The CTEQ Nuclear PDFs

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NuInt14
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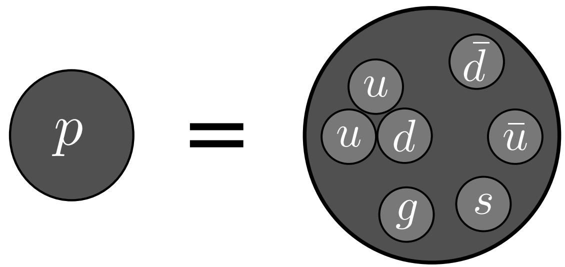
Introduction to PDFs

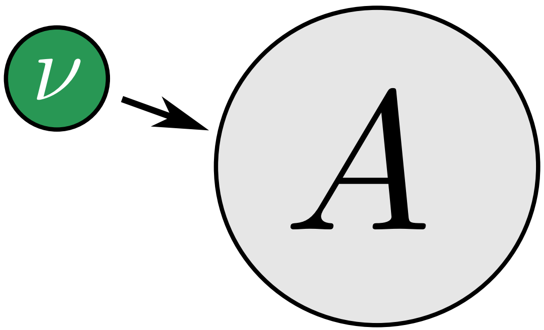
- PDF = parton distribuion (density) function



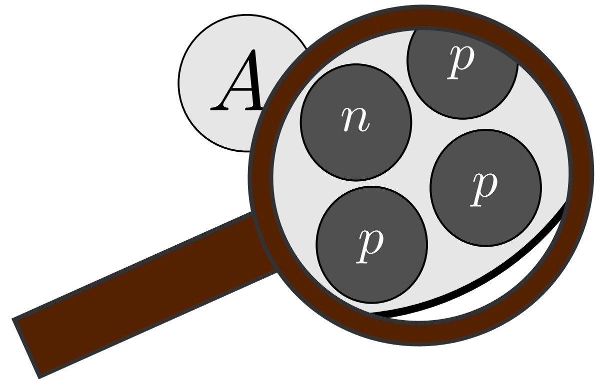
- describe how nucleons compose of partons
- PDF: f(x,Q), x momentum fraction, Q scale
- x-dep. not calculable in perturbative QCD
- evolution in Q accodring to DGLAP
- generalization to nuclei: nuclear PDFs (nPDFs)

Introduction to PDFs

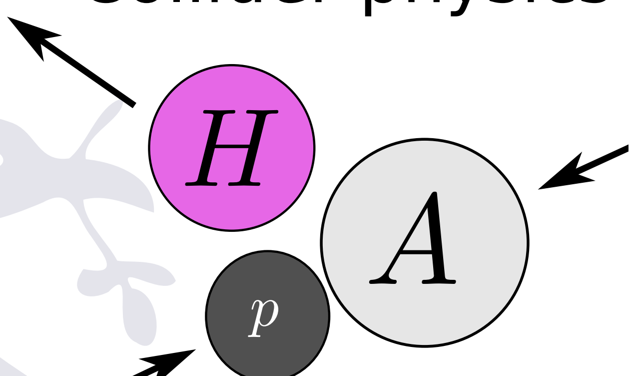
Neutrino physics



Nuclear physics

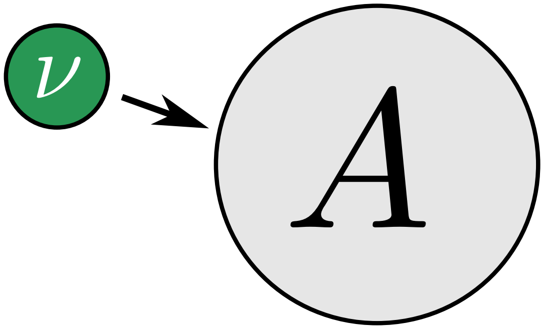


Collider physics



Introduction to PDFs

Neutrino physics

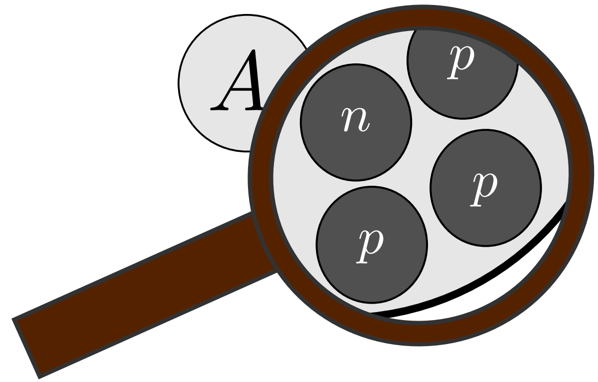


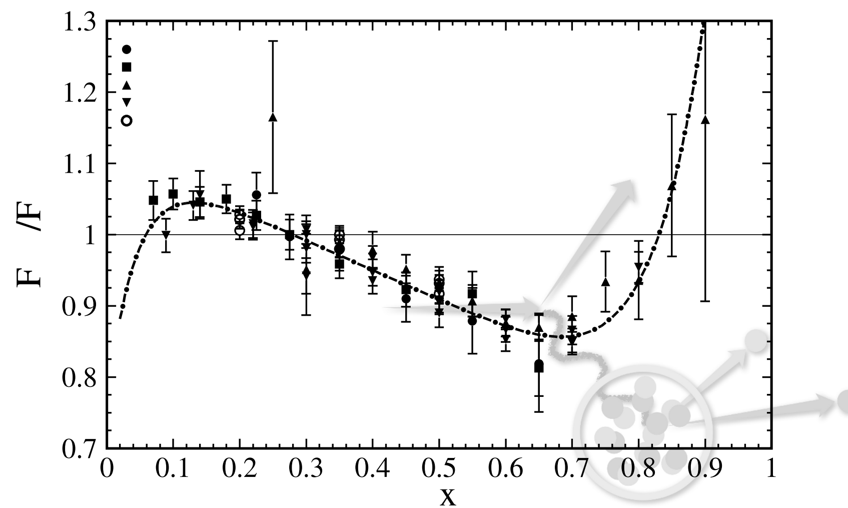
- $\sigma_{\nu A}$ small
- heavy targets
- nPDFs

Introduction to PDFs

- nuclear effects
  - Pauli principle
  - Fermi motion
  - Multiple scattering
- nuclear corrections
  - PDFs => nPDFs

Nuclear physics

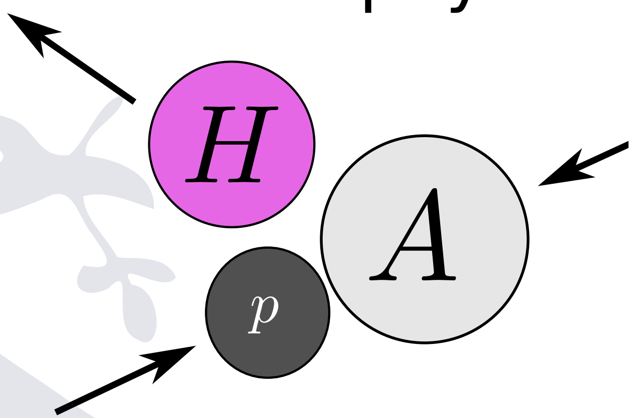




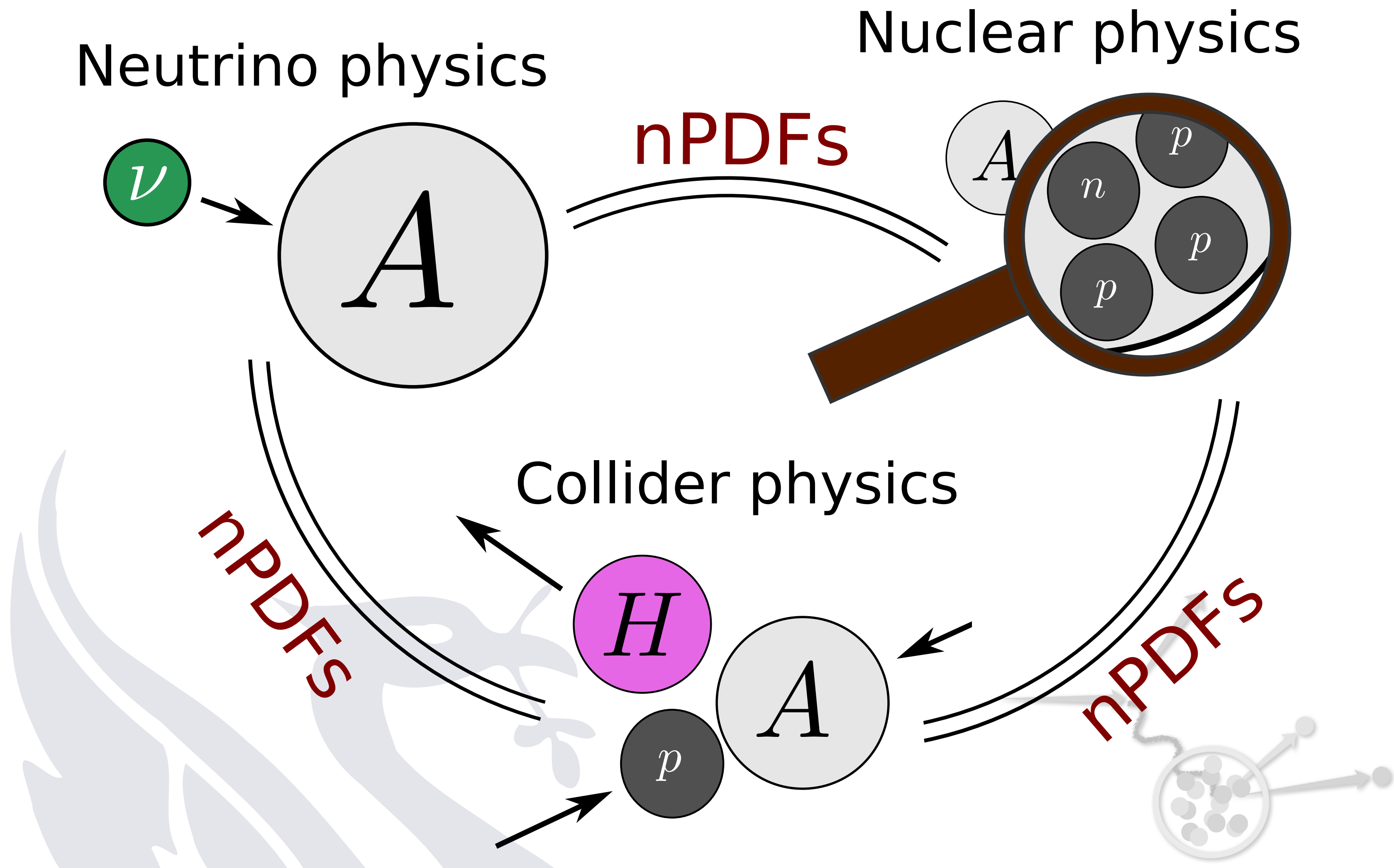
Introduction to PDFs

- hardon collider predictions require PDFs
  - pp collisions ... free-proton PDFs
  - AA collisions ... nPDFs
  - data from collisions of nuclei used also in free-proton analysis

