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*Global Analysis of Helicity PDFs:
past – present - future*

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Global Analysis of Helicity PDFs: past - present - future¹

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Abstract. We discuss the current status of the DSSV global analysis of helicity-dependent parton densities. A comparison with recent semi-inclusive DIS data from COMPASS is presented, and constraints on the polarized strangeness density are examined in some detail.

INTRODUCTION: DSSV GLOBAL ANALYSIS

Helicity-dependent parton densities (PDFs) tell us precisely how much quarks and gluons with a given momentum fraction x tend to have their spins aligned with the spin direction of a nucleon in a helicity eigenstate. Their knowledge is essential in the quest to answer one of the most basic questions in hadronic physics, namely how the spin of a nucleon is composed of the spins and orbital angular momenta of its constituents.

More than a dozen experiments have measured with increasing precision various observables sensitive to different combinations of quark and gluon polarizations in the nucleon. The experimental progress was matched by advancements in corresponding theoretical higher order calculations in the framework of pQCD and phenomenological analyses of available data [1, 2]. The most comprehensive global fits [1] include data taken in spin-dependent DIS, semi-inclusive DIS (SIDIS) with identified pions and kaons, and proton-proton collisions. They allow for extracting sets of helicity PDFs consistently at next-to-leading order (NLO) accuracy along with estimates of their uncertainties. Contributions from the orbital angular momenta of quarks and gluons completely decouple from such type of experimental probes and need to be quantified by other means. One important asset in the DSSV global analysis framework is the use of a numerically fast Mellin moment technique [3, 1] which allows one to incorporate complicated NLO expressions for pp processes [4] without any approximations.

Unlike unpolarized PDF fits, where a separation of different quark flavors is obtained from inclusive DIS data taken with neutrino beams, differences in polarized quark and antiquark densities are at present determined exclusively from SIDIS data and hence require knowledge of fragmentation functions (FFs). Reliable sets of FFs at NLO accuracy have been extracted in global fits to inclusive hadron yields in e^+e^- , ep , and pp

¹ talk presented by M. Stratmann

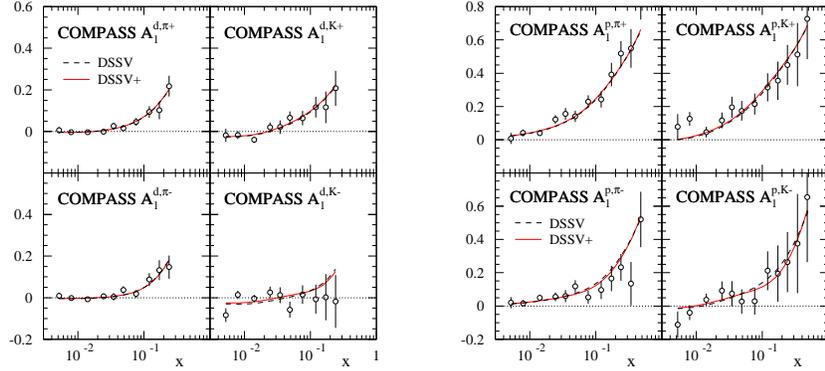


FIGURE 1. COMPASS results [7, 8] for SIDIS spin asymmetries on a deuteron (left) and proton target (right) compared to DSSV and DSSV+ fits (see text).

collisions [5]. Even though pion FFs are rather well constrained by data, corresponding kaon FFs suffer from larger uncertainties which complicate current extractions of $\Delta s(x)$.

RECENT DIS AND SIDIS DATA

Recently, the COMPASS collaboration has published new DIS [6] and SIDIS [7, 8] data. The latter extend the coverage in x down to about $x \simeq 5 \times 10^{-3}$, almost an order of magnitude lower than the kinematic reach of the HERMES data used in the DSSV global analysis of 2008 [1]. For the first time, the new results comprise measurements of identified pions and kaons taken with a longitudinally polarized proton target. Clearly, these data can have a significant impact on fits of helicity PDFs and estimates of their uncertainties. In particular, the new kaon data will serve as an important check of the validity of the strangeness density obtained in the DSSV analysis, which instead of favoring a negative polarization as in most fits based exclusively on DIS data, prefers a vanishing or perhaps even slightly positive Δs in the measured range of x , see below.

The new data for the inclusive spin asymmetry A_1^p appear to be well described by the original DSSV set of helicity PDFs yielding a $\chi^2/\text{d.o.f.} \approx 1$. Figure 1 shows a detailed comparison between the new SIDIS spin asymmetries from COMPASS [7, 8] and the original DSSV fit (dashed lines). Also shown is the result of a re-analysis at NLO accuracy (denoted as “DSSV+”) based on the updated data set. The differences between the DSSV and the DSSV+ fits are hard to notice for both identified pions and kaons. The total χ^2 of the fit drops only by a few units upon refitting, which is not really a significant improvement for a PDF analysis in view of non-Gaussian theoretical uncertainties. The change in χ^2 is also well within the maximum $\Delta\chi^2/\chi^2 = 2\%$ tolerated as a faithful, albeit conservative estimate of PDF uncertainties within the DSSV global analysis [1].

