Overview on unpolarized and polarized baryon fragmentation functions

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Outline

- Definitions of FF
- What is known about the polarized baryon FF?
- Earlier attempts to understand some Λ, $\bar{\Lambda}$ data
- Basic procedure to construct the statistical unpolarized octet baryon FF
- Conclusions

Definitions of FF

$D_f^h(z,Q^2)$ is the probability to find, at scale Q, a hadron h with fraction z of the parton f momentum. Note that $Q^2>0$ and FF is the counterpart of the PDF $f_h(x,Q^2)$ defined for $Q^2<0$. QCD predicts their Q^2 evolution and like the PDF, they should be universal, i.e. processes independent. If h has spin-1/2 can define similarly to Δf for PDF the polarized FF

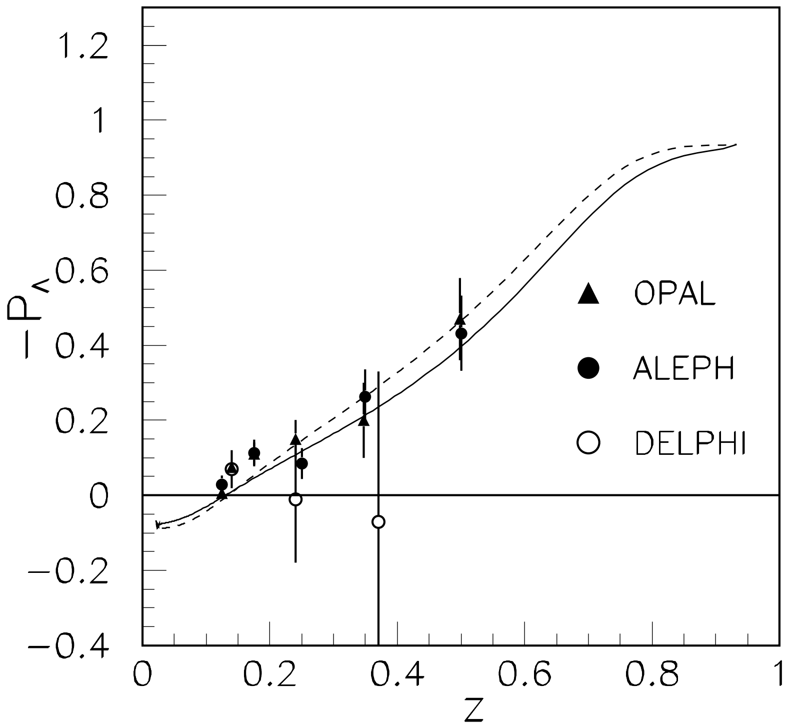
$$\Delta D_f^h = D_{f(+)}^{h(+)} - D_{f(+)}^{h(-)}$$

D_f^h is the sum

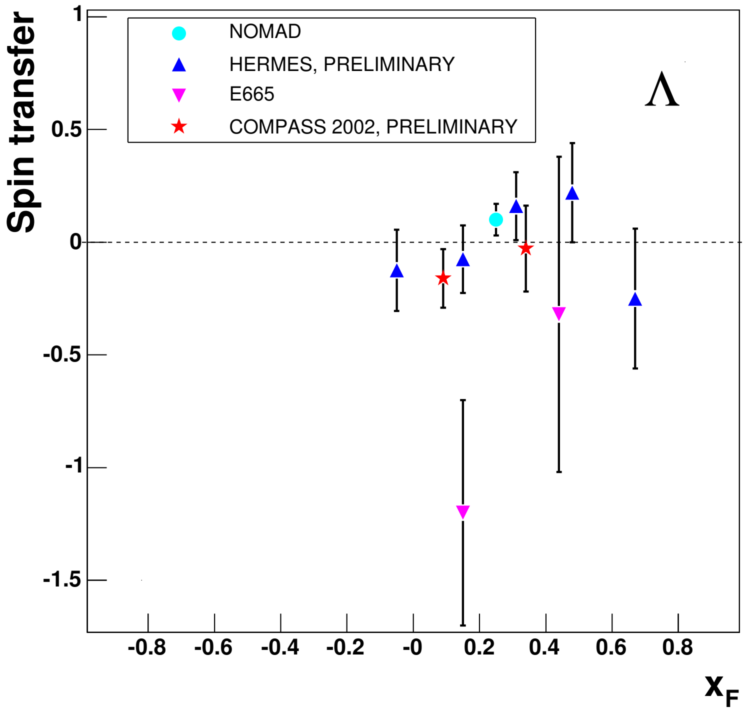
What is known on the polarized baryon FF?