Collider physics

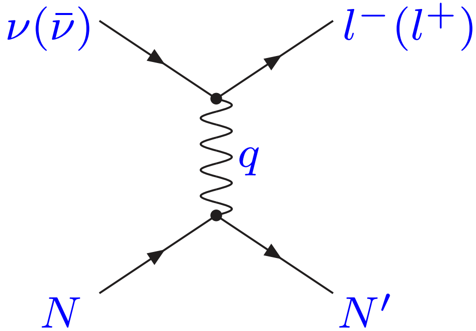


Introduction to PDFs



Neutrino-nucleon interactions

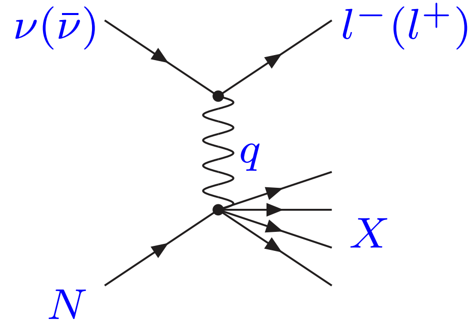
- Quasi-elastic scattering



CC: $\nu(\bar{\nu}) + N \rightarrow l^-(l^+) + N'$

NC: $\nu(\bar{\nu}) + N \rightarrow \nu(\bar{\nu}) + N'$

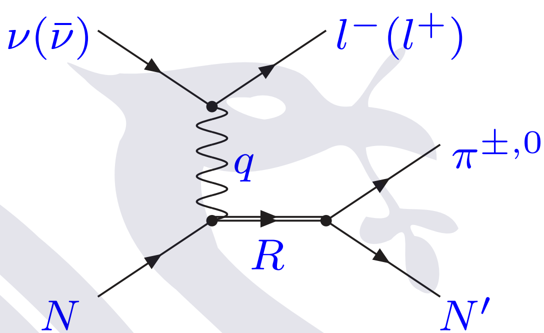
- Deep inelastic scattering (DIS)



CC: $\nu(\bar{\nu}) + N \rightarrow l^-(l^+) + X$

NC: $\nu(\bar{\nu}) + N \rightarrow \nu(\bar{\nu}) + X$

- Resonance production



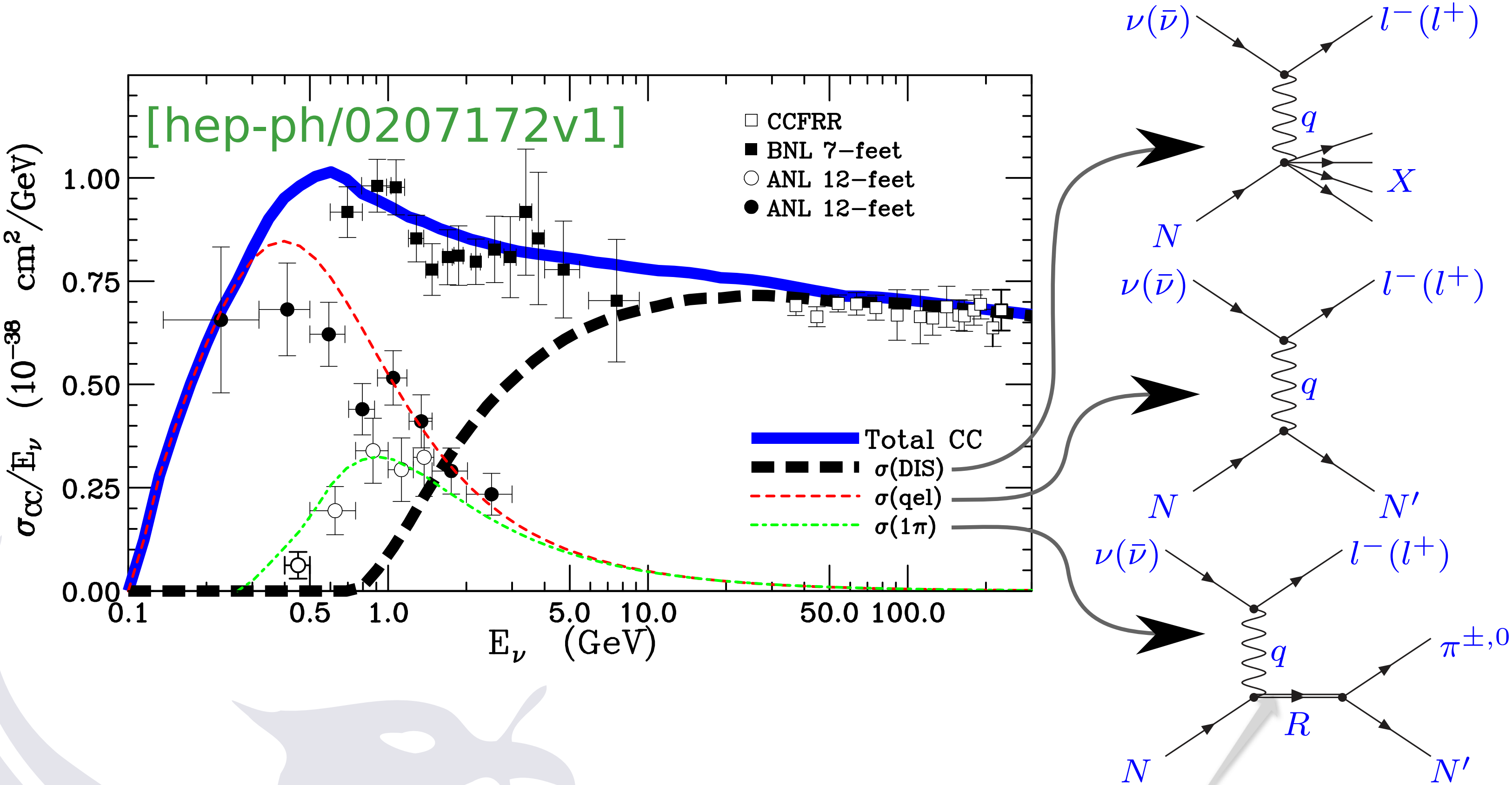
Charged Current (CC):

$\nu(\bar{\nu}) + N \rightarrow l^-(l^+) + N + \pi^{\pm,0}$

Neutral Current (NC):

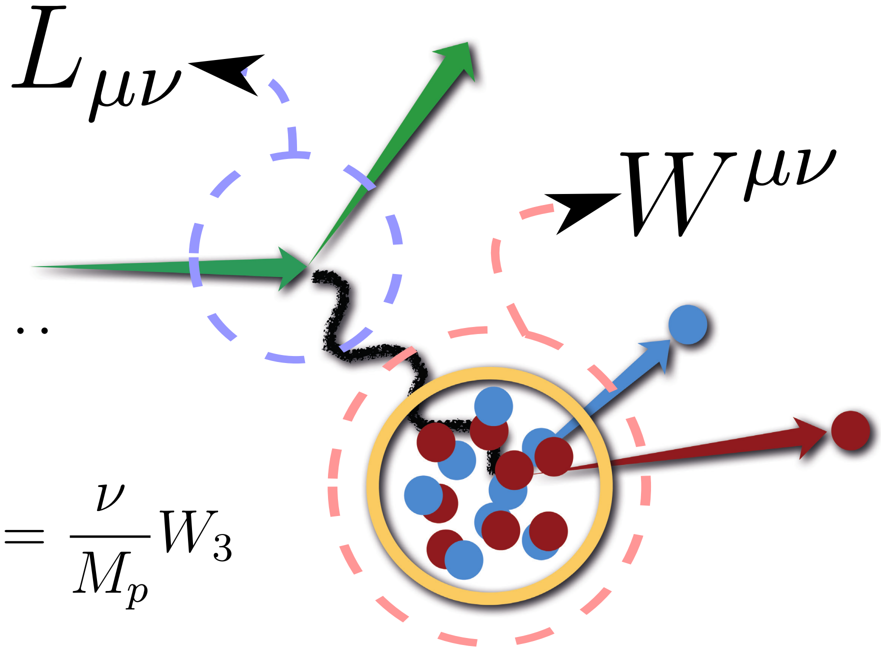
$\nu(\bar{\nu}) + N \rightarrow \nu(\bar{\nu}) + N + \pi^{\pm,0}$

Neutrino-nucleon interactions



- DIS coss section dominates above a few GeV

Deep Inelastic Scattering (DIS)



$$W^{\mu\nu} = -g^{\mu\nu}W_1 + \frac{p^\mu p^\nu}{M_p^2}W_2 - i\frac{\epsilon^{\mu\nu\alpha\beta}p_\alpha q_\beta}{2M_p^2}W_3 \;+\; \cdots$$

$$F_1 = W_1\,,\;\; F_2 = \frac{\nu}{M_p}W_2\,,\;\; F_3 = \frac{\nu}{M_p}W_3$$

$$\frac{d^2\sigma(\nu,\bar{\nu})}{dxdy} \sim L\cdot W \sim g_{+l}\left[xF_1y^2 + F_2\left[(1-y) - \left(\frac{M_p x y}{2E_\nu}\right)\right]\right] \pm g_{-l}\left[xF_3y\left(1-\frac{y}{2}\right)\right]$$

$$x \equiv \frac{Q^2}{2M_p\nu} \quad \nu \equiv E_L - E_{L'} \quad y \equiv \frac{E_L - E_{L'}}{E_L}$$

