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Lambda Polarization in the Target Fragmentation Region

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Abstract

We propose a measurement program of Λ polarization in semi-inclusive and exclusive processes at large momentum transfer Q^2. Lambdas will be measured in the target fragmentation region using the CLAS12 detector. The experiment makes use of the base equipment in Hall B, including the CLAS12 and ancillary beamline instrumentation.

1 Introduction

The spin structure of the nucleon has been of central interest since the EMC [1] measurements implied that the helicity of the constituent quarks accounts for only a fraction of the nucleon spin. This so-called "spin crisis" was subsequently confirmed by a number of other experiments at CERN [2], SLAC [3, 4], HERA [5, 6] and JLab [7]. Possible interpretations of this result include a significant polarization of either the strange sea (negatively polarized) or the gluons (positively polarized). The contributions to the sum rule for the total helicity of the nucleon include the following:

$$\frac{1}{2} = \frac{1}{2}\sum_q \Delta q^{val} + \Delta q^{sea} + L_z^{val} + L_z^{sea} + L_z^{glue} + \Delta G,$$

where Δq, L_z and ΔG are respectively the quark helicity, the orbital angular momentum of all partons, and the gluon helicity.

One of the most remarkable results from semi-inclusive deep inelastic scattering (SIDIS) studies is the measurement by the HERMES collaboration of Δs being consistent with zero [5, 6], in contrast to expectations of $\Delta s \approx -0.1$ from DIS measurements. The origin of this negative sea polarization is likely nonperturbative and still has to be understood.

The analysis of QCD sum rules indicates that the condensate of $\bar{s}s$ pairs in the vacuum is not small, but is comparable with the condensate of the light quarks [9]. The strong attraction in the spin-singlet pseudoscalar channel may induce correlations between valence quarks from the proton wave function and vacuum antiquarks with opposite spins. Polarization measurements provide sensitive tests of models of strong–interaction dynamics. Measurements of the Λ polarization in SIDIS provide an important probe of the strange sea in the nucleon [8, 16] and may shed light on the proton spin puzzle. The advantage of detecting Λs in the final state lies in the fact that the Λ is self-analyzing. It can be used as a s quark polarimeter since the polarization of the Λ is defined by the polarization of its s quark. Most of the Λ particles in CLAS12 kinematics are in the target fragmentation region.

The target fragmentation region of DIS, which also carries interesting information about the spin and flavor structure of the nucleon, is still poorly understood, and has not been studied systematically in experiments. The main physical question is how the diquark-like remnant system after the DIS process dresses itself up to become a full-fledged hadron, i.e., by which mechanism the quark-antiquark pairs restoring color neutrality are produced, and how this process is correlated with the spin of the target or/and the produced particles.

In electroproduction, the polarized lepton emits a virtual photon with non–zero longitudinal polarization, which in turn selects preferentially one polarization state of the struck quark. The opposite polarization of a remnant $\bar{s}s$ pair can again be transferred to the final–state Λ polarization, with the efficiency extracted from eN collisions. After removing a polarized scattered quark from an unpolarized nucleon, the remnant diquark may combine with an s quark, which could originate from the nucleon sea or from a color string between the diquark and the scattered quark to form a Λ hyperon (see Fig. 1).

The polarization of Λ hyperons in the target fragmentation region of DIS has been considered in the meson cloud model [16]. Due to the pseudoscalar nature of the $NK\Lambda$ coupling, the polarization of final-state Λ hyperons was predicted to be strongly anticorrelated to that of the nucleon, vanishing for an unpolarized target.

Exclusive production of Lambdas, $\gamma^* p \to K\Lambda$ or $K^*\Lambda$, can be regarded as the limiting case of target fragmentation, in which both the current jet and the target jet reduce to a single hadron. In the exclusive case, a QCD factorization theorem states that the color-neutralizing quark-antiquark pair is produced by hard gluon exchange a mechanism which has very different properties compared to the soft non-perturbative interactions (e.g. string breaking, instanton-induced interaction) dominating in the semi-inclusive case. A better understanding of semi-inclusive target fragmentation