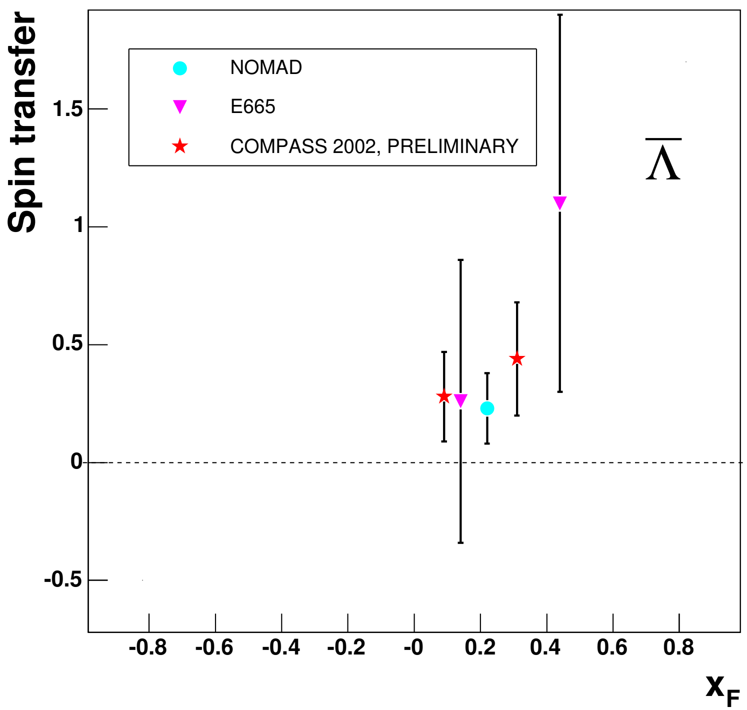
Very little and only for Λ and $\bar{\Lambda}$