Goal for this talk

- explain:
  - extraction of nPDFs from experiment
  - estimation of uncertainities
- present:
  - most recent fit including uncertainities
  - previous fit including neutrino data
  - the compatibility of neutrino DIS data with other data sets

Available nuclear PDFs

- **Multiplicative nuclear correction factors**

$$f_i^{p/A}(x_N, \mu_0) = R_i(x_N, \mu_0, A)\ f_i^{free\ proton}(x_N, \mu_0)$$

  - Hirai, Kumano, Nagai [PRC 76, 065207 (2007), arXiv:0709.3038]
  - Eskola, Paukkunen, Salgado [JHEP 04 (2009) 065, arXiv:0902.4154]
  - de Florian, Sassot, Stratmann, Zurita [PRD 85, 074028 (2012), arXiv:1112.6324]

- **Native nuclear PDFs**
  - nCTEQ [PRD 80, 094004 (2009), arXiv:0907.2357]

$$f_i^{p/A}(x_N, \mu_0) = f_i(x_N, A, \mu_0)$$

$$f_i(x_N, A = 1, \mu_0) \equiv f_i^{free\ proton}(x_N, \mu_0)$$

nCTEQ framework

[PRD 80, 094004 (2009), arXiv: 0907.2357]

- Functional form of the bound proton PDF same as for the free proton (∼CTEQ61 [hep-ph/0702159], x restricted to $0 < x < 1$)

$$x f_i^{p/A}(x, Q_0) = c_0 x^{c_1}(1-x)^{c_2} e^{c_3 x}(1+e^{c_4}x)^{c_5}, \qquad i = u_v, d_v, g, \ldots$$
$$\bar{d}(x, Q_0)/\bar{u}(x, Q_0) = c_0 x^{c_1}(1-x)^{c_2} + (1+c_3 x)(1-x)^{c_4}$$

- A-dependent fit parameters (reduces to free proton for $A = 1$)

$$c_k \to c_k(A) \equiv c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right), \quad k = \{1, \ldots, 5\}$$

- PDFs for nucleus (A, Z)

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

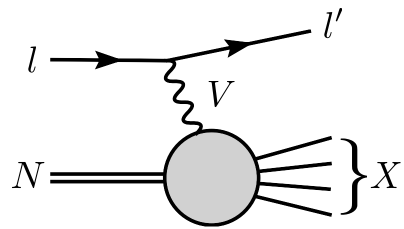
(bound neutron PDF $f_i^{n/A}$ by isospin symmetry)

Data sets

- NC DIS & DY

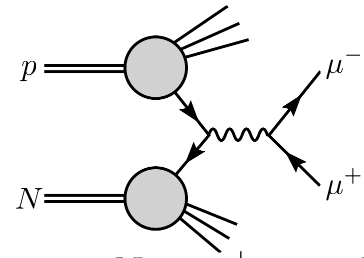
  CERN BCDMS & EMC & NMC
  N = (D, Al, Be, C, Ca, Cu, Fe, Li, Pb, Sn, W)
  FNAL E-665
  N = (D, C, Ca, Pb, Xe)
  DESY Hermes
  N = (D, He, N, Kr)
  SLAC E-139 & E-049
  N = (D, Ag, Al, Au, Be,C, Ca, Fe, He)
  FNAL E-772 & E-886
  N = (D, C, Ca, Fe,W)

NC DIS



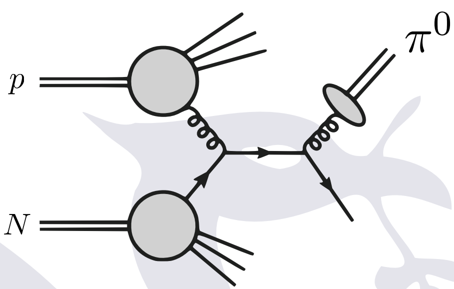
$l + N \rightarrow l' + X$

DY



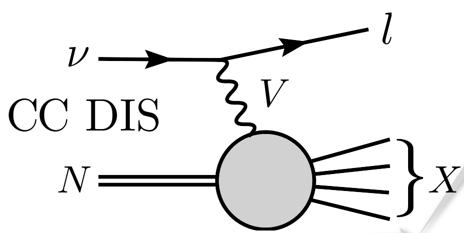
$p + N \rightarrow \mu^+\mu^- + X$

- Single pion production (new)



RHIC - PHENIX & STAR
N = Au

- Neutrino (to be included later)



$\nu(\bar{\nu}) + N \rightarrow l + X$

CHORUS CCFR & NuTeV
N = Pb N = Fe

Schematics of Global Analysis

1. Parametrize PDFs at low initial scale $\mu = Q_0 = 1.3\text{GeV}$:

$$f(x, Q_0) = f(x; a_0, a_1, \ldots) = a_0 x^{a_1} (1-x)^{a_2} P(x; a_3, \ldots)$$

2. Use DGLAP equation to evolve $f(x, \mu)$ from $\mu = Q_0$ to $\mu = Q_{\text{max}}$.
3. Define and minimize appropriate χ^2 function (with respect to parameters $a_0, a_1, \ldots$)

$$\chi^2(\{a_i\}) = \sum_{\text{experiments}} w_n \chi_n^2(\{a_i\})$$

$$\chi_n^2(\{a_i\}) = \sum_{\text{data points}} \left(\frac{\text{data} - \text{theory}(\{a_i\})}{\text{uncertainty}} \right)^2$$

(by default $w_n = 1$)

Fit details

Fit properties:

- fit @NLO
- $Q_0 = 1.3\text{GeV}$
- using ACOT heavy quark scheme
- kinematical cuts: $Q > 2\text{GeV}$, $W > 3.5\text{GeV}$
- 708 (DIS & DY) + 32 (single π^0) = 740 data points after cuts
- 16 free parameters

  7 gluon
  7 valence
  2 sea
- $\chi^2 = 618$, giving $\chi^2/\text{dof} = 0.85$

Error analysis:

- use Hessian method

$$\chi^2 = \chi_0^2 + \frac{1}{2} H_{ij}(a_i - a_i^0)(a_j - a_j^0)$$

$$H_{ij} = \frac{\partial^2 \chi^2}{\partial a_i \partial a_j}$$

- tolerance $\Delta\chi^2 = 35$ (every nuclear target within 90% C.L.)
- eigenvalues span 10 orders of magnitude $\rightarrow$ require numerical precision
- use noise reducing derivatives

Hessian method

[JHEP 07 (2002) 012, arXiv: hep-ph/0201195]

- **Expand** χ^2 function around minimum, $\{a_i^0\}$,

$$\chi^2 = \chi_0^2 + \sum_{ij} \frac{1}{2}(a_i - a_i^0)(a_j - a_j^0)\left(\frac{\partial^2 \chi^2}{\partial a_i \partial a_j}\right)_0$$

Hessian method

[JHEP 07 (2002) 012, arXiv: hep-ph/0201195]

- **Expand** χ^2 function around minimum, $\{a_i^0\}$, and **diagonalize**

$$\chi^2 = \chi_0^2 + \sum_{ij} \frac{1}{2}(a_i - a_i^0)(a_j - a_j^0)\left(\frac{\partial^2 \chi^2}{\partial a_i \partial a_j}\right)_0 = \chi_0^2 + \sum_i z_i^2$$

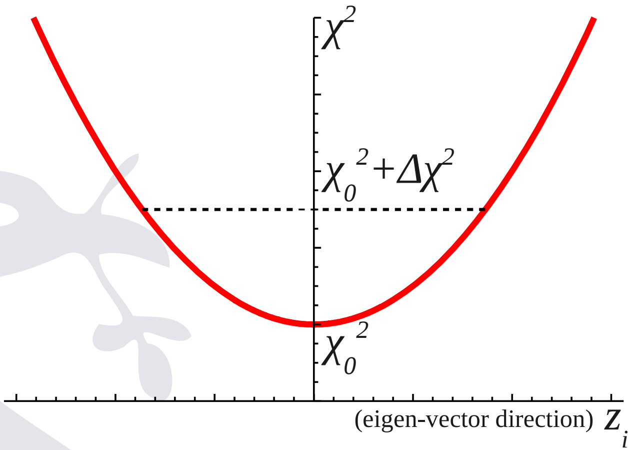
Hessian method

[JHEP 07 (2002) 012, arXiv: hep-ph/0201195]

- **Expand** χ^2 function around minimum, $\{a_i^0\}$, and **diagonalize**

$$\chi^2 = \chi_0^2 + \sum_{ij} \frac{1}{2}(a_i - a_i^0)(a_j - a_j^0)\left(\frac{\partial^2 \chi^2}{\partial a_i \partial a_j}\right)_0 = \chi_0^2 + \sum_i z_i^2$$

- Choose tolerance criteria $\Delta\chi^2 = \chi^2 - \chi_0^2$ value (defining 1-σ uncertainty),
  - ideal case $\Delta\chi^2 = 1$
  - realistic global analysis $\Delta\chi^2 \sim 1 - 100$



Hessian method

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- **Expand** χ^2 function around minimum, $\{a_i^0\}$, and **diagonalize**