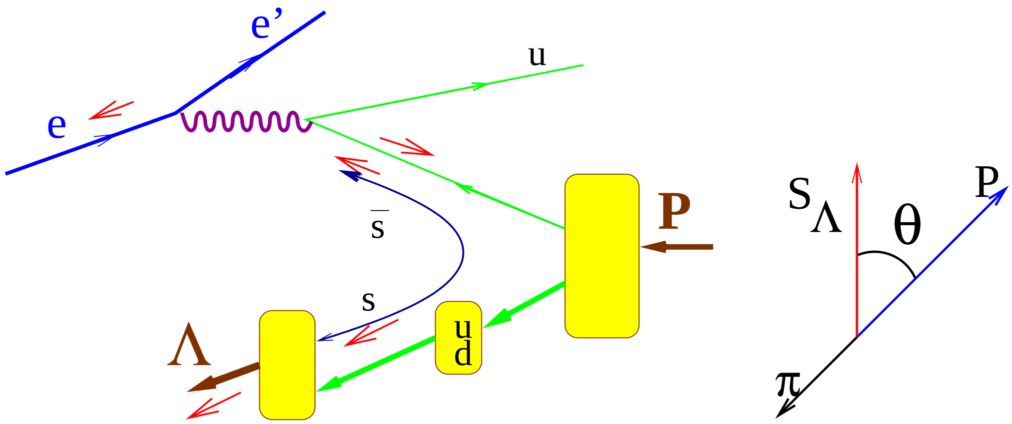

Figure 1: *Dominant diagram for Λ production in the target fragmentation region due to scattering on a valence u quark (left) and the Λ decay kinematics (right).*

Table 1: Combinations of proton GPDs in $e\Lambda X$

$K^{*+}\Lambda$	$-\frac{1}{\sqrt{6}}\Big(2[2H^u - H^d - H^s] - [2H^{\bar{u}} - H^{\bar{d}} - H^{\bar{s}}]\Big)$
$K^{+}\Lambda$	$-\frac{1}{\sqrt{6}}\Big(2[2\tilde{H}^u - \tilde{H}^d - \tilde{H}^s] + [2\tilde{H}^{\bar{u}} - \tilde{H}^{\bar{d}} - \tilde{H}^{\bar{s}}]\Big)$

will be a benefit also to the phenomenology of exclusive meson production, as the exclusive data indicate that the contributions from soft reaction mechanisms (higher twist from the QCD point of view) are still substantial at momentum transfers $Q^2 <$ 10 GeV^2.

In exclusive processes, the final state is a recoiling baryon B together with a single meson or a few-meson system carrying nearly the full photon energy in the target rest frame. A QCD factorization theorem states that in the Bjorken limit, and for longitudinal photon polarization, the amplitudes of such processes are calculable in terms of the light-cone distribution amplitude of the produced meson and generalized parton distributions (GPDs) for the $p \to B$ transition. The GPD combination involved in exclusive production of $K^+\Lambda$ and $K^{*+}\Lambda$ (see Tab.1) was discussed by M. Diehl and collaborators [10]

Using flavor SU(3) symmetry one can relate the transition GPDs from the proton to a hyperon to the distributions $H^q(x,\xi,t)$ for quark flavor q in the proton [12, 13]. This gives in particular $H_{p\to\Lambda} = -[2H^u - H^d - H^s]/\sqrt{6}$ and an analogous relation for $\tilde{H}_{p\to\Lambda}$. Measurement of the recoil polarization of Λ hyperons in $K^+\Lambda$ and $K^{*+}\Lambda$ exclusive processes, thus, may provide additional constraints on the underlying GPDs. Comparisons of data with model calculations based on GPDs generally indicate the presence of substantial higher-twist corrections up to momentum transfer of several GeV^2. In the Q^2 range covered by JLab, the main focus of exclusive meson production programs will be the study of different ratio observables as a function of Q^2 to observe early scaling in these ratios which is expected based on a rather early onset of the regime of squeezing. Some predictions of ratios of exclusive kaon and ρ cross sections at large Q^2 are shown in Fig. 2.

In order to describe hadrons produced in the target fragmentation region, new distribution functions have been introduced [11]. The so-called Fracture Functions, $M_{i,h/N}(x,z)$, represent the probability of finding a parton of flavor i with a momentum fraction x in a hadron h with a momentum fraction z in the target N. Since the probability of current parton fragmentation into a Λ (given by fragmentation functions) is comparatively small with respect to that of processes originating in the target (fracture functions), Λ production can be a perfect tool to access these essentially unknown fracture functions.

