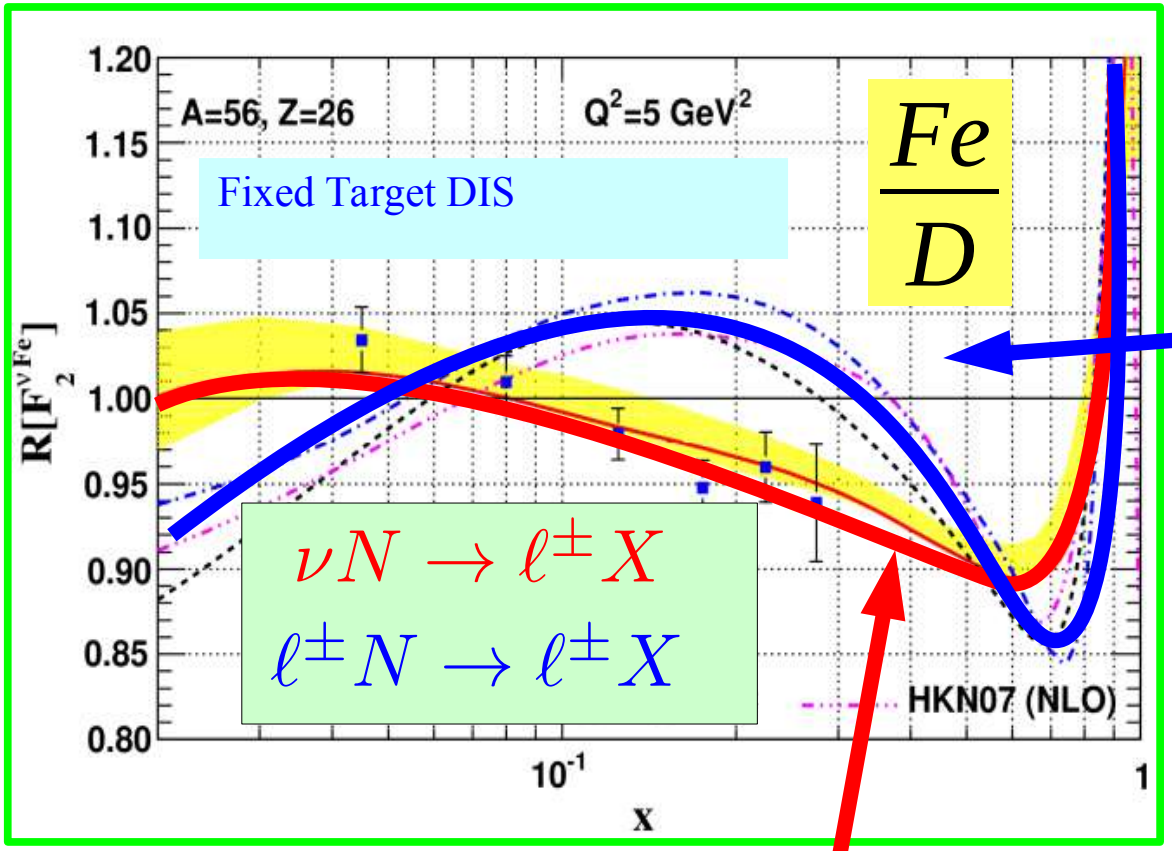
Depends on nuclear corrections



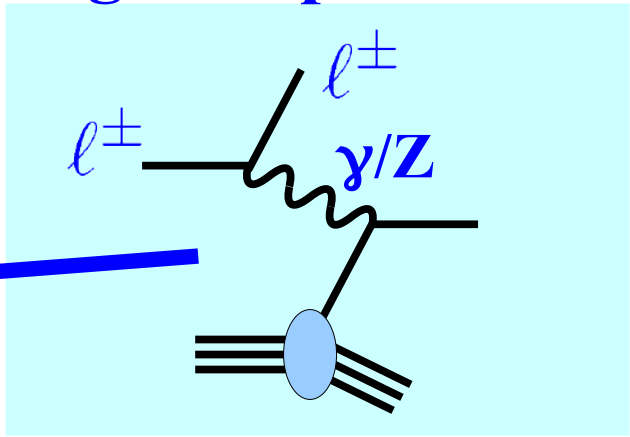
ν DIS yields flavors

- **But, nuc. targets**
- **key for s(x)**

Puzzle: Split Personality … *What is the correct Nuclear ratio*

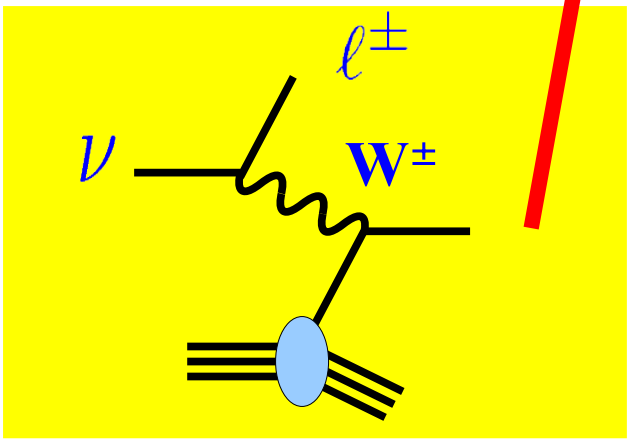


Charged Lepton DIS



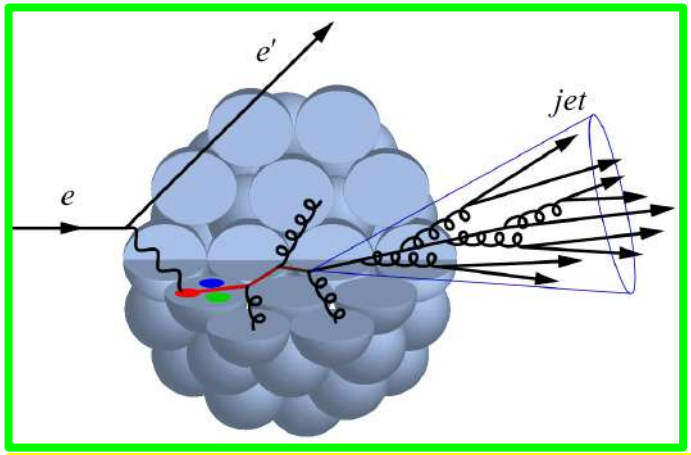
some caveats
… correlated errors

Ingo Schienbein, … (2007)
Karol Kovarik, … (2010)



Neutrino DIS

Depends on nuclear corrections



Propagation of γ/W thru nuclei

OUTLINE: *... can we cure the "split personality"*

PHYSICAL REVIEW D **106,** 074004 (2022)

Compatibility of neutrino DIS data and its impact on nuclear parton distribution functions

K. F. Muzakka,[1,*] P. Duwentäster,[1] T. J. Hobbs,[2,3] T. Ježo,[1] M. Klasen,[1] K. Kovařík,[1,†] A. Kusina,[4] J. G. Morfín,[2] F. I. Olness,[5] R. Ruiz,[4] I. Schienbein,[6] and J. Y. Yu[5]

- **Update analysis with all neutrino data**
  - still observe tensions
- **Remove correlated errors** (add uncertainties in quadrature)
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- Where do we go from here