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- Choose tolerance criteria $\Delta\chi^2 = \chi^2 - \chi_0^2$ value (defining 1-σ uncertainty),
  - ideal case $\Delta\chi^2 = 1$
  - realistic global analysis $\Delta\chi^2 \sim 1 - 100$
- Construct error PDFs corresponding to each eigenvector direction:

$$f_i^{\pm} = f(\{z_i\}) = f(0, \ldots, z_i = \pm\sqrt{\Delta\chi^2}, \ldots, 0)$$

$$z_i = \pm\sqrt{\Delta\chi^2}$$

- Calculate errors of observable X:

$$\Delta X = \frac{1}{2}\sqrt{\sum_i \left[X(f_i^+) - X(f_i^-)\right]^2}$$

nCTEQ results

impact of single π^0 production data

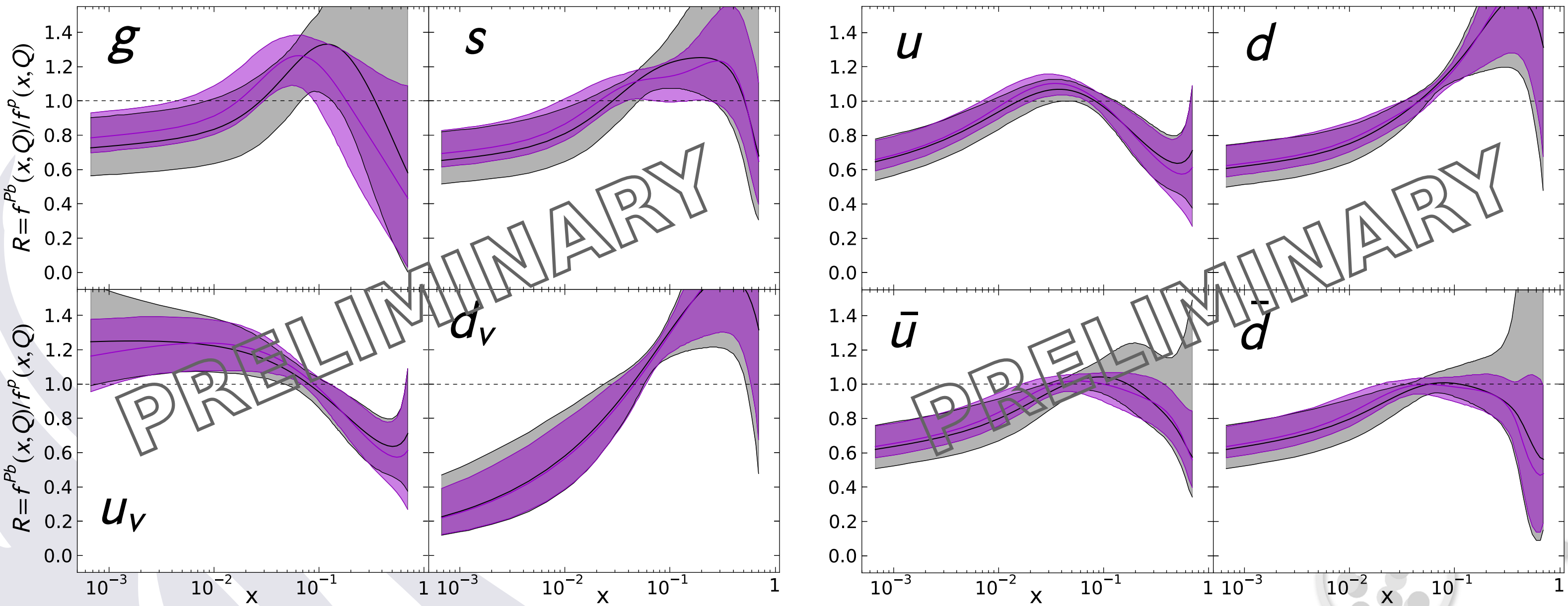
Nuclear correction factors
$(Q = 10\text{GeV})$

$$R_i(Pb) = \frac{f_i^{Pb}(x,Q)}{f_i^p(x,Q)}$$

Compare nCTEQ fits:

with π^0 data (violet)

without π^0 data (gray)



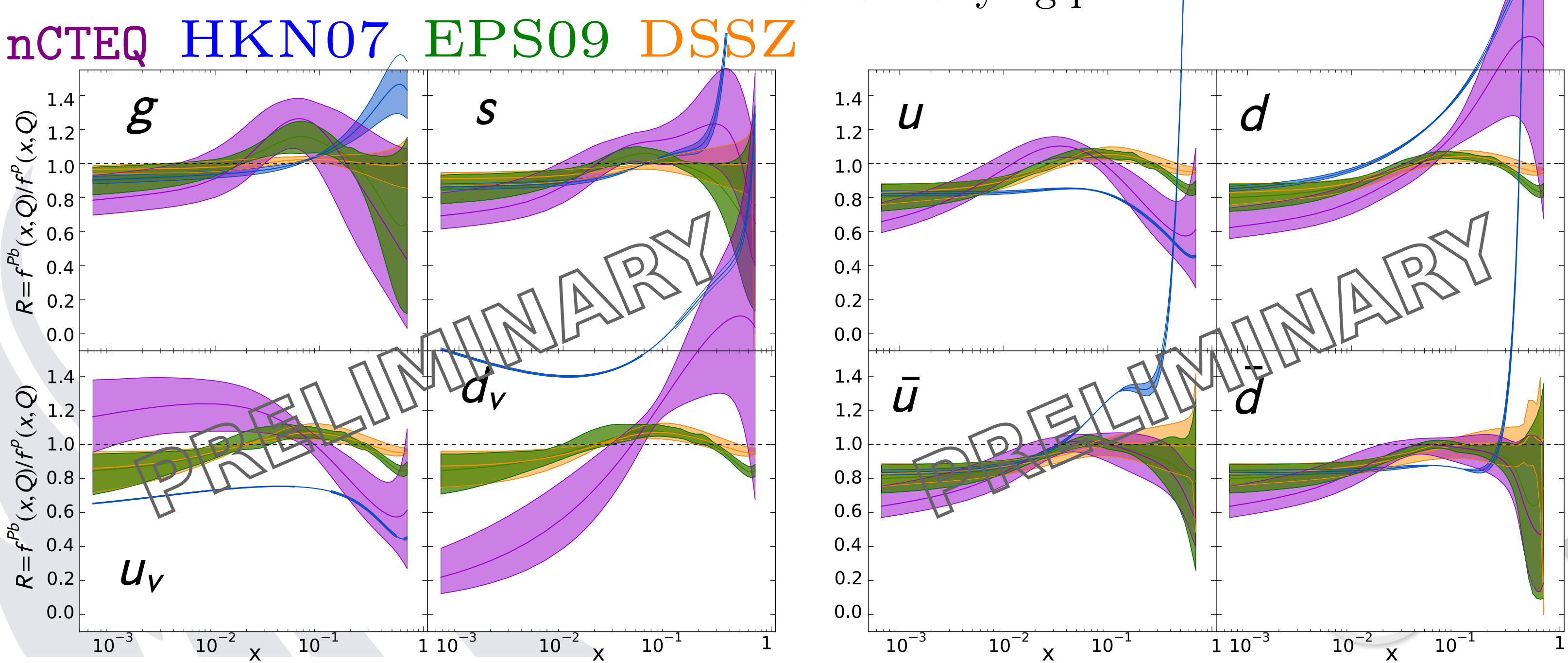
nCTEQ results

comparison with other nPDF fits

Nuclear correction factors ($Q = 10\text{GeV}$)

$$R_i(Pb) = \frac{f_i^{Pb}(x,Q)}{f_i^{p}(x,Q)}$$

- different solution for d-valence & u-valence compared to EPS09 & DSSZ
- sea quark nuclear correction factors similar to EPS09
- nuclear correction factors depend largely on underlying proton baseline



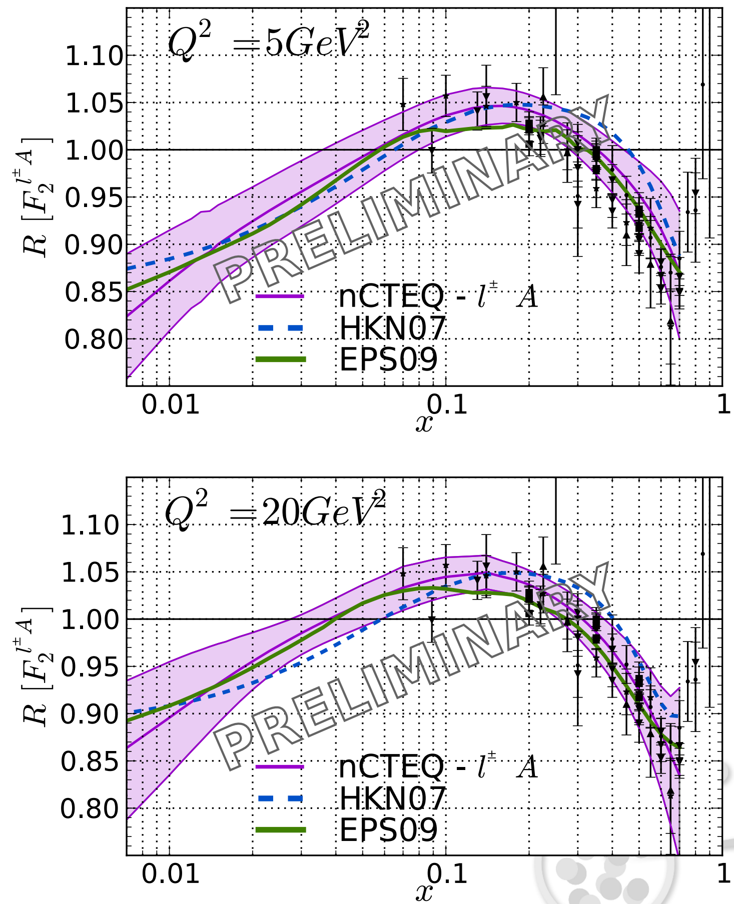
nCTEQ results

F_2 ratios

Structure function ratio

$$R = \frac{F_2^{Fe}(x,Q)}{F_2^{D}(x,Q)}$$

- good data description
- despite different u-valence & d-valence ratios are similar to EPS09