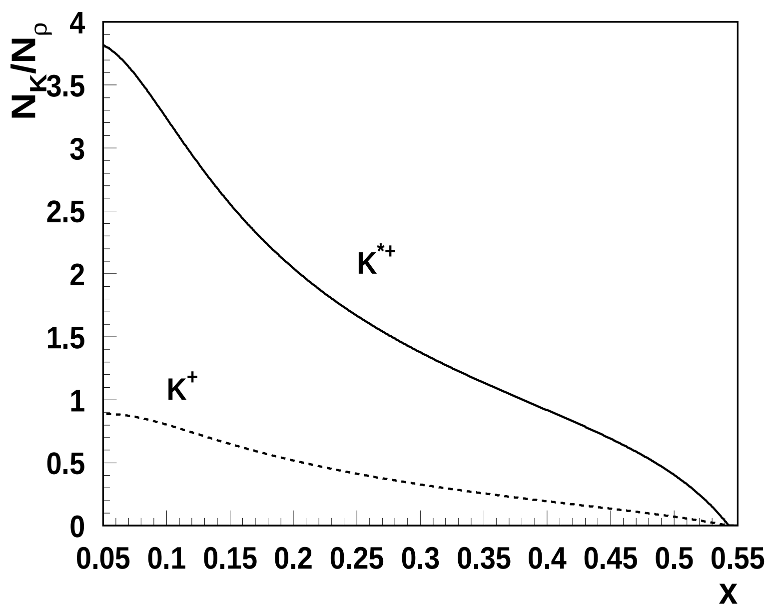

Figure 2: *Ratio of $\sigma(\gamma_l p \to K^+\Lambda)/\sigma(\gamma_l p \to \rho^+ n)$ for exclusive production with longitudinal photons of kaons and ρ calculated in the GPD framework [10].*

The proton from Λ decay follows the distribution,

$$d\sigma/d\cos\theta \sim (1 + \alpha P_\Lambda \cos\theta),$$

where P_Λ is the polarization of the decaying hyperon, α is the weak decay parameter ($\alpha = 0.642 \pm 0.013$) and θ is the angle between the momentum vector of the proton and the chosen polarization axis in the center of momentum frame of the decaying Λ hyperon.

The traditional approach to extract the Λ polarization requires detailed modeling of the acceptance of the proton and pion from the Λ decay. Because the Λ's polarization flips sign when reversing the beam helicity, the beam-helicity asymmetry measurement is possible. In that case (used also in exclusive analysis [14]), first order acceptance corrections are not required as it cancels in both the numerator and denominator.

2 Studies with CLAS at 5.5 GeV

2.1 LUND MC studies

Λ production was studied using the LUND-MC. The CLAS data shows a decent agreement with LUND predictions for the shapes of the distributions $(x, Q^2, cos\theta)$ already at 5.5 GeV (see Fig.3).

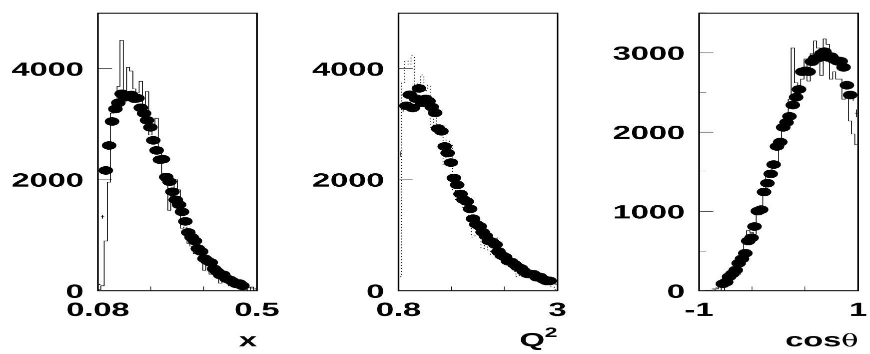

Figure 3: Distribution of $e'\Lambda X$ as a function of x, Q^2 and $\cos\theta$ $(M_{\Lambda X} > 1GeV)$ from 5.5 GeV data (filled circles) and LUND-MC

Λ production was studied with CLAS at 5.5 GeV using direct detection of Λ by measurement of final state proton and π^-. Two exclusive final states, namely $K^+\Lambda$ and $K^{*+}\Lambda$, are visible in the missing mass of the $e'\Lambda X$ system at 5.5 GeV (see Fig. 4). The measurements with semi-inclusive Λs were performed requiring a the missing mass of the $e'\Lambda X$ above 1 GeV, where no structure is visible due to pure exclusive events ($K^+\Lambda$ and $K^{*+}\Lambda$).