New Nu Datasets

Dataset	Nucleus	$E_{\nu/\bar{\nu}}$ (GeV)	Number of points	Corr.sys.
CDHSW ν	Fe	23–188	465	No
CDHSW $\bar{\nu}$			464	
CCFR ν	Fe	35–340	1109	No
CCFR $\bar{\nu}$			1098	
NuTeV ν	Fe	35–340	1170	Yes
NuTeV $\bar{\nu}$			966	
Chorus ν	Pb	25–170	412	Yes
Chorus $\bar{\nu}$			412	
CCFR dimuon ν	Fe	110–333	40	No
CCFR dimuon $\bar{\nu}$		87–266	38	
NuTeV dimuon ν	Fe	90–245	38	No
NuTeV dimuon $\bar{\nu}$		79–222	34	

Iron (56) and Lead (208) targets

ν Error: ~6-8%

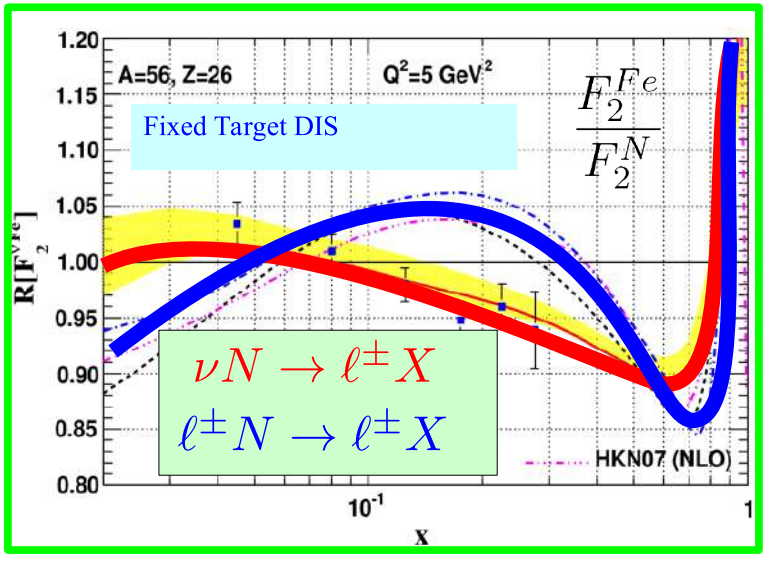
$\bar{\nu}$ Error: ~10-18%

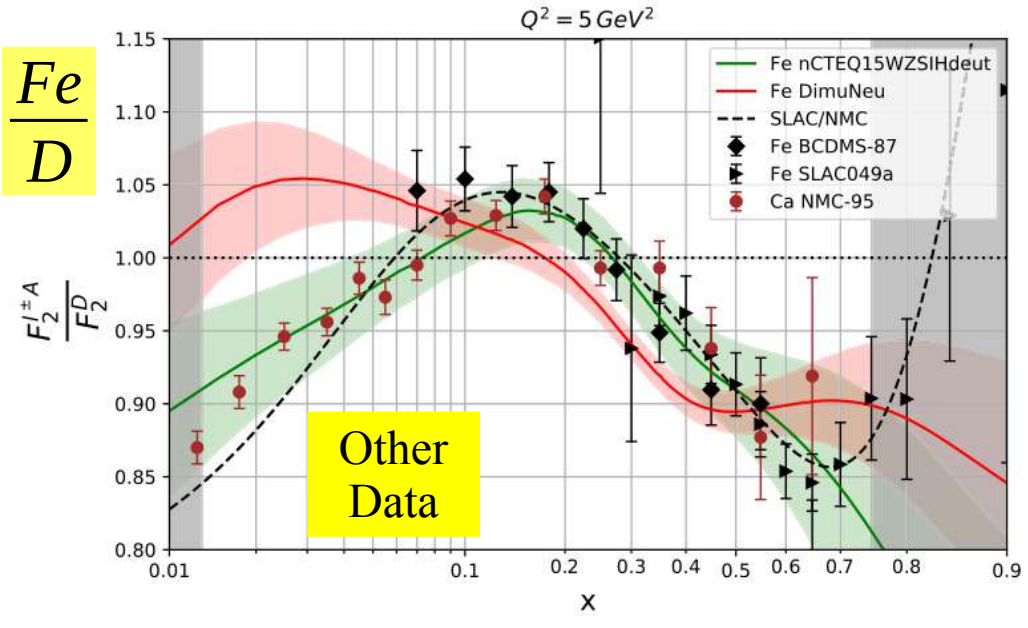
Fit 1) Neutrino Data ONLY, and 2) Fit OTHER data

Red: Neutrino data ONLY

Green: Other data (nCTEQ15WZSIH)

