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# First unbiased determination of the parton distributions of lead nuclei

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**Abstract** A nice abstract

We present

## Contents

# 1 Introduction

In a series of papers [1–11], the NNPDF collaboration has introduced a methodology aimed at reducing as much as possible this procedural uncertainty.

Now we want to apply it to the case of nuclear PDFs ....

## 2 Dataset

In this section we summarize the data that has been used, the kinematic cuts, and the treatment of experimental uncertainties

The data in our analysis consist of $l + A$ DIS measurements. These nuclear data comprise the NMC [12–15], SLAC 139 [16] and EMC [17] results for ratios of the DIS structure function $F_2^A(x, Q^2)$ for several heavy nuclei to those of deuterium, lithium or carbon, see Tab. 1.

The kinematical variables in DIS are the Bjorken-x and the virtuality of the photon $Q^2$. As the compression of the nuclear data to lead structure function is done using EPS09 NLO nPDFs, the kinematical cut $Q^2 \geq 1.69$ is imposed [18].

The experimental uncertainty, $d\sigma_i^{exp}$, is obtained adding in quadrature the systematic and statistical errors dor each point. The theoretical uncertainty, $d\sigma_i^{th}$, is the one due to the conversion factor. We require that only points where $d\sigma_i^{th} \leq 1.5\ d\sigma_i^{exp}$ are included in the fit.

## 3 Compression of nuclear data to lead structure functions

Here we explain how all the nuclear ratio data for different values of $A$ is compressed to the lead structure function.

We write the relevant conversion formula, discuss error propagation, and show representative results for the various experiments.

$$F_2^{Pb}(x, Q^2) = \frac{F_2^{Pb}(x, Q^2)}{F_2^A(x, Q^2)} R^A_{F_2^{D,C,Li}}(x, Q^2) F_2^{D,C,Li}(x, Q^2), \tag{1}$$

where $R^A_{F_2^{D,C,Li}}(x, Q^2)$ are the experimental data for ratios of the DIS structure function $F_2^A(x, Q^2)$ for various heavy nuclei to those for deutherium, lithium or carbon,

$$R^A_{F_2^{D,C,Li}}(x, Q^2) = \frac{F_2^A(x, Q^2)}{F_2^{D,C,Li}(x, Q^2)}, \tag{2}$$

see Tab. 1.

For $F_2^{Pb}(x, Q^2)$, $F_2^A(x, Q^2)$, $F_2^{Li}(x, Q^2)$ and $F_2^C(x, Q^2)$ we use EPS09 NLO nPDFs [18] and, in order to obtain the DIS structure functions for deuterium, $F_2^D(x, Q^2)$, we neglect any nuclear effect, assume isospin symmetry ($u^p = d^n$ and $d^p = u^n$) and use the free proton NLO PDFs of MSTW [19].

Therefore, the idea is to transform the DIS nuclear data, $R^A_{F_2^{D,C,Li}}(x, Q^2)$, into lead structure functions $F_2^{Pb}(x, Q^2)$ using equation (1). We define, the conversion factor of this transformation as,

$$\mathcal{C}(x, Q^2) = \frac{F_2^{Pb}(x, Q^2)}{F_2^A(x, Q^2)} F_2^{D,C,Li}(x, Q^2) \tag{3}$$

and, consequently, $F_2^{Pb}(x, Q^2) = \mathcal{C}(x, Q^2) R^A_{F_2^{D,C,Li}}(x, Q^2)$.