2.2 Preliminary results from CLAS at 5.5 GeV

Significant effects were observed already at 5.5 GeV with CLAS both for exclusive [14] and semi-inclusive Λ production. The fits to invariant mass distributions for different

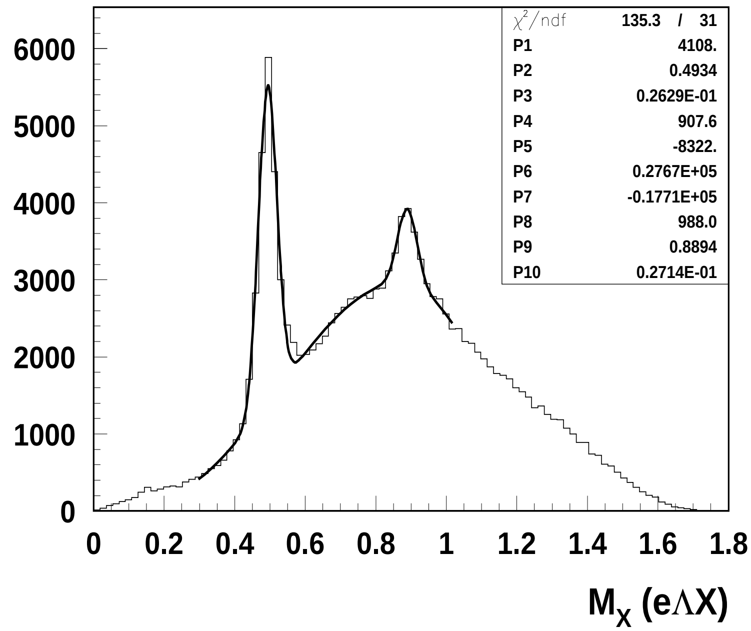

Figure 4: *Missing mass distribution for $e'\Lambda X$ events at 5.5 GeV (CLAS e1f experiment).*

helicities were used to extract the contributions of Λ and the background (see Fig. 5). Extracted preliminary asymmetry for Lambda events and background is shown in Fig. 6 as a function of Feynman x_F (ratio of the longitudinal momentum of the particle in the CMS frame to its maximum value).

3 Studies with CLAS12

The same LUND-MC was used to study the Λ production at 11 GeV. The missing mass distributions of $e\Lambda X$ and angular distributions of protons and pions from Λ decay at 11 GeV are shown in Figs. 7 and 8 respectively. Detection of pions at large angle is important for studies of target fragmentation region in general and for Λ production in particular. The CLAS12 central detector [21] significantly increases the acceptance of low momentum pions (Fig.8) and is a crucial component of proposed measurements.

The first indication of single transverse spin asymmetries in high energy inclusive processes came from Lambda transverse polarization studies. Large asymmetries triggered further studies of Lambda production at different facilities worldwide. Sig-

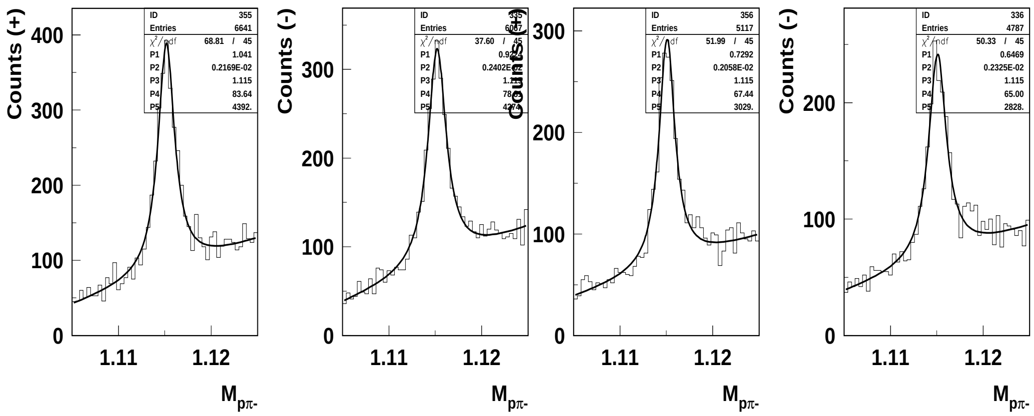

Figure 5: *Fit to the invariant mass distribution for 2 bins in* $\cos\theta$ *(e1f 5.5 data set) for positive (+) and negative (-) electron helicities. Background under the* Λ *peak is defined from the fit.*

nificant transverse polarization of Lambda hyperons was observed recently by HERMES collaboration in quasireal photoproduction [22]. Preliminary data on transverse Lambda polarization were also reported by COMPASS collaboration [23].