Very different nuclear correction functions





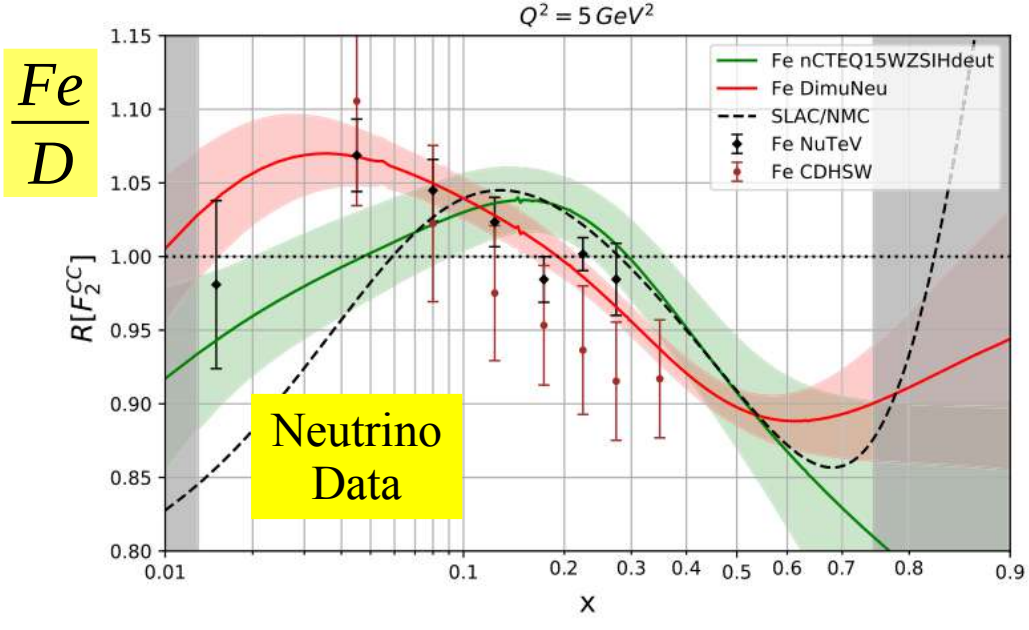
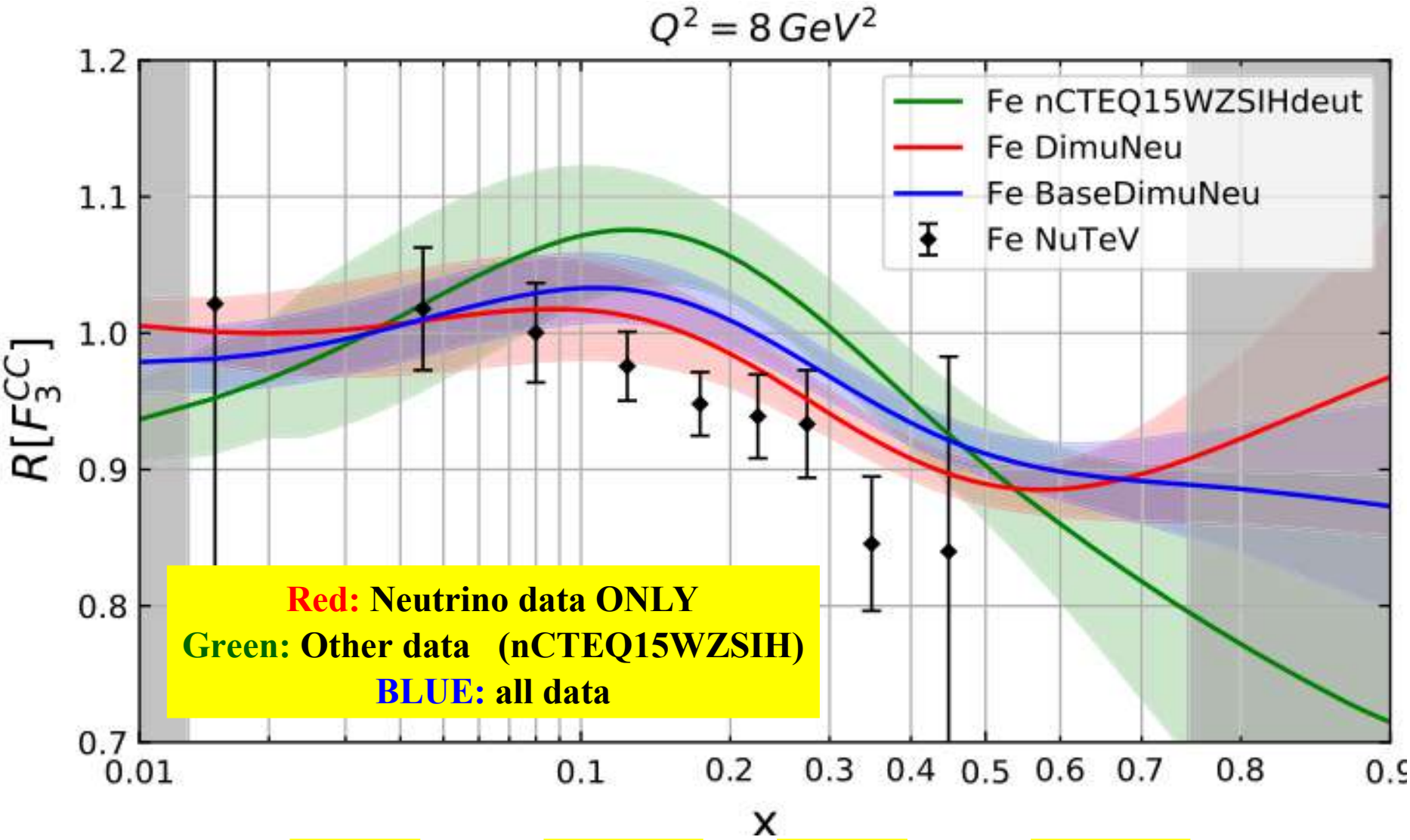


FIG. 6. The structure function ratio predictions from DimuNeu and nCTEQ15WZSIHdeut fits. The gray bands on the left and on the right highlight the regions without any data points passing the kinematic cuts.

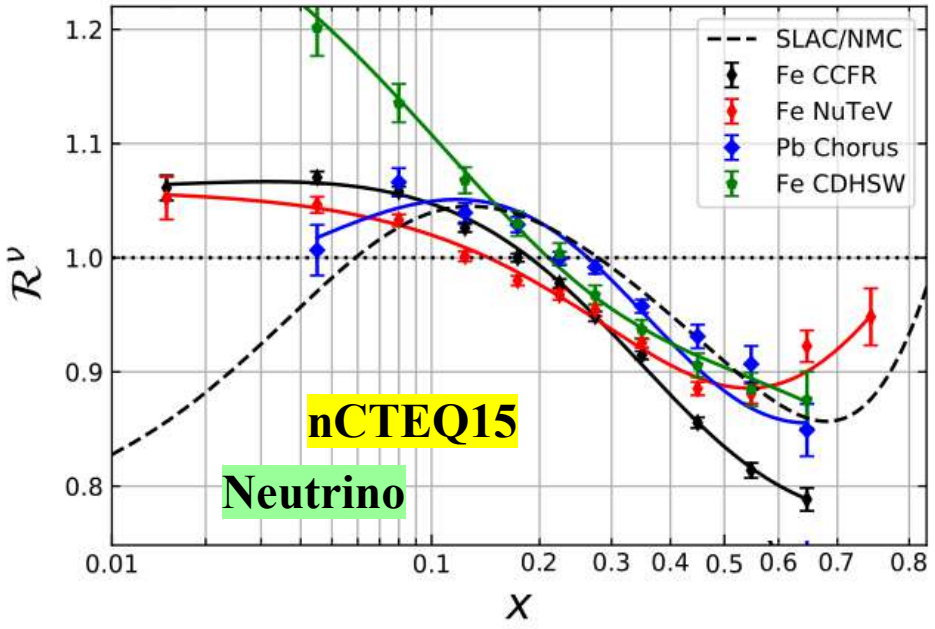
Combine All Data: …. NOT compatible!!!