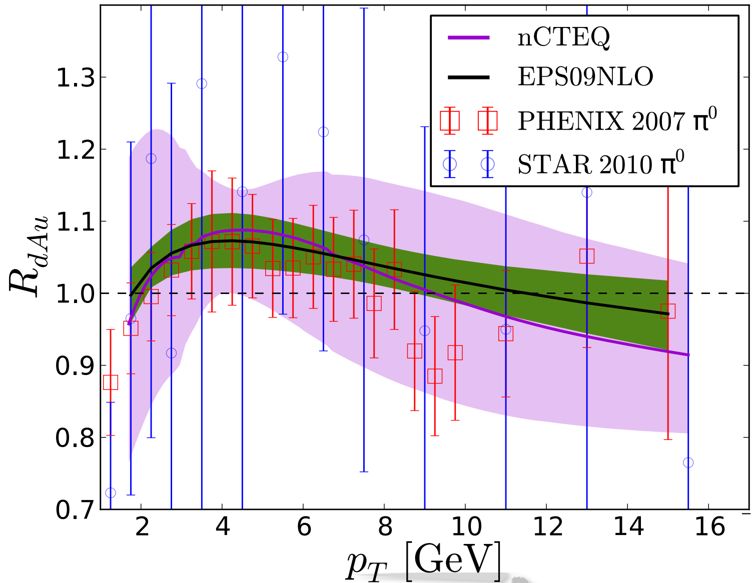
nCTEQ results

π^0 production

Pion production, ratio

$$R^{\pi}_{\text{dAu}} = \frac{\frac{1}{2A} d^2\sigma_\pi^{\text{dAu}}/dp_T dy}{d^2\sigma_\pi^{\text{pp}}/dp_T dy}$$

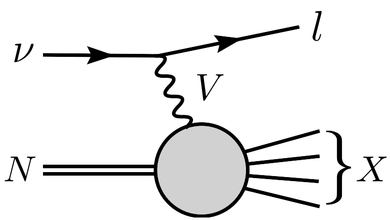
- good data description, however big experimental uncertainities do not allow for strong constraints on PDFs
- despite different u-valence & d-valence ratios are similar to EPS09



Neutrino DIS

[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

Neutrino DIS cross-section data



$$\nu(\bar{\nu}) + N \to l + X$$

NuTeV & di-muon $N = \mathrm{Fe}$ → 2310 data points

CHORUS $N = \mathrm{Pb}$ → 824 data points

(after cuts)

All charged lepton DIS & Drell-Yan data → 708 data points

Challenges in combining the neutrino & charged lepton data

- deal with the disparity of number of data points - assigning weights to neutrino data
- neutrino DIS data only with 2 heavy nuclei - insufficient to get a reliable A-dependance

Neutrino DIS

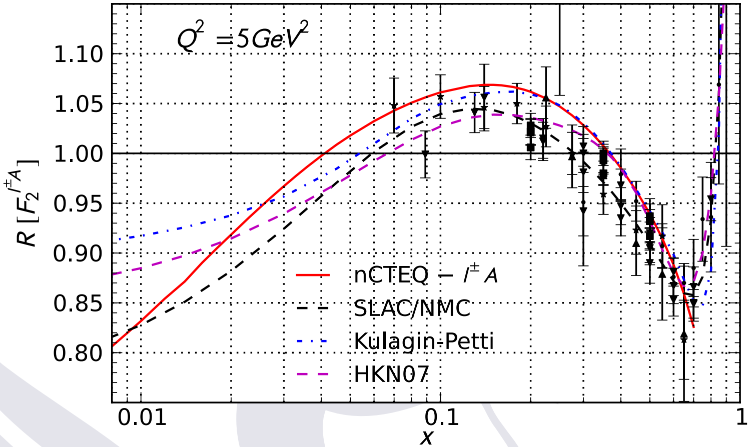
[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

Comparison of charged lepton and neutrino fits

Fit to charged lepton data

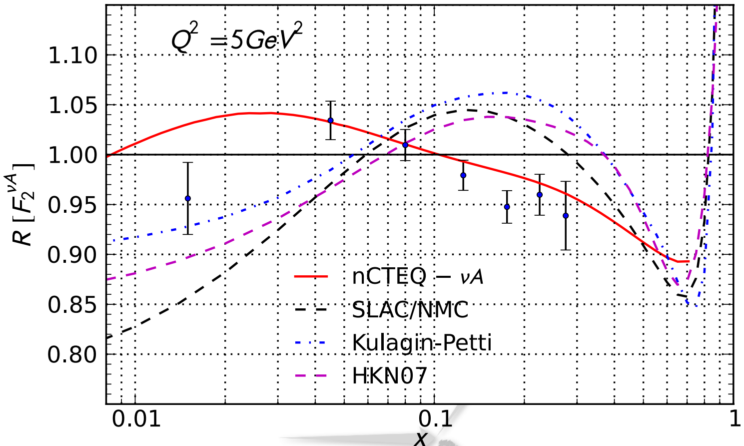
DIS & DY

$\chi^2/\mathrm{d.o.f} = 0.89$



Fit to only neutrino DIS

$\chi^2/\mathrm{d.o.f} = 1.33$



can we explain the difference and fit all data together in a global fit ?

Neutrino DIS

[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

- It was argued in the literature that νA DIS data is compatible with $l^{\pm}A$ data:

  Paukkunen, Salgado, JHEP **07**, 32 2010, `arXiv:1004.3140`

  de Florian, Sassot, Stratmann, Zurita, PRD85, 074028 (2012), `arXiv:1112.6324`

- However these results were obtained using **uncorrelated errors** for NuTeV experiment, which were crucial for the `nCTEQ` conclusions PRL106, 122301 (2011).

w	$l^{\pm}A$	$\chi^2(/\text{pt})$	νA	$\chi^2(/\text{pt})$	total $\chi^2(/\text{pt})$
1-corr	708	736 (1.04)	3134	4246 (1.36)	4983 (1.30)
1-uncorr	708	809 (1.14)	3110	3115 (1.00)	3924 (1.02)

Neutrino DIS

[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

- Recent paper
  Paukkunen, Salgado, PRL110, 212301 (2013), arXiv:1302.2001
  suggests a method to renormalize the NuTeV data so that the tension between νA and $l^{\pm}A$ data sets are removed

  Instead of looking at the ratio of cross-sections $R^{\nu}(x,y,E) \equiv \frac{\sigma^{\nu}_{\rm exp}(x,y,E)}{\sigma^{\nu}_{\rm CTEQ6.6}(x,y,E)}$

  they suggest considering

$$\overline{R}^{\nu}(x,y,E) \equiv \frac{\sigma^{\nu}_{\rm exp}(x,y,E)/I^{\nu}_{\rm exp}(E)}{\sigma^{\nu}_{\rm CTEQ6.6}(x,y,E)/I^{\nu}_{\rm CTEQ6.6}(E)}$$

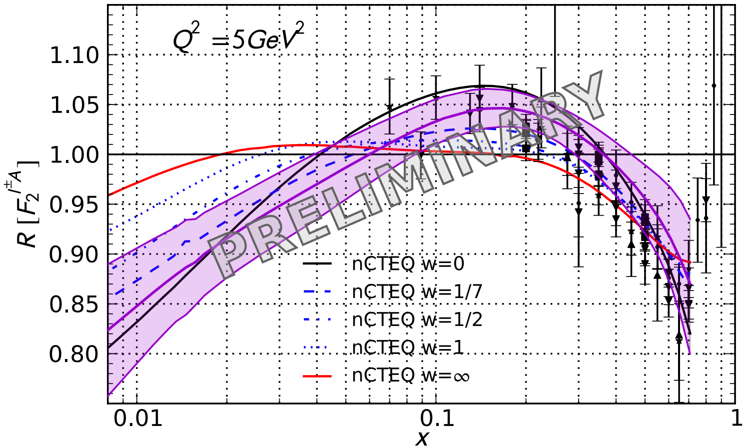
  where

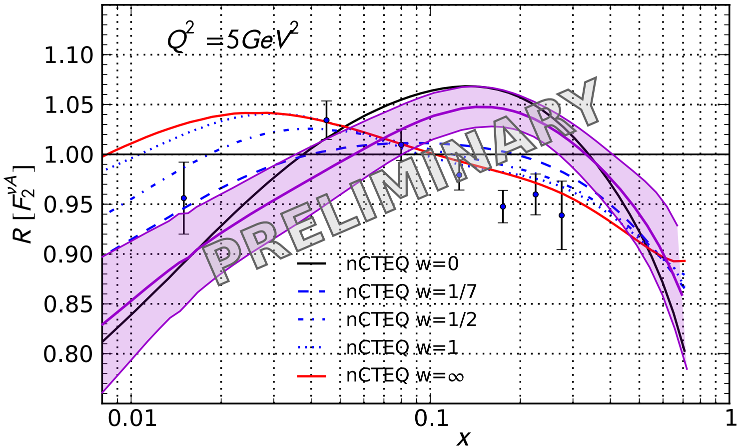
$$I^{\nu}_{\rm exp}(E) \equiv \sum_{i \in \text{fixed } E} \sigma_{{\rm exp},i}(x,y,E) \times B_i(x,y)$$

  $B_i(x,y)$ is size of the experimental (x,y)-bin

- However this analysis still **do not** take into account correlated errors provided by NuTeV collaboration.