$P_L(\Lambda + \bar{\Lambda})$ at the Z pole in e^+e^- collisions at LEP

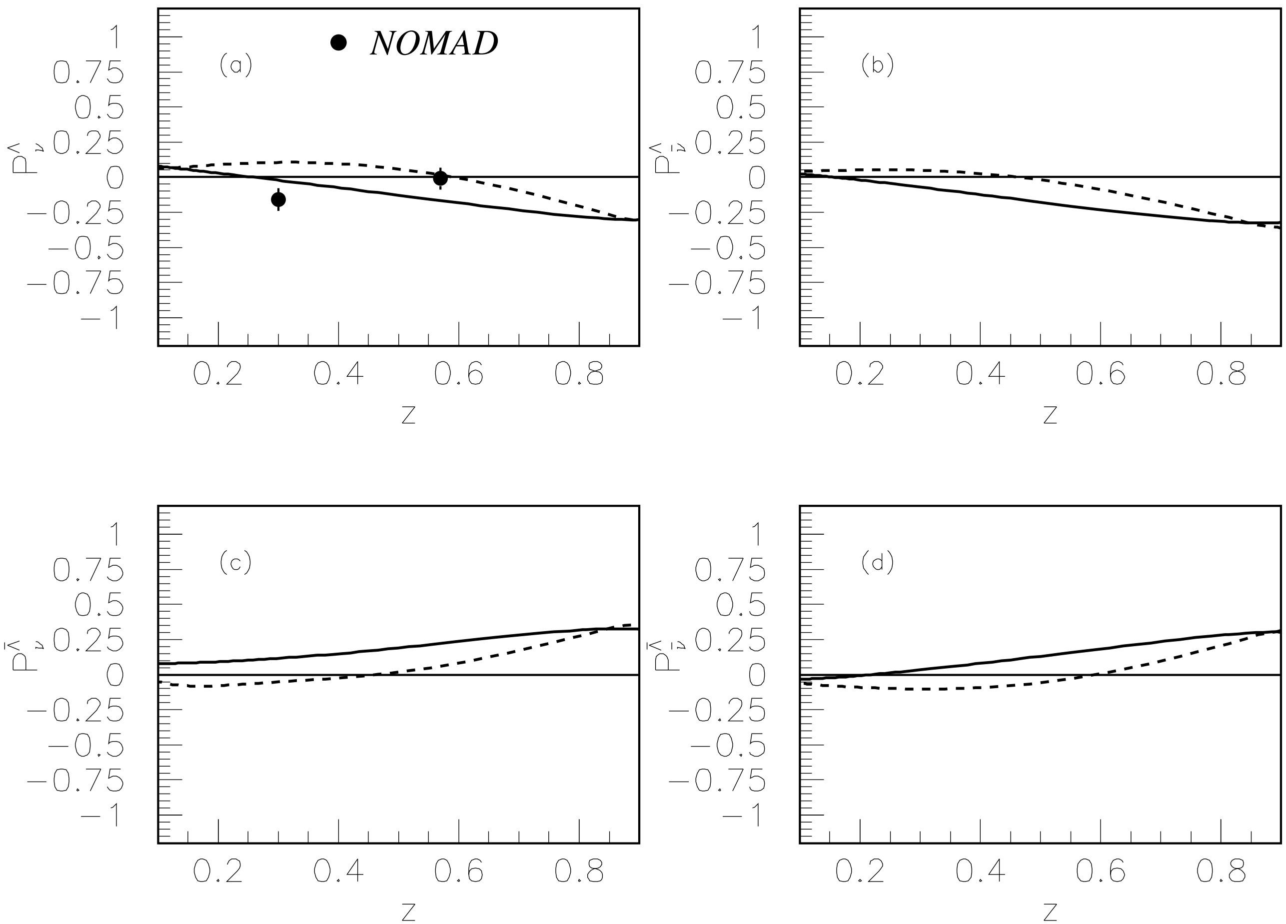


Spin transfer for Λ and $\bar{\Lambda}$

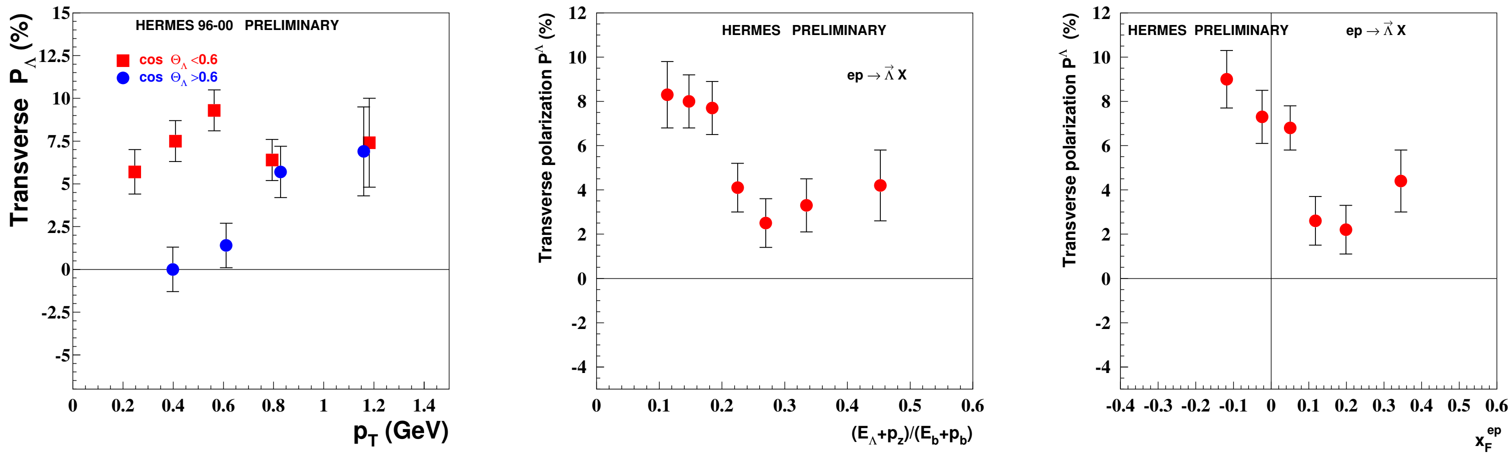




Spin transfer for Λ from NOMAD



Transverse Λ polarization from Hermes



(+ some NOMAD results large < 0 for $x_F < 0$)

This is a transverse SSA hard to interpret

Definitions

For a longitudinally polarized charged lepton beam and an unpolarized target, the Λ polarization along its own momentum axis is given in the quark parton model by

$$P_\Lambda(x,y,z) = P_B D(y) A^\Lambda(x,z) \ ,$$

where P_B is the polarization of the charged lepton beam, which is of the order of 0.7 or so.
$\nu = E - E'$, $x = Q^2/2M\nu$, $y = \nu/E$, $z = E_\Lambda/\nu$

$D(y)$, whose explicit expression is

$$D(y) = \frac{1-(1-y)^2}{1+(1-y)^2},$$

is the longitudinal depolarization factor of the virtual photon with respect to the parent lepton, and

$$A^{\Lambda}(x,z) = \frac{\sum_q e_q^2 [q^N(x,Q^2)\Delta D_q^{\Lambda}(z,Q^2) + (q \rightarrow \bar{q})]}{\sum_q e_q^2 [q^N(x,Q^2) D_q^{\Lambda}(z,Q^2) + (q \rightarrow \bar{q})]},$$

is the longitudinal spin transfer to Λ.

Earlier attempts to understand some Λ, $\bar{\Lambda}$ data

D. De Florian et al., Phys. Rev. D57 (1998) 5811