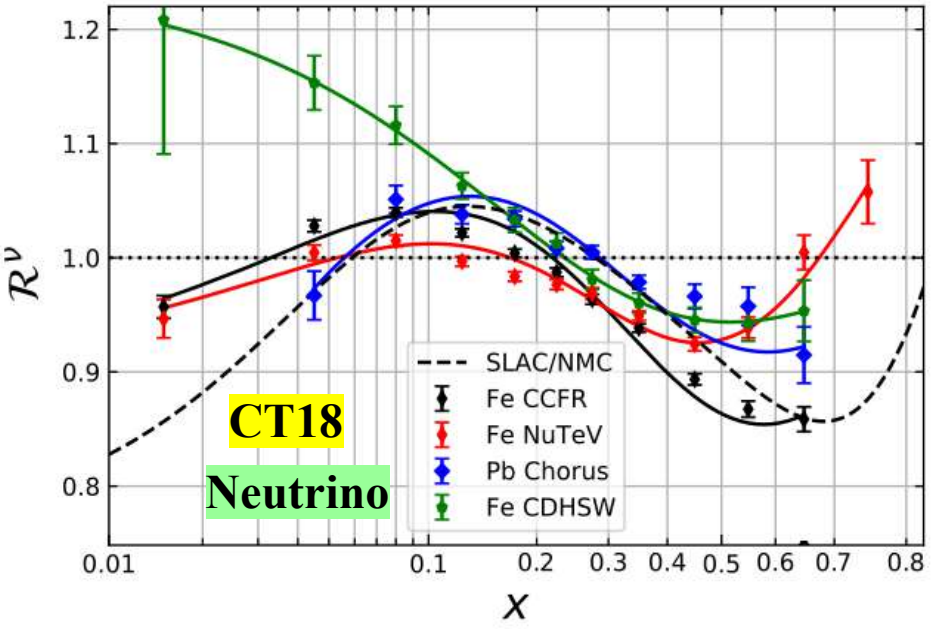


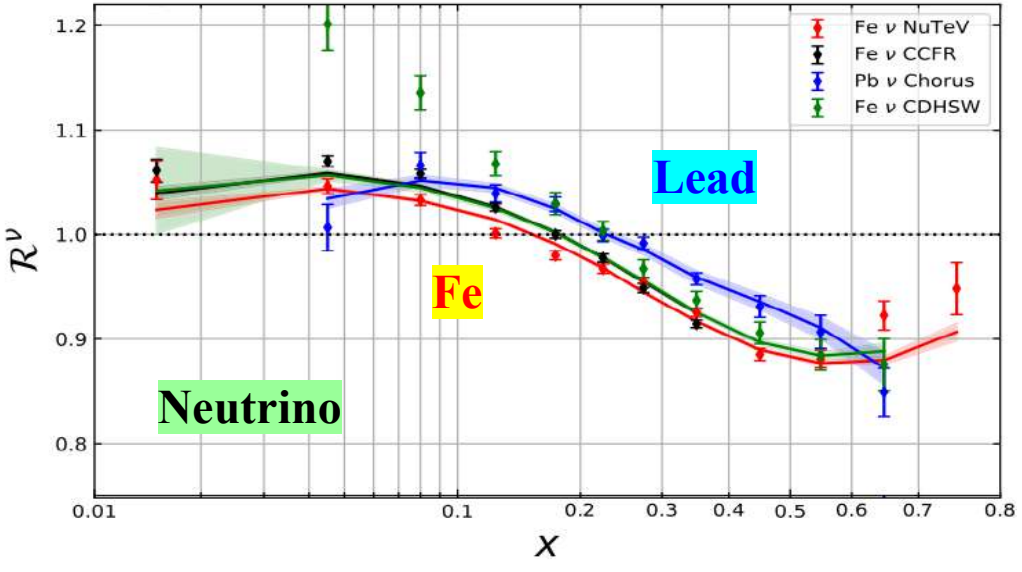
Analysis name		Other χ^2_S/N	Neutrino $\chi^2_{\bar{S}}/N$	Other $\Delta\chi^2_S$		Neutrino $\Delta\chi^2_{\bar{S}}$	$p_S/p_{\bar{S}}$
nCTEQ15WZSIHdeu	Green	735/940	···	0	Green	···	0.500/···
DimuNeu	Red	···	6383/5689	···	Red	0	···/0.500
BaseDimuNeu	Blue	866/940	6666/5689	131	Blue	283	0.99987/0.990

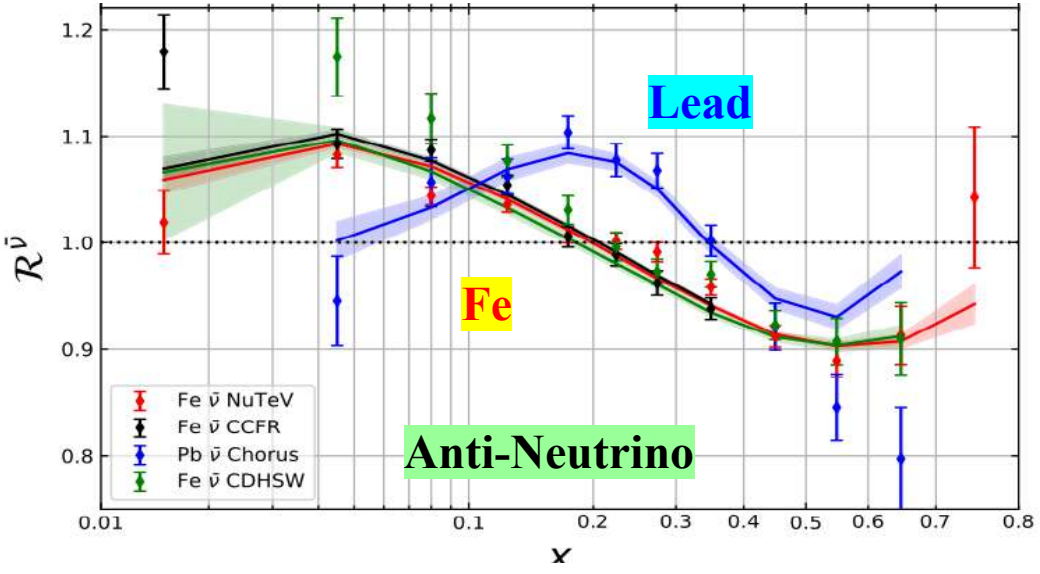
What is happening inside the Black Box ???

Data → Fitting Program → nPDFs

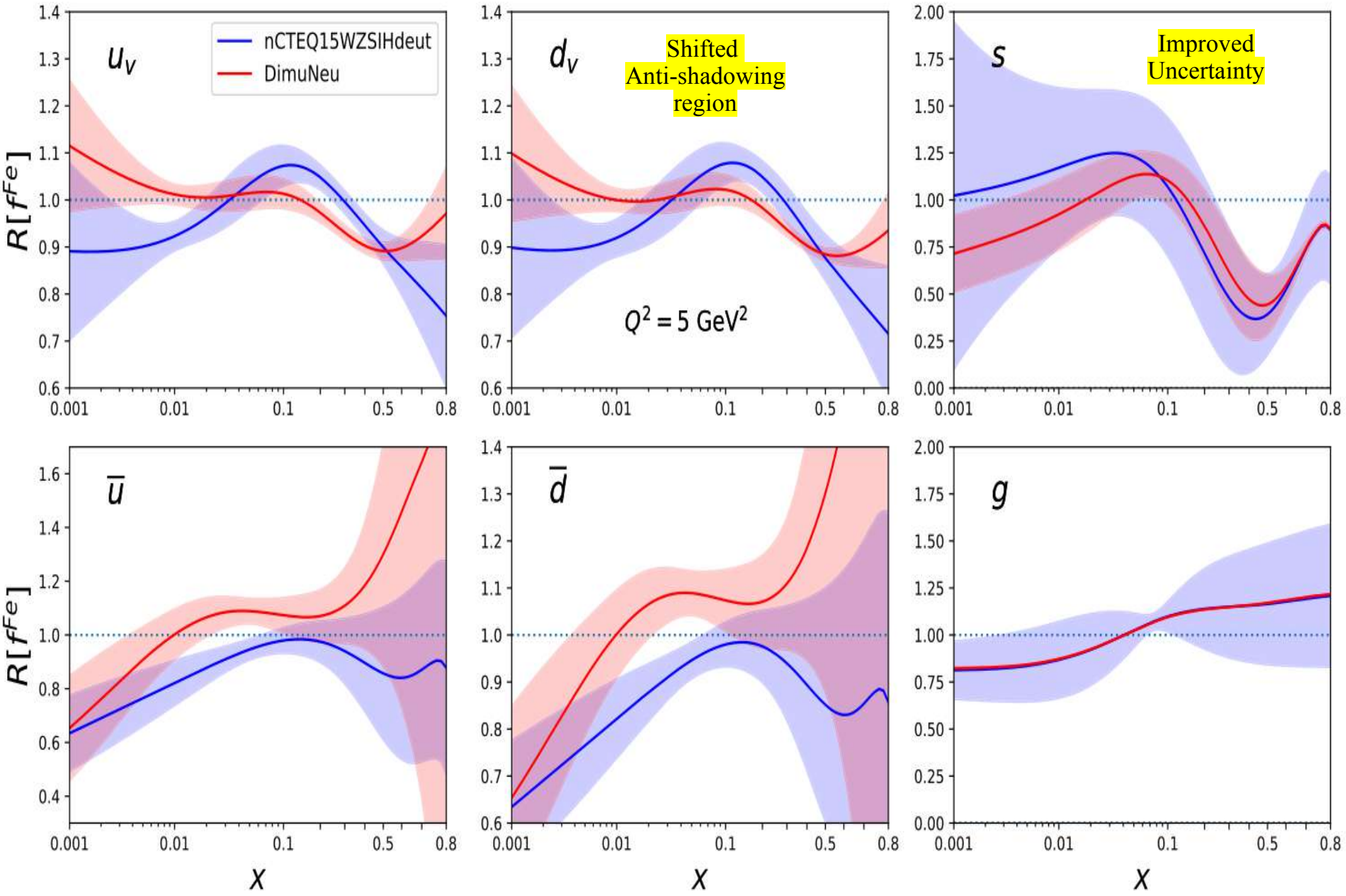








What is happening to the nPDFs ???