Neutrino DIS





- when correlated errors taken into account νA and $l^\pm A$ prefer different nuclear corrections

Summary and outlook

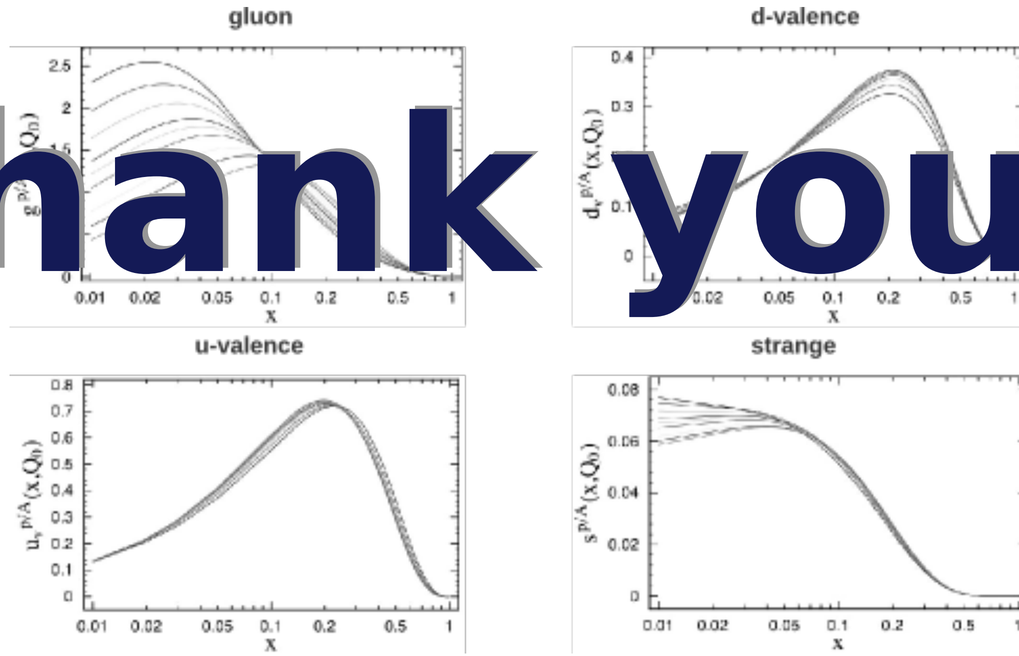
- We have updated the **nCTEQ** error PDFs (still preliminary).
- **nCTEQ** PDFs features larger uncertainties but they are still underestimated.
- To have reliable estimate of nuclear corrections we need more data (LHC *lead* run can help).
- Nuclear component important not only for heavy ion collisions, but also for the free-proton analysis.
- Plans for future:
  - official release of current analysis
  - revisit question of neutrino nuclear corrections
  - include new data (LHC, JLAB, Minerνa)
  - high x region, deuterium nuclear corrections, higher twist effects – CJ collaboration in JLAB

nCTEQ

nuclear parton distribution functions

- Home
- PDF grids & code
- Papers & Talks
- Subversion
- Tracker
- Wiki

nCTEQ project is an extension of the CTEQ collaborative effort to determine parton distribution functions inside of a free proton. It generalizes the free-proton PDF framework to determine densities of partons in bound protons (hence nCTEQ which stands for nuclear CTEQ). More details on the framework and the first results can be found in arXiv:09072357 [hep-ph]. The effects of the nuclear environement on the parton densities can be shown as modified parton densities



where all black curves stand for free proton PDF and red, green, blue, cyan, pink, yellow, magenta and brown curves show PDF in protons bound in nuclei - from deuterium (red) to lead (brown).

An alternative way how effects of nuclear environement can be displayed is in ratios of Deep Inelastic Scattering (DIS) structure functions e.g. ratios of of the structure function F_2 for a neutral current DIS as in the figure below on the left or ratios of of the same structure function F_2 but for a charged current DIS.

Thank you!

Assumptions entering the nuclear PDF analysis

1. **Factorization** & DGLAP evolution
   - allow for definition of **universal PDFs**
   - make the formalism **predictive**
   - needed even if it is broken
2. Isospin symmetry $\begin{cases} u^{n/A}(x) = d^{p/A}(x) \\ d^{n/A}(x) = u^{p/A}(x) \end{cases}$
3. $x \in (0, 1)$ like in free-proton PDFs [instead of $(0, A)$]

Then observables $\mathcal{O}^A$ can be calculated as:

$$\mathcal{O}^A = Z\,\mathcal{O}^{p/A} + (A - Z)\,\mathcal{O}^{n/A}$$

With the above assumptions we can use the free proton framework to analyze nuclear data

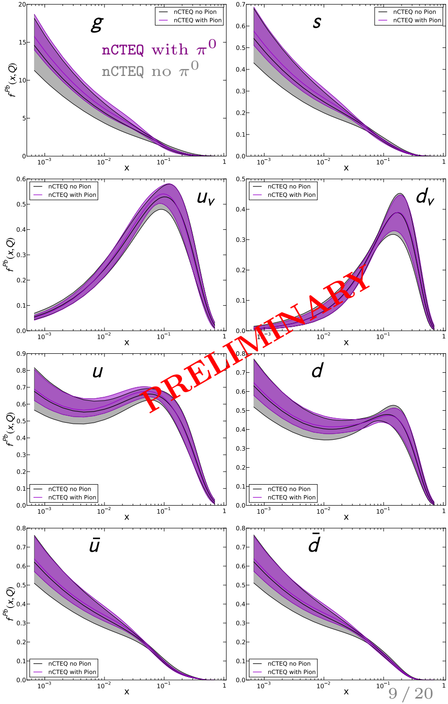
nCTEQ results

Nuclear PDFs ($Q = 10\text{GeV}$)

$$x f_i^{Pb}(x, Q)$$

Compare **nCTEQ** fits:

- with π^0 data (violet)
- without π^0 data (gray)



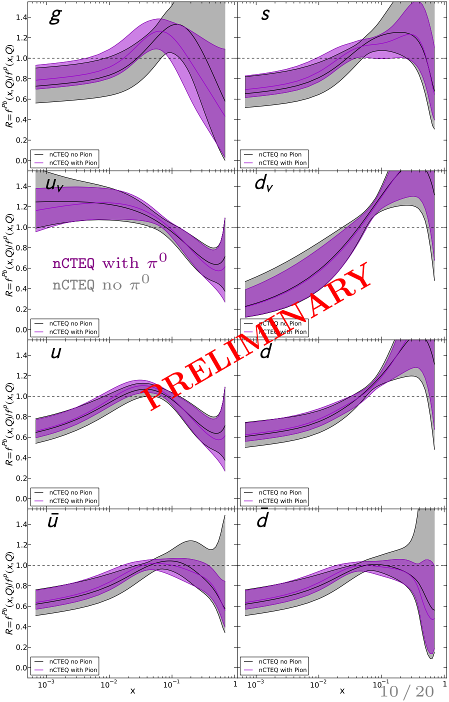
nCTEQ results

Nuclear correction factors
($Q = 10\text{GeV}$)

$$R_i(Pb) = \frac{f_i^{Pb}(x,Q)}{f_i^p(x,Q)}$$

Compare **nCTEQ** fits:

- with π^0 data (violet)
- without π^0 data (gray)



nCTEQ vs. EPS09

nCTEQ

$$x u_v^{p/A}(Q_0) = x^{c_1^u}(1-x)^{c_2^u} e^{c_3^u x}(1+e^{c_4^u}x)^{c_5^u}$$

$$x d_v^{p/A}(Q_0) = x^{c_1^d}(1-x)^{c_2^d} e^{c_3^d x}(1+e^{c_4^d}x)^{c_5^d}$$

$$c_k^{u_v} = c_{k,0}^{u_v} + c_{k,1}^{u_v}\left(1 - A^{-c_{k,2}^{u_v}}\right)$$

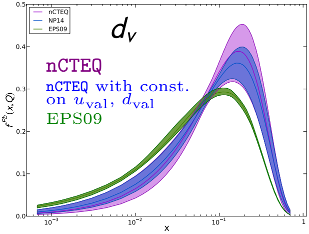
$$c_k^{d_v} = c_{k,0}^{d_v} + c_{k,1}^{d_v}\left(1 - A^{-c_{k,2}^{d_v}}\right)$$

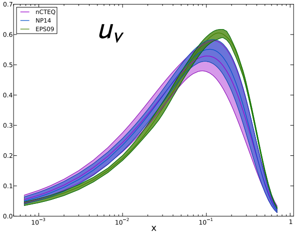
EPS09

$$u_v^{p/A}(Q_0) = R_v(x, A, Z)\, u(x, Q_0)$$

$$d_v^{p/A}(Q_0) = R_v(x, A, Z)\, d(x, Q_0)$$

$$R_v = \begin{cases} a_0 + (a_1 + a_2 x)(e^{-x} - e^{-x_a}) & x \le x_a \\ b_0 + b_1 x + b_2 x^2 + b_3 x^3 & x_a \le x \le x_e \\ c_0 + (c_1 - c_2 x)(1-x)^{-\beta} & x_e \le x \le 1 \end{cases}$$

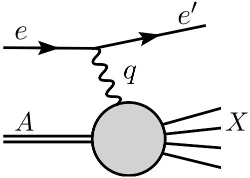




we set:

$$\begin{cases} c_1^{d_v} = c_1^{u_v} \\ c_2^{d_v} = c_2^{u_v} \end{cases}$$

Variables: DIS of nuclear target $eA \to e'X$



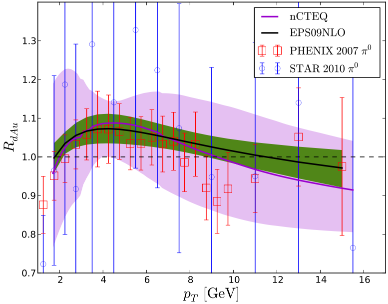
- DIS variables in case on nucleons in nucleus $\begin{cases} Q^2 \equiv -q^2 \\ x_A \equiv \frac{Q^2}{2\,p_A \cdot q} \end{cases}$
  - p^A – nucleus momentum
  - $x_A \in (0,1)$ – analog of Bjorken variable (fraction of the nucleus momentum carried by a nucleon)
- Analogue variables for partons:
  - $p_N = \frac{p_A}{A}$ – *average* nucleon momentum
  - $x_N \equiv \frac{Q^2}{2\,p_N \cdot q} = A\,x_A$ – parton momentum fraction with respect to the avarage nucleon momentum p_N
  - $x_N \in (0, A)$ – parton can carry more than the average nucleon momentum p_N.