C. Boros et al., Phys. Rev. D62 (2000) 014021
Use only data from e^+e^- collisions

$$D_q^{\Lambda+\bar{\Lambda}}(z) = N z^\alpha (1-z)^\beta$$

which implies no flavor separation and no $q, \bar{q}$ separation. Use simple scenarios to construct $\Delta D_q(z) = N_q z^\delta D_q(z)$ with $N_s = 1$ and $N_u = N_d = 1, -0.2, 0$.

Earlier attempts..(cont.)

Another approach based on the use of our knowledge of the PDF and the use of the reciprocity relation (Gribov-Lipatov)(see next slide).

B.-Q. Ma, I. Schmidt, J.S. and J.J. Yang, EPJ C16, 657 (2000)

B.-Q. Ma, I. Schmidt, J.S. and J.J. Yang, Phys. Rev. D62, 114009 (2000)

It works reasonably well but E665 remains puzzling. We generalize to all baryons with a SU(6) spectator quark-diquark model

Gribov and Lipatov have pointed out that the FF $D_q^h(z)$, for a quark q splitting into a hadron h with longitudinal momentum fraction z, can be related to the quark distribution $q_h(x)$, for finding the quark q inside the hadron h carrying a momentum fraction x, by the reciprocity relation

$$D_q^h(z) \sim q_h(x) \ .$$

This relation holds, in principle, in a certain Q^2 range and in leading order approximation. It is only valid at $x \to 1$ and $z \to 1$, but it provides a reasonable guidance for a phenomenological parametrization of the various FF.