OUTLINE: *... can we cure the "split personality"*

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Compatibility of neutrino DIS data and its impact on nuclear parton distribution functions

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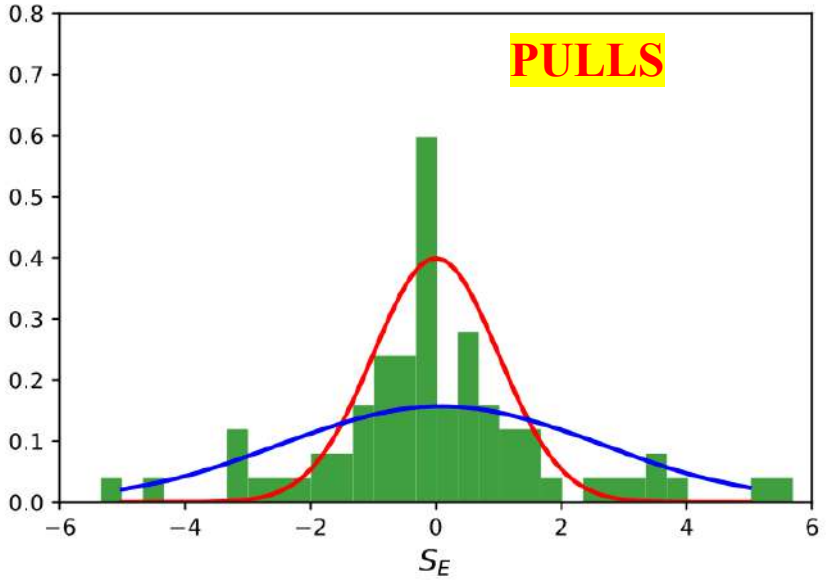
Puzzle: Which datasets are compatible ???

BaseDimuNeuU: Uncorrelated NuTeV

Uncorr: DiMu NuTeV S_E=3.19 CCFR 4.77

BaseDimuNeuX: x>0.1 Cut

x>0.1 Cut: NuTeV S_E=9.72 (ν) & 3.37 (νb)



		Other	Neutrino	Other	Neutrino	Other	Neutrino	
Analysis name		χ^2_S/N	χ^2_S/pt	$\chi^2_{\bar{S}}/N$	$\chi^2_{\bar{S}}/pt$	$\Delta\chi^2_S$	$\Delta\chi^2_{\bar{S}}$	$p_S/p_{\bar{S}}$
nCTEQ15WZSIHdeut		735/940	0.78	···	···	0	···	0.500/···
DimuChorus		···	···	1059/974	1.09	···	0	···/0.500
BaseChorus		737/940	0.78	969/824	1.18	2	···	0.530/···
BaseCDHSW		778/940	0.83	584/929	0.63	43	···	0.895/···
BaseCCFR		815/940	0.87	2119/2207	0.96	80	···	0.989/···
BaseNuTeV		807/940	0.86	3049/2136	1.43	72	···	0.981/···
BaseNuTeVU		787/940	0.84	1984/2136	0.93	52	···	0.933/···
BaseDimuNeuU	Unc	861/940	0.92	5569/5689	0.98	126	···	0.99978/···
BaseDimuNeuX	X-cut	781/940	0.83	5032/4644	1.08	46	···	0.908/···
BaseDimuChorus	15ν	740/940	0.79	1117/974	1.15	5	58	0.559/0.885