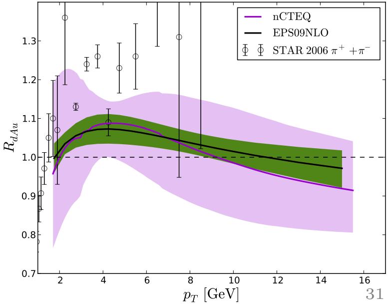
nCTEQ results

Pion production, ratio

$$R^{\pi}_{\mathrm{dAu}} = \frac{\frac{1}{2A} d^2\sigma^{\mathrm{dAu}}_{\pi} / dp_T dy}{d^2\sigma^{\mathrm{pp}}_{\pi} / dp_T dy}$$

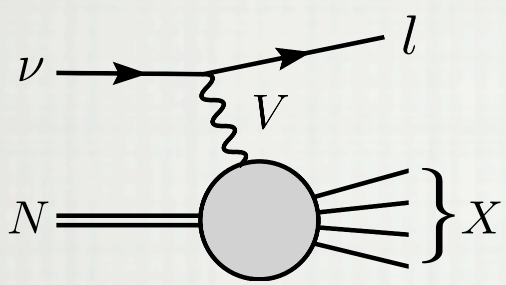
- good data description, however big experimental uncertainities do not allow for strong constraints on PDFs
- despite different u-valence & d-valence ratios are similar to EPS09





NEUTRINO DIS

- Neutrino DIS cross-section data



$\nu + N \rightarrow l + X$

NuTeV & di-muon
$N = \mathrm{Fe}$ → 2310 data points

CHORUS
$N = \mathrm{Pb}$ → 824 data points

All charged lepton
DIS & Drell-Yan data
→ 708 data points

- Challenges in combining the neutrino & charged lepton data
  - deal with the disparity of number of data points - assigning weights to neutrino data
  - neutrino DIS data only with 2 heavy nuclei - insufficient to get a reliable A-dependance
  - do all neutrino data show the different behavior or only NuTeV ?
- Different neutrino observables

$$\frac{d\sigma^{\nu A}}{dx dQ^2} \;\&\; \frac{d\sigma^{\bar{\nu} A}}{dx dQ^2} \quad \text{vs.} \quad F_2^{\nu+\bar{\nu}}(x, Q^2) \;\&\; xF_3^{\nu+\bar{\nu}}(x, Q^2)$$

needs theory assumptions to extract

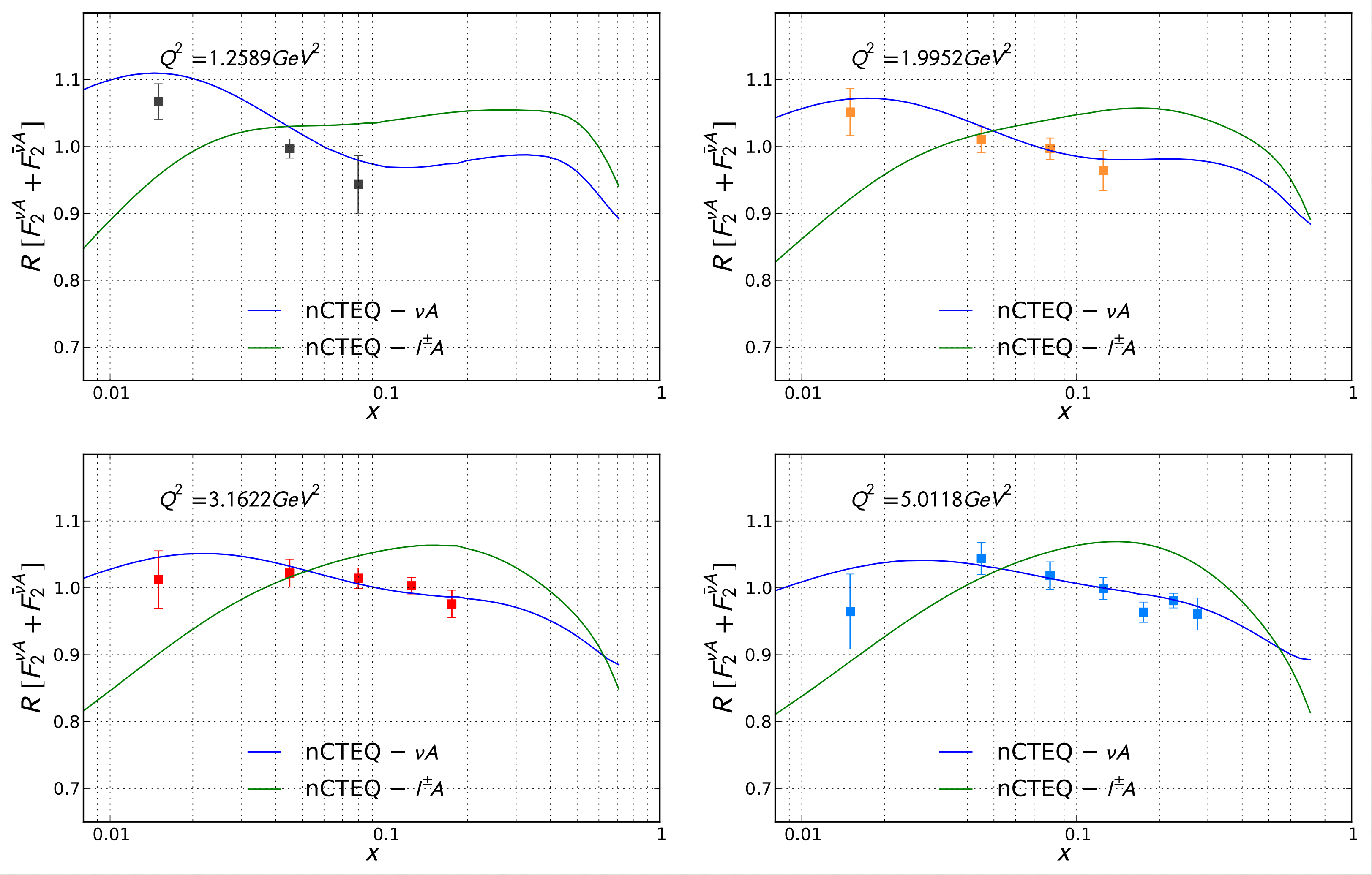
- Nuclear correction factors
  - we show correction factors defined e.g. as $R[F_2^{\nu}] = F_2^{\nu A} / F_2^{\nu A,\mathrm{free}}$

from free proton PDF

KIT Karlsruhe Institute of Technology

NEUTRINO DIS

- NLO QCD calculation of $\frac{F_2^{\nu A} + F_2^{\bar{\nu} A}}{2}$ in the ACOT-VFN scheme
  - comparison of nCTEQ - only neutrino fit against extracted NuTeV data at different Q^2
  - charge lepton fit undershoots low-x data & overshoots mid-x data
  - low-Q^2 and small-x data cause tension with the shadowing observed in charged lepton data



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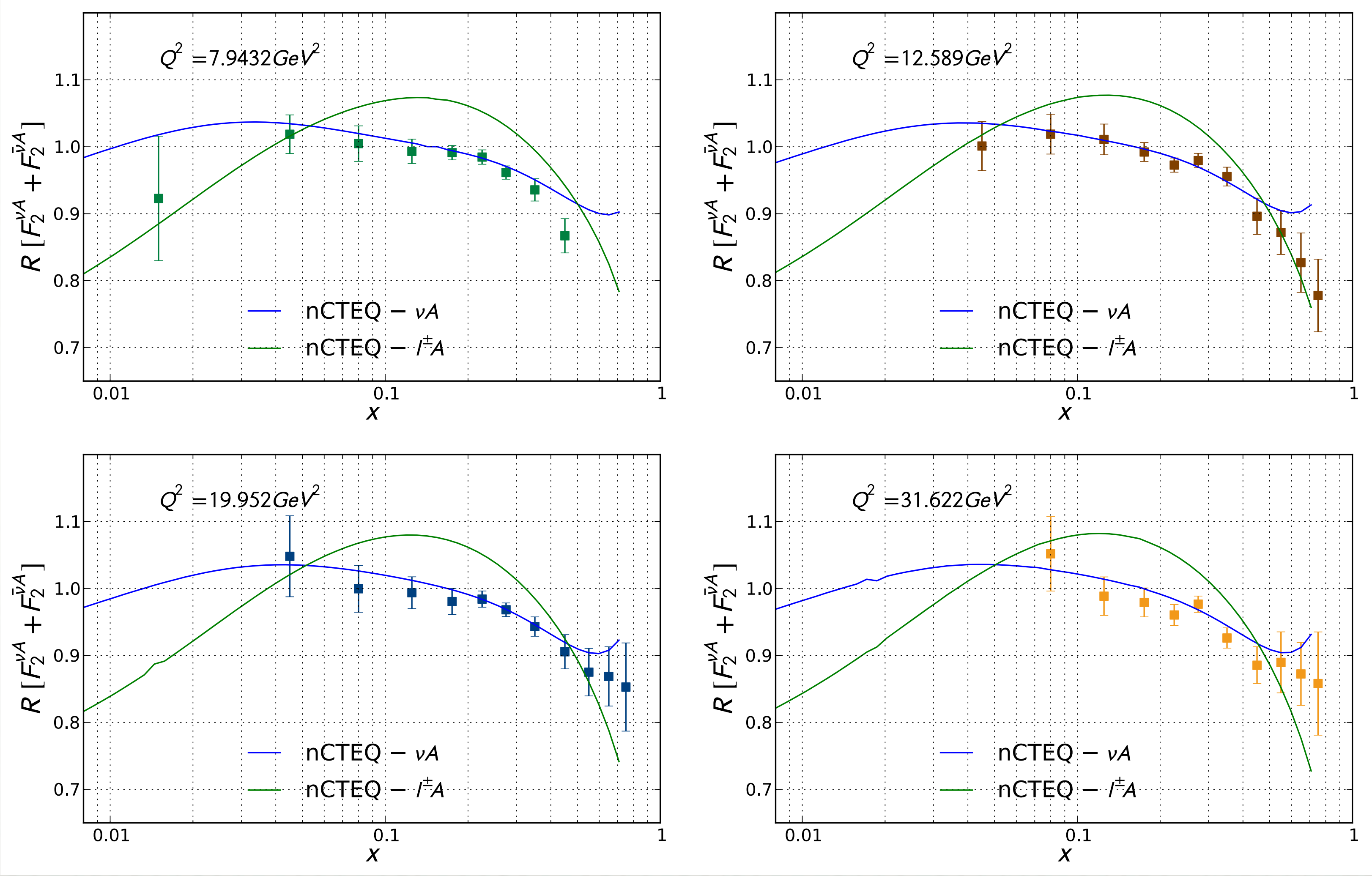