Large acceptance of CLAS12 would allow a superior measurements of Λ polarization (see Fig. 9). Curves on the projection plot represent predictions from two different models and error bars correspond to 2000h of running with an unpolarized target at a luminosity of $10^{35}\mathrm{sec}^{-1}\mathrm{cm}^{-2}$. Recoil polarization measurements in Lambda production also open access to studies of interference effects involving different GPDs depending on the final state particles [24].

In this LOI, we study Lambda production in the target fragmentation region of semi-inclusive DIS as well as in the exclusive limit. In the semi-inclusive case we aim to significantly improve the accuracy of previous measurements of Lambda production and polarization [17, 18, 19, 20], allowing for decisive tests of models of the reaction mechanism. In the exclusive case, we plan to focus on ratio observables such as the $\gamma^* p \to K\Lambda$ to $K^*\Lambda$ ratio, which are expected to follow the QCD factorization predictions earlier than the individual cross sections themselves and will provide tests of GPD models. More generally, our results will allow us to follow the inclusive - exclusive transition in Lambda production, hopefully providing new insights into the exclusive reaction mechanism.

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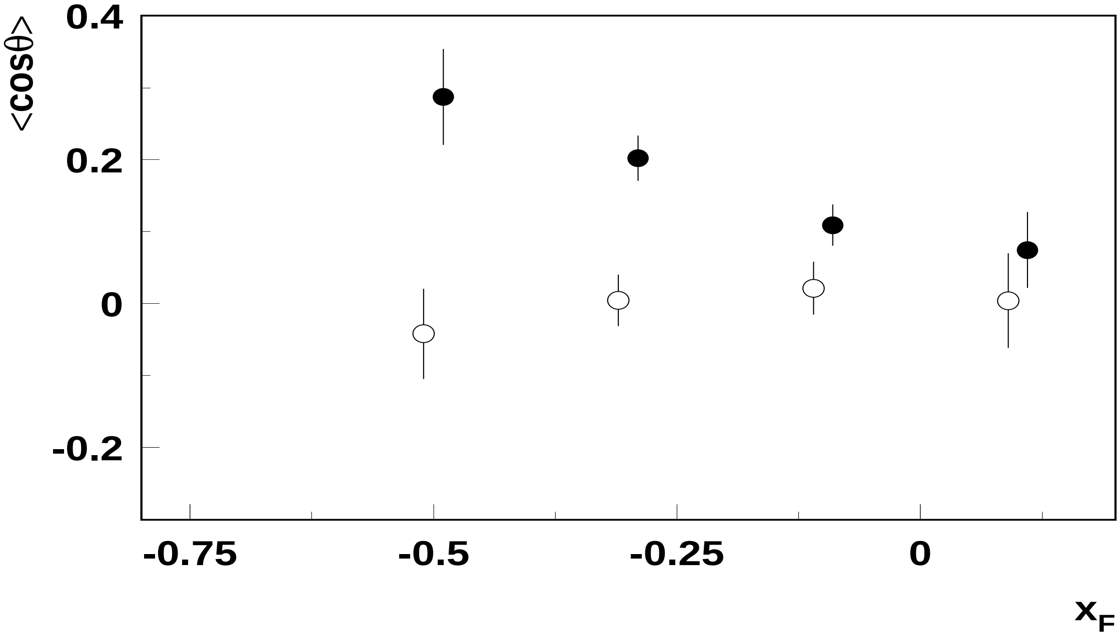

Figure 6: *The preliminary result from CLAS at 5.5 GeV for the average* $\cos\theta$*, corrected for acceptance and depolarization, for* Λ *(filled circles) and background under the* Λ *peak (open circles) as a function of* x_F *(*$M_{\Lambda X} > 0.7$ *GeV).*