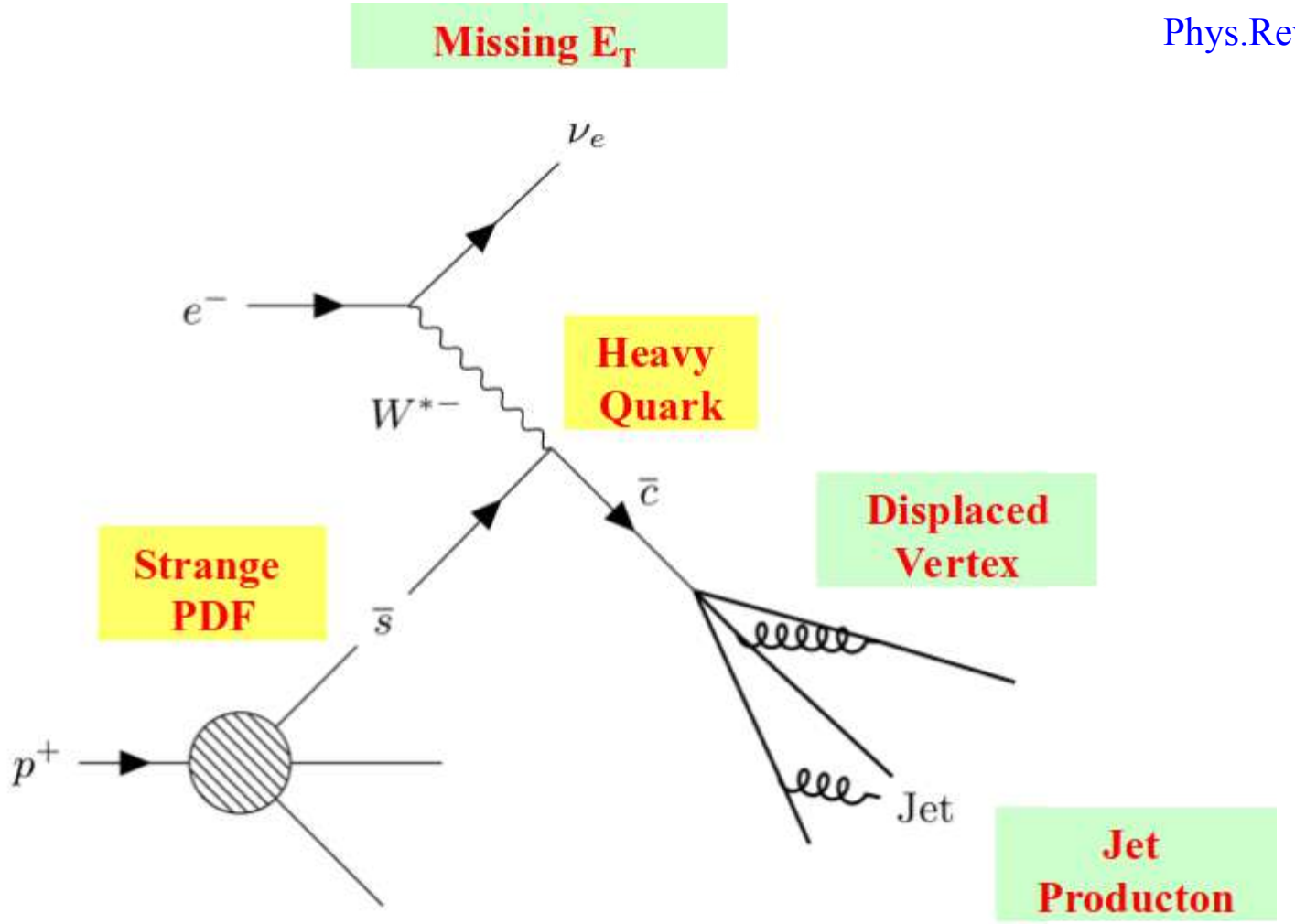
Charm Jets at the EIC

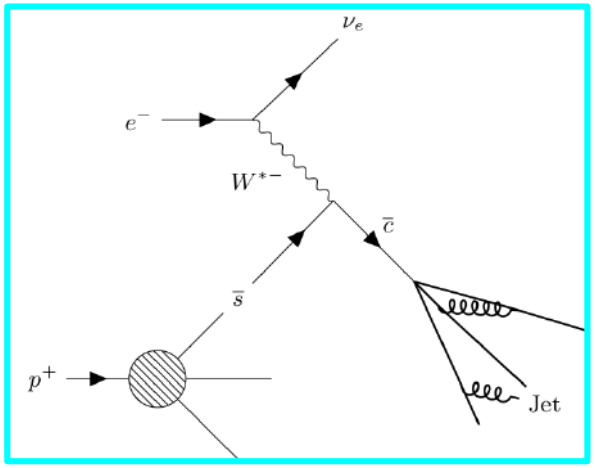
JLAB-PHY-20-3205, SMU-HEP-20-05

Charm jets as a probe for strangeness at the future Electron-Ion Collider

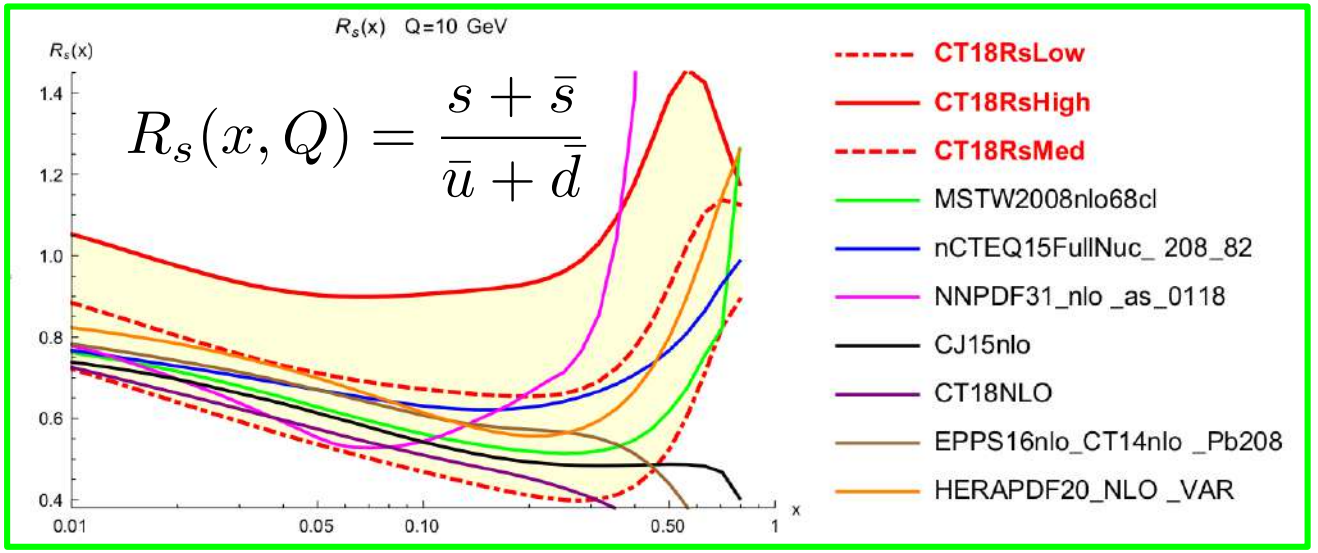
Miguel Arratia,[1,2] Yulia Furletova,[2] T. J. Hobbs,[3,4] Fredrick Olness,[3] and Stephen J. Sekula[3,*]