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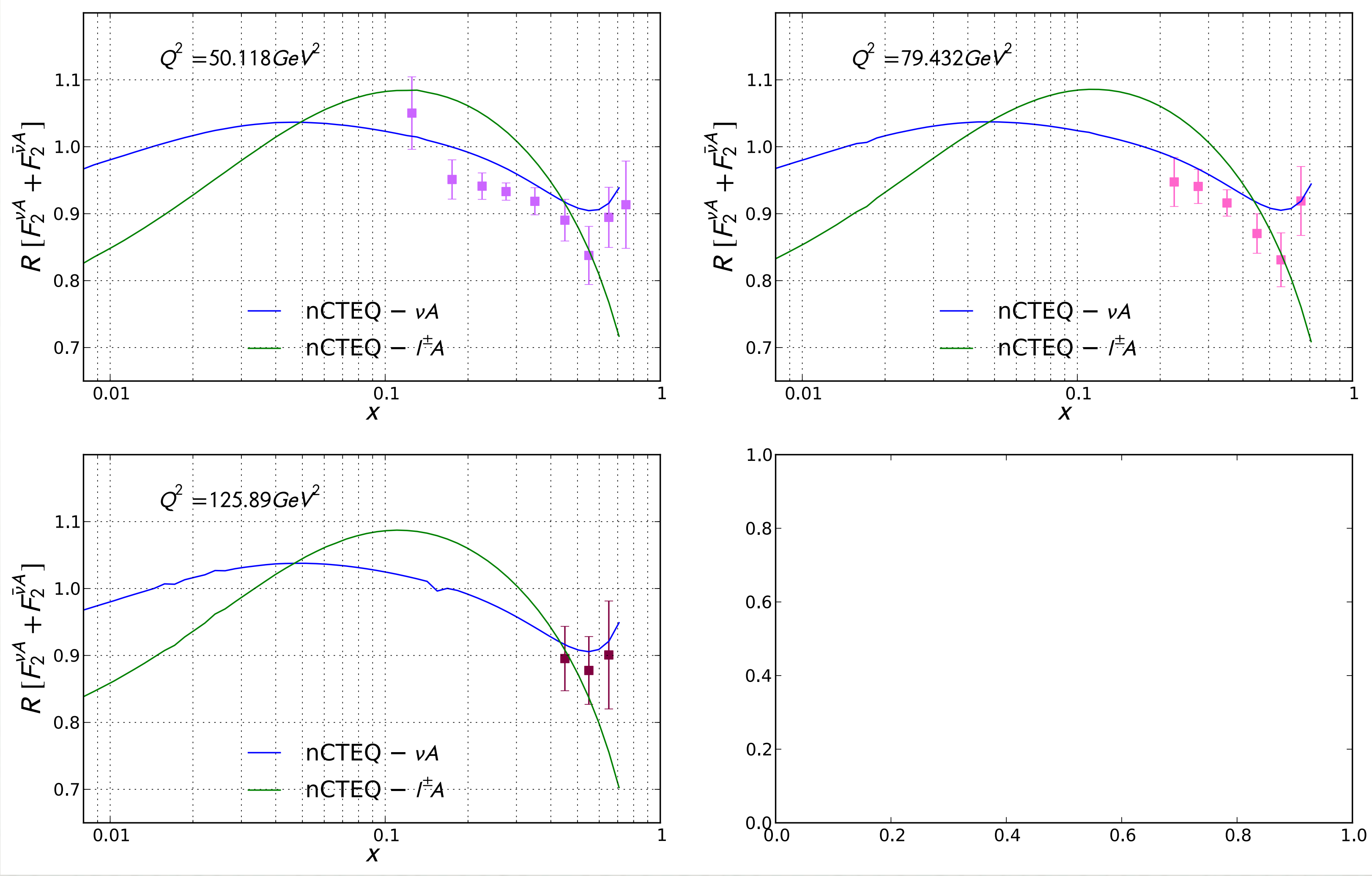

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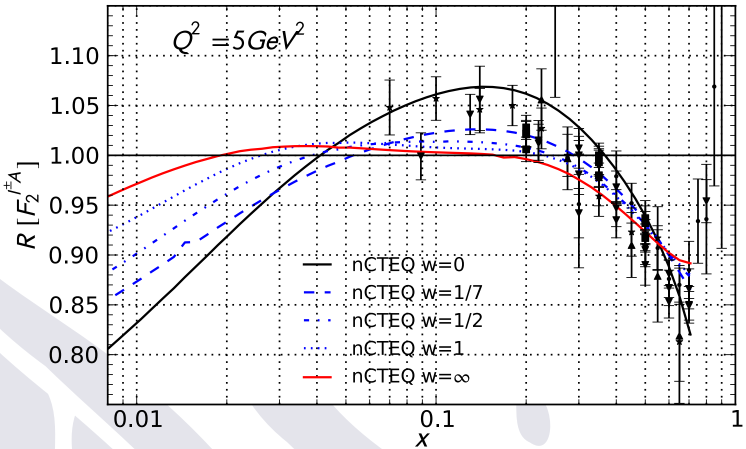
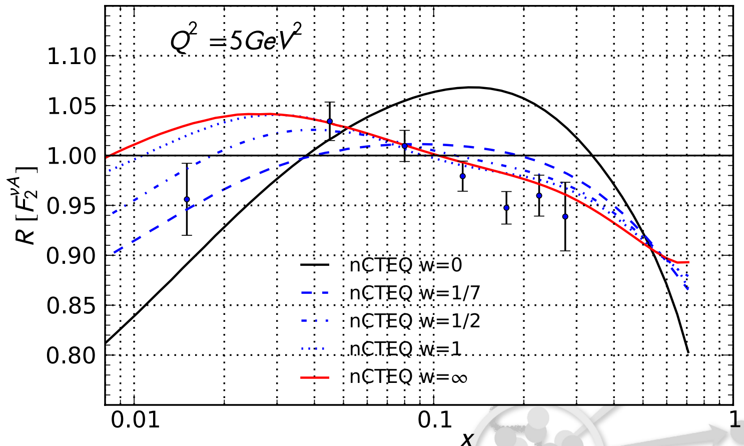
Neutrino DIS

[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

Analysis of fits with different weights of neutrino DIS (correlated errors)

w	$l^{\pm}A$	χ^2 (/pt)	νA	χ^2 (/pt)	total χ^2(/pt)
0	708	630 (0.89)	-	-	630 $\pm$ 58
1/7	708	645 (0.91)	3134	4681 (1.50)	5326 $\pm$ 203
1/2	708	680 (0.96)	3134	4375 (1.40)	5055 $\pm$ 192
1	708	736 (1.04)	3134	4246 (1.36)	4983 $\pm$ 190
∞	-	-	3134	4167 (1.33)	4167 $\pm$ 176





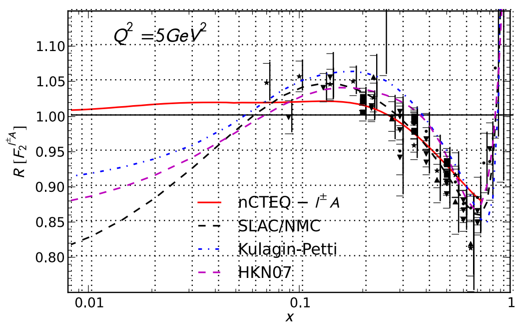
Neutrino DIS

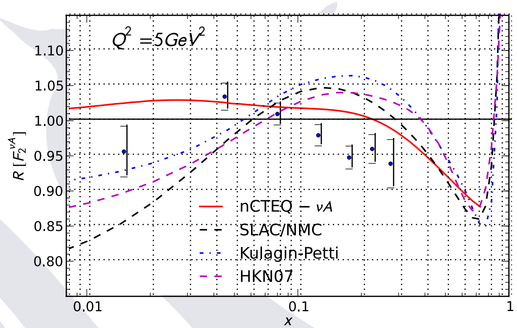
[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

Analysis of fits with neutrino DIS (uncorrelated errors)

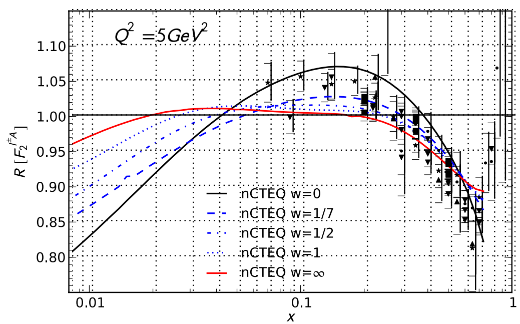
w	$l^{\pm}A$	χ^2 (/pt)	νA	χ^2 (/pt)	total χ^2(/pt)
1-corr	708	736 (1.04)	3134	4246 (1.36)	4983 (1.30)
1-uncorr	708	809 (1.14)	3110	3115 (1.00)	3924 (1.02)

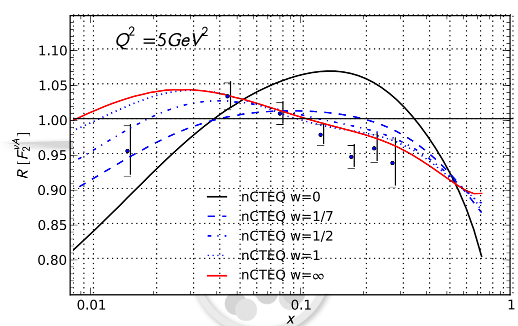
uncorrelated errors





correlated errors





Neutrino DIS

[Phys.Rev.Lett. 106(2011) 122301, arXiv: 1012.1178]

Properties of neutrino fits

CHORUS data are in good agreement with the charged lepton data

combined: χ^2/pt=1.03

NuTeV data (with correlated errors) difficult to fit alone or with the charged lepton data

alone: χ^2/pt=1.35 combined: χ^2/pt=1.33