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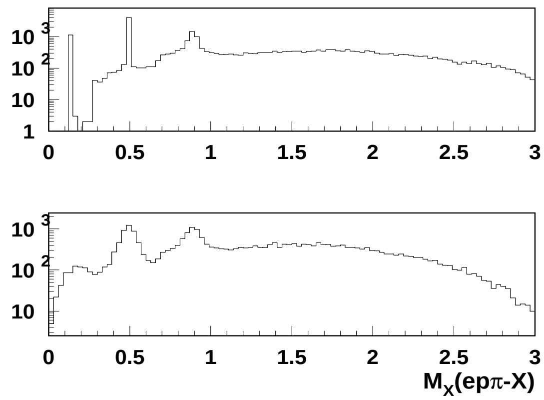
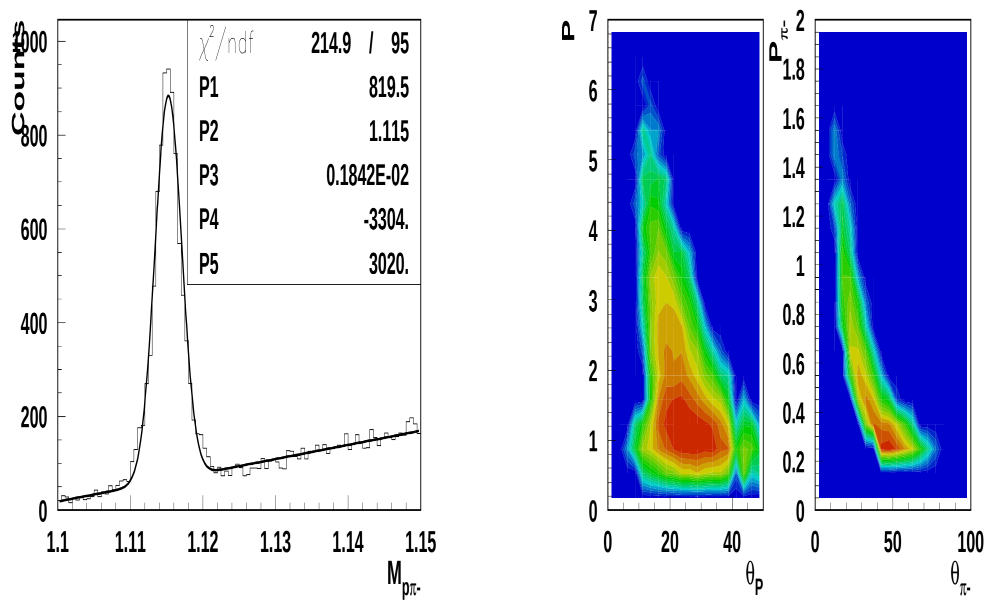


Figure 7: Distribution of the missing mass of $e\Lambda X$ from LUND-MC in CLAS12 kinematics for generated (top) and reconstructed (bottom) direct Λs.



(a) (b)

Figure 8: Mass and angular distributions of Λ decay particles at CLAS12.

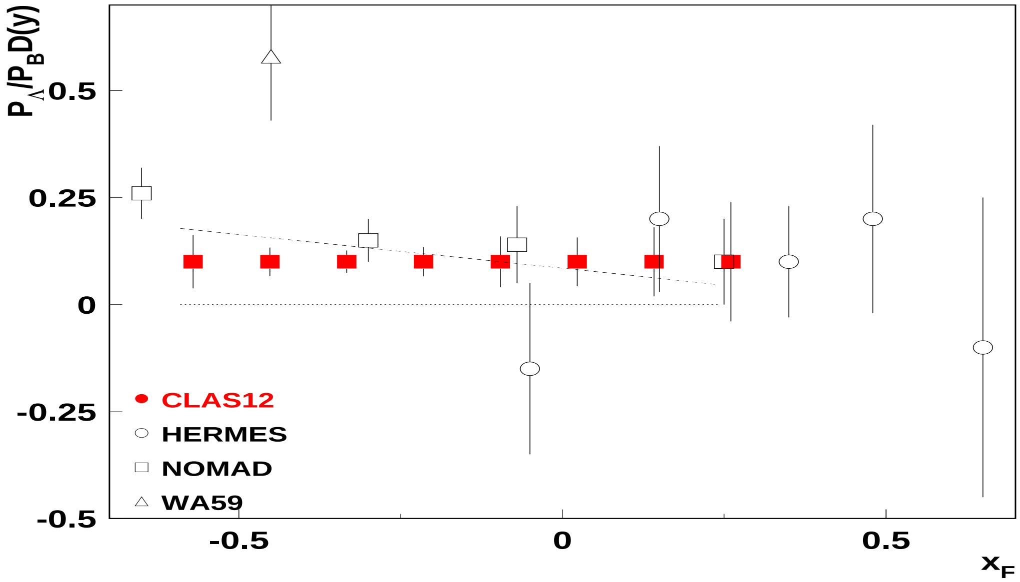


Figure 9: CLAS12 projections compared to Λ polarization measurements at different labs [17, 18, 19, 20]. The dashed curve are calculations using an intrinsic strangeness model [8, 15] and the dotted line is for a meson cloud model [16].

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