Phys.Rev.D 103 (2021) 7, 074023

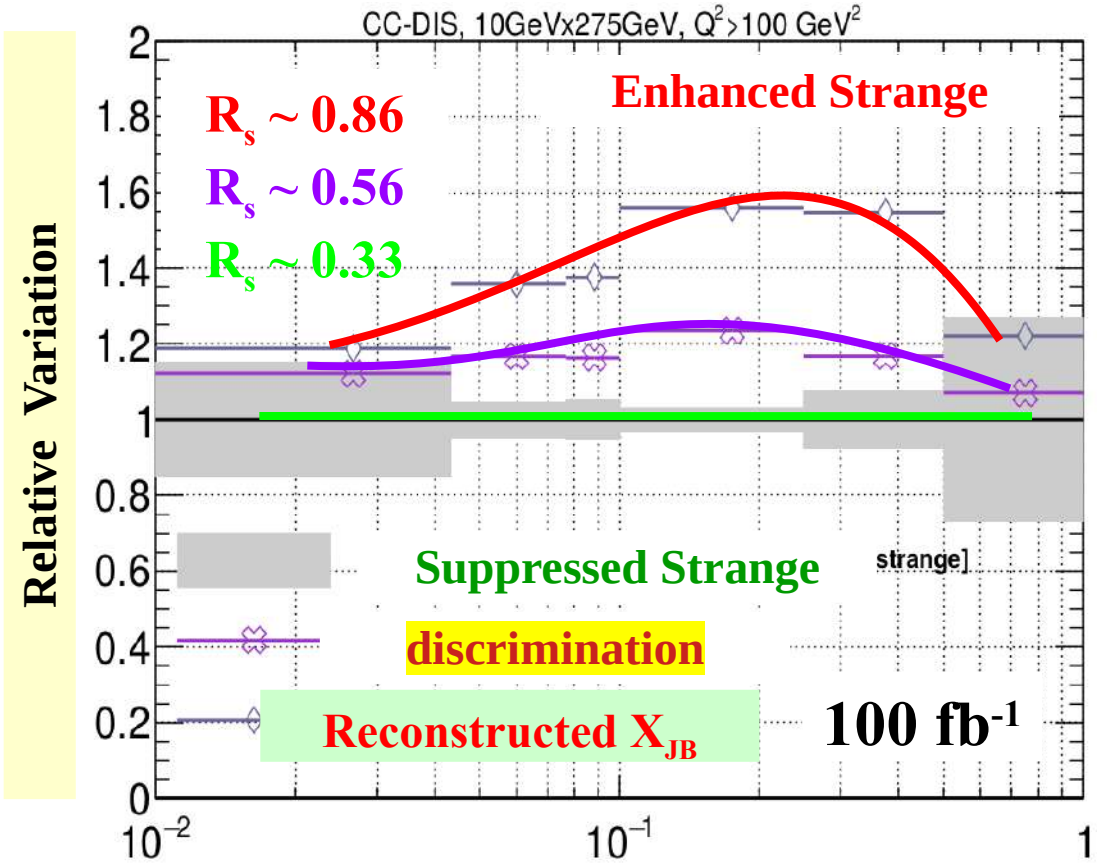




W+s → c_{jet}



Clear measure of Strange PDF beyond uncertainties



M. Arratia, Y. Furletova, T.J. Hobbs, F. Olness, S.J. Sekula, Phys.Rev.D 103 (2021) 7, 074023

CONCLUSIONS

CONCLUSIONS: Neutrino Data are ESSENTIAL for PDFs

- **Update analysis with all neutrino data**
  - still observe tensions

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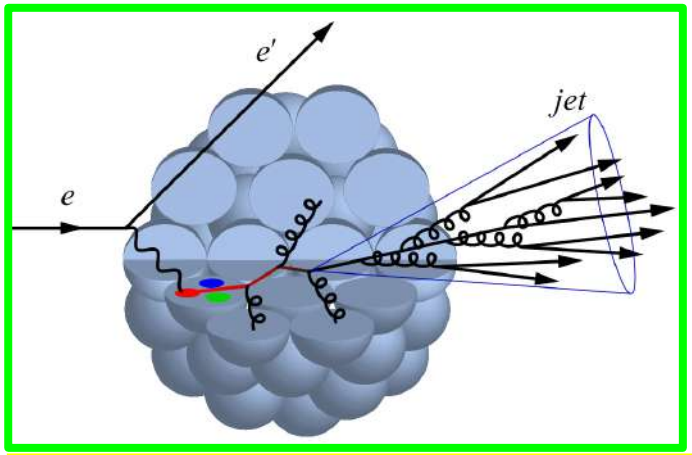
nCTEQ: K.F. Muzakka et al.,
Phys.Rev.D 106 (2022) 7, 074004
e-Print: 2204.13157 [hep-ph]

- **Remove correlated errors** (add uncertainties in quadrature)
  - still observe tensions

- **Remove low x** (x>0.1) (what is motivation ???)
  - still observe tensions

What is minimal neutrino data set we can use? nCTEQ15ν (Chorus + DiMu)

- Where do we go from here: EIC … *DUNE add-on detector??? ...*



Propagation of γ/W thru nuclei

neutrino DIS

$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
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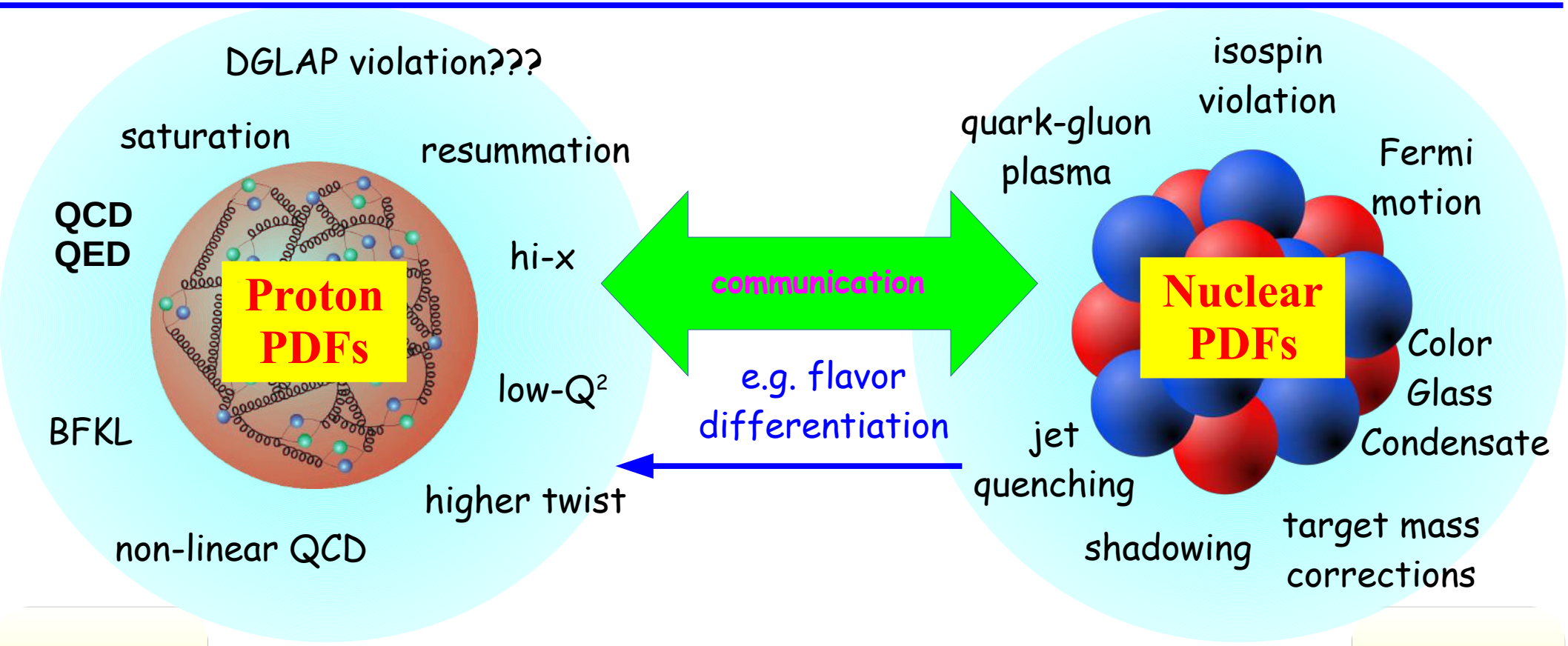
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

Differentiate flavors of free-proton PDFs:

EXTRAS

… the ultimate goal for nPDFs

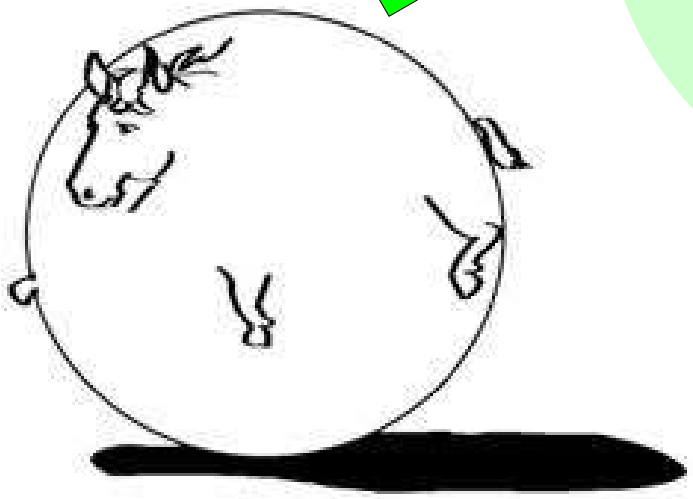


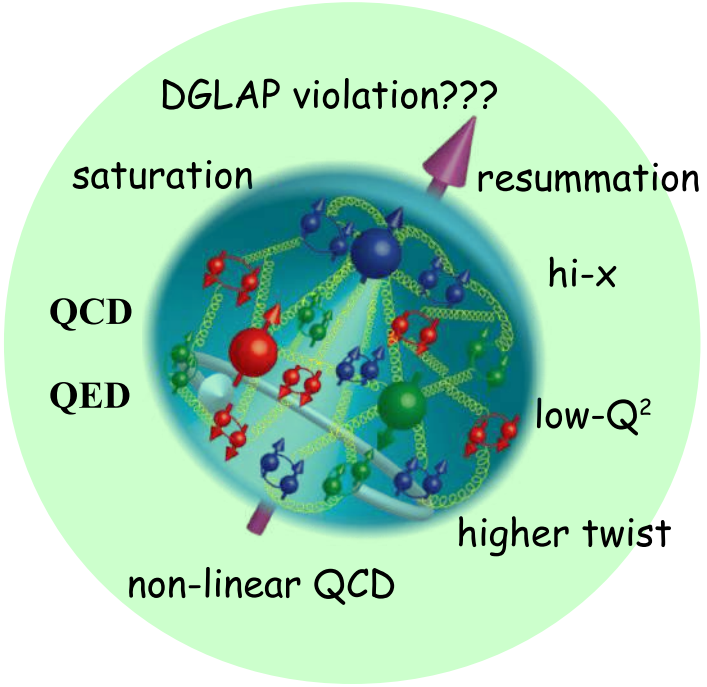
nCTEQ
nuclear parton distribution functions