We use the Hessian method [20] to calculate the uncertainty of the conversion factor. In the Hessian approach, the corresponding uncertainty for a PDF-dependent quantity $\mathcal{O} = \mathcal{O}[f]$ can be computed as,

$$(\Delta\mathcal{O})^2 = \frac{1}{4} \sum_k \left(\mathcal{O}[S_k^+] - \mathcal{O}[S_k^-]\right)^2, \tag{4}$$

| Experiment | Nuclei | Data points | ref. |
|---|---|---|---|
| SLAC E-139 | He(4)/D | 9 | [16] |
| NMC 95, re. | He/D | 8 | [12] |
| | | | |
| NMC 95 | Li(6)/D | 10 | [13] |
| NMC 95, $Q^2$ dependence | Li/D | 144 | [13] |
| | | | |
| SLAC E-139 | Be(9)/D | 9 | [16] |
| NMC 96 | Be/C | 12 | [14] |
| | | | |
| CERN EMC | C(12)/D | 9 | [17] |
| SLAC E-139 | C/D | 3 | [16] |
| NMC 95, NMC 95, re. | C/D | 10 | [12, 13] |
| NMC 95, $Q^2$ dependence | C/D | 159 | [13] |
| NMC 95, re. | C/Li | 6 | [12] |
| | | | |
| SLAC E-139 | Al(27)/D | 13 | [16] |
| NMC 96 | Al/C | 15 | [14] |
| | | | |
| SLAC E-139 | Ca(40)/D | 5 | [16] |
| NMC 95, re. | Ca/D | 15 | [12] |
| NMC 95, re. | Ca/Li | 7 | [12] |
| NMC 96 | Ca/C | 15 | [14] |
| | | | |
| SLAC E-139 | Fe(56)/D | 23 | [16] |
| NMC 96 | Fe/C | 15 | [14] |
| | | | |
| CERN EMC | Cu(64)/D | 19 | [17] |
| | | | |
| SLAC E-139 | Ag(108)/D | 7 | [16] |
| | | | |
| CERN EMC | Sn(117)/C | 8 | [17] |
| NMC 96 | Sn/C | 10 | [14] |
| NMC 96, $Q^2$ dependence | Sn/C | 139 | [15] |
| | | | |
| SLAC E-139 | Au(197)/D | 17 | [16] |
| | | | |
| NMC 96 | Pb/C | 15 | [14] |
| Total | | 702 | |

Table 1: Data sets included in the analysis. The mass numbers are indicated in parentheses. The number of data points refers to those falling within our cuts: $Q^2 \geq 1.69$ and $d\sigma_i^{th} \leq 1.5\ d\sigma_i^{exp}$.

where $\mathcal{O}[S_k^+]$ and $\mathcal{O}[S_k^-]$ denote the values of the quantity $\mathcal{O}$, computed by the nPDF error sets $S_k^+$ and $S_k^-$ and $S_0$ is the central PDF set.

For the lithium and carbon cases, the uncertainty of the conversion factor is given by

$$(\Delta\mathcal{C})^2 = \frac{1}{4}\sum_k \left(\frac{F_2^{Pb}[S_k^+]}{F_2^A[S_k^+]}F_2^{C,Li}[S_k^+] - \frac{F_2^{Pb}[S_k^-]}{F_2^A[S_k^-]}F_2^{C,Li}[S_k^-]\right)^2 . \tag{5}$$

Neglecting the uncertainty due to the deuterium PDF, the uncertainty of the conversion factor is in this case,

$$(\Delta\mathcal{C})^2 = \frac{1}{4}\sum_k \left(\frac{F_2^{Pb}[S_k^+]}{F_2^A[S_k^+]}F_2^{D}[S_0] - \frac{F_2^{Pb}[S_k^-]}{F_2^A[S_k^-]}F_2^{D}[S_0]\right)^2 , \tag{6}$$

where $F_2^D[S_0]$ in the value of $F_2$ computed by the central NLO MSTW PDF set [19] and $F_2^{Pb,C,Li,A}[S_k^{-,+}]$ are computed by the NLO EPS09 sets [18].

Therefore, the theoretical uncertainty of the lead structure functions is

$$d\sigma^{th} = \Delta\mathcal{C}R^A_{F_2^{D,C,Li}} . \tag{7}$$

# 4 Fitting methodology

Here we discuss the fitting methodology, the sum rules, the flavor decomposition, positivity, the parameterization of nuclear PDFs as ratios etc

# 5 Results

Here we show, well, the results of the fit

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