At first sight it may seem that the new SIDIS data have only very little impact on the fit. This is not the case if one studies individual χ^2 profiles in more detail. Compared to the original DSSV fit we find a trend towards smaller net polarization for $\Delta\bar{u}$ and $\Delta\bar{d}$ in

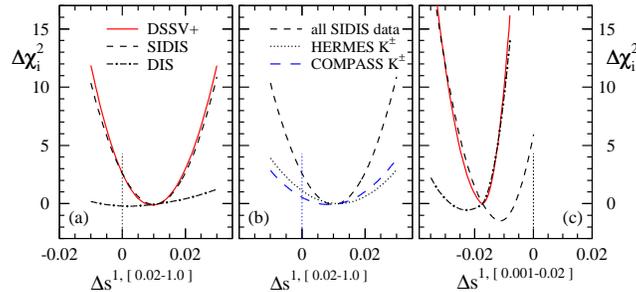


FIGURE 2. (a), (c): χ^2 profiles for the truncated first moment of Δs in two different x intervals. (b): impact of kaon data from COMPASS and HERMES in the range $0.02 \leq x \leq 1$.

the range $0.001 \leq x \leq 1$. In addition, one finds a significant reduction in the uncertainties, as determined by the width of the χ^2 profiles at a given $\Delta\chi^2$. There is, however, some mild tension with older SIDIS sets, but this is well within the tolerance of the fit and most likely caused by the different x ranges covered by the different data sets.

Constraining the strangeness helicity density

A much debated feature of the strangeness helicity PDF obtained in the DSSV fit is its unexpected small value at medium-to-large x which, when combined with a node at intermediate x , still allows for acquiring a significant negative first moment at small x , in accordance with expectations from SU(3) symmetry and fits to DIS data only. To investigate the possibility of a node in $\Delta s(x)$ further, we present in Fig. 2 the χ^2 profiles for two different intervals in x : (a) $0.02 \leq x \leq 1$ and (c) $0.001 \leq x \leq 0.02$. The middle panel (b) demonstrates the impact and consistency of kaon data from HERMES and COMPASS in constraining $\Delta s(x)$ in the region $0.02 \leq x \leq 1$.

The profiles in Fig. 2 clearly show that the result for Δs for $0.001 \leq x \leq 0.02$ is a compromise between DIS and SIDIS data, the latter favoring less negative values. For $0.02 \leq x \leq 1$ everything is determined by SIDIS data, and all sets consistently ask for a small, slightly positive strange quark polarization. There is no hint of a tension with DIS data here as they do not provide a useful constraint at medium-to-large x . We note that at low x , most SIDIS sets in the original DSSV fit give indifferent results. The new COMPASS data, which extend towards the smallest x values so far, actually show some preference for a slightly negative value for Δs . We also notice that in the range $x > 0.001$ the hyperon decay constants, the so-called F and D values, do not play a significant role in constraining $\Delta s(x)$. To quantify possible SU(3) breaking effects one needs to probe $\Delta s(x)$ at smaller values of x , for instance in SIDIS at a future EIC [9].

Clearly, all current extractions of Δs from SIDIS data suffer from a significant dependence on kaon FFs, see, e.g., Ref. [7, 8], and better determinations of $D^K(z)$ are highly desirable. Contrary to other fits of FFs [10], only the DSS sets [5] provide a satisfactory description of pion and kaon multiplicities in the same kinematic range where we have

polarized SIDIS data.

OUTLOOK

Existing experiments, like PHENIX and STAR at RHIC, will continue to add data in the next couple of years. Preliminary single-inclusive jet data from STAR presented at this conference exhibit a non-zero double-spin asymmetry A_{LL} in the covered range of transverse momenta p_T [11]. Measurements of A_{LL} for di-jet correlations [12] should help to improve the current constraints on $\Delta g(x)$ and extend them towards somewhat smaller values of x . As soon as these data sets are finalized they will be incorporated in our global analysis framework, and their implications for $\Delta g(x)$ will be studied in detail.

Parity-violating, single-spin asymmetries for W boson production from RHIC should reach a level where they help to constrain Δu , $\Delta \bar{u}$, Δd , and $\Delta \bar{d}$ at moderately large x , $0.07 \leq x \leq 0.4$ at scales $Q \simeq M_W$, much larger than typically probed in SIDIS [13]. The strangeness polarization is, however, very hard to access in polarized pp collisions. In the future, JLab12 will add very precise DIS data at large x , which will allow one to challenge ideas like helicity retention, predicting that $\Delta f(x)/f(x) \rightarrow 1$ as $x \rightarrow 1$.

Most of the remaining open questions concerning helicity PDFs are related to their behavior at small x and can be only addressed at a future, high-energy polarized electron-proton collider. At an EIC, the gluon polarization can be determined precisely from studies of DIS scaling violations [9]. A full flavor decomposition down to about $x \simeq 10^{-4}$, including $\Delta s(x)$ and $\Delta \bar{s}(x)$, should be possible by studying the semi-inclusive production of pions and kaons. If necessary, unpolarized hadron multiplicities will help to constrain FFs better. An EIC also has the unique opportunity to access polarized electroweak structure functions via charged and neutral current DIS measurements. These novel probes constrain various different combinations of polarized quark PDFs.

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