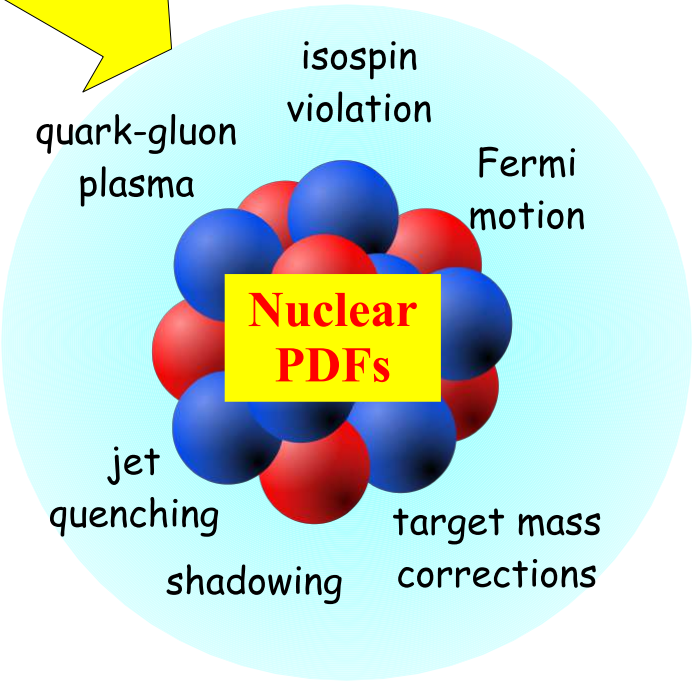
Data from nuclear targets play a key role in the characteristics of the strong nuclear force

nuclear parton distribution functions

Detailed modeling of nuclear structure







SURGE COLLABORATION

xFitter

PROTON

NUCLEON

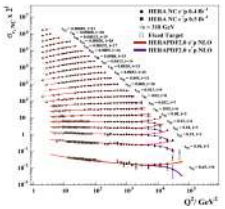
MESON

www.xFitter.org

Sample data files:

LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: …
User Supplied: ...

Experimental Data



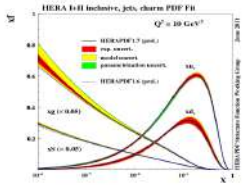
Data: HERA, Tevatron, LHC, fixed target experiments

Processes:
Inclusive DIS, Jets, Drell-Yan, Diffraction, Top production W and Z production

Theory Calculations

HQ Schemes:	MSTW, NNPDF, ABM, ACOT
Jets, W, Z:	FastNLO, ApplGrid
Top:	Hathor
Evolution:	QCDNUM, APFEL, k_T
Other:	NNPDF reweighting TMDs, Dipole Model, ...

xFitter



Parton Distribution Functions: PDF, Updf, TMD

$\alpha_S(M_Z)$, m_c,m_b,m_t ...

Theoretical Cross Sections

Comparisons to other PDFs (LHAPDF)

extensions include nuclear PDFs

Features & Recent Updates:

NNLO DGLAP
Photon PDF & **QED**
Pole & MS-bar masses
Profiling and Re-Weighting
BFKL interface

Heavy Quark Variable Treshold
Improvements in χ^2 and correlations
TMD PDFs (uPDFs)
… and many other

xFitter 2.2.0
Future Freeze

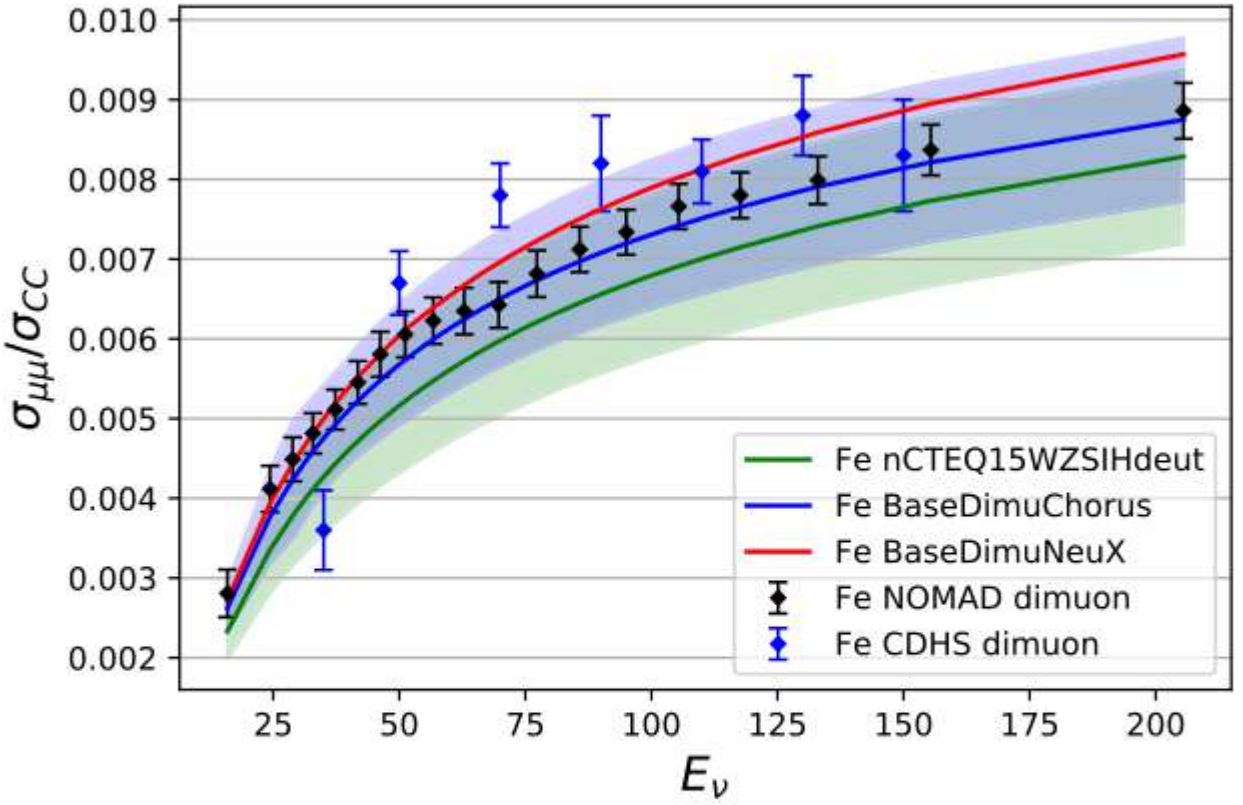


FIG. 24. Comparison between the data from the NOMAD experiment [60] and our theory predictions using our fitted PDFs for the ratio of the dimuon production and the total charged current DIS cross-section.