For the Λ, we have explicit spin distributions for each valence quark,

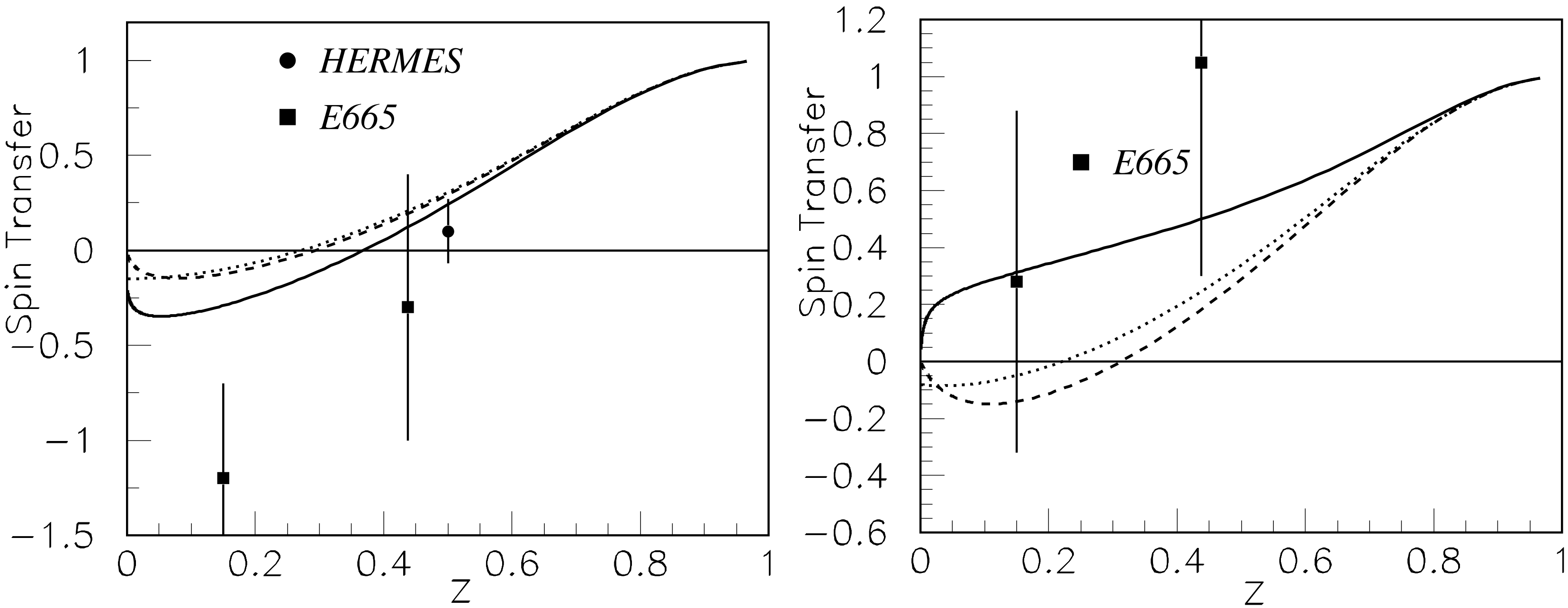
$$u_v^{\uparrow}(x) = d_v^{\uparrow}(x) = \frac{1}{x^{\alpha_v}}[A_{u_v}(1-x)^3 + B_{u_v}(1-x)^4],$$

$$u_v^{\downarrow}(x) = d_v^{\downarrow}(x) = \frac{1}{x^{\alpha_v}}[C_{u_v}(1-x)^5 + D_{u_v}(1-x)^6],$$

$$s_v^{\uparrow}(x) = \frac{1}{x^{\alpha_v}}[A_{s_v}(1-x)^3 + B_{s_v}(1-x)^4],$$

$$s_v^{\downarrow}(x) = \frac{1}{x^{\alpha_v}}[C_{s_v}(1-x)^5 + D_{s_v}(1-x)^6].$$

Spin transfer for Λ (right) and $\bar{\Lambda}$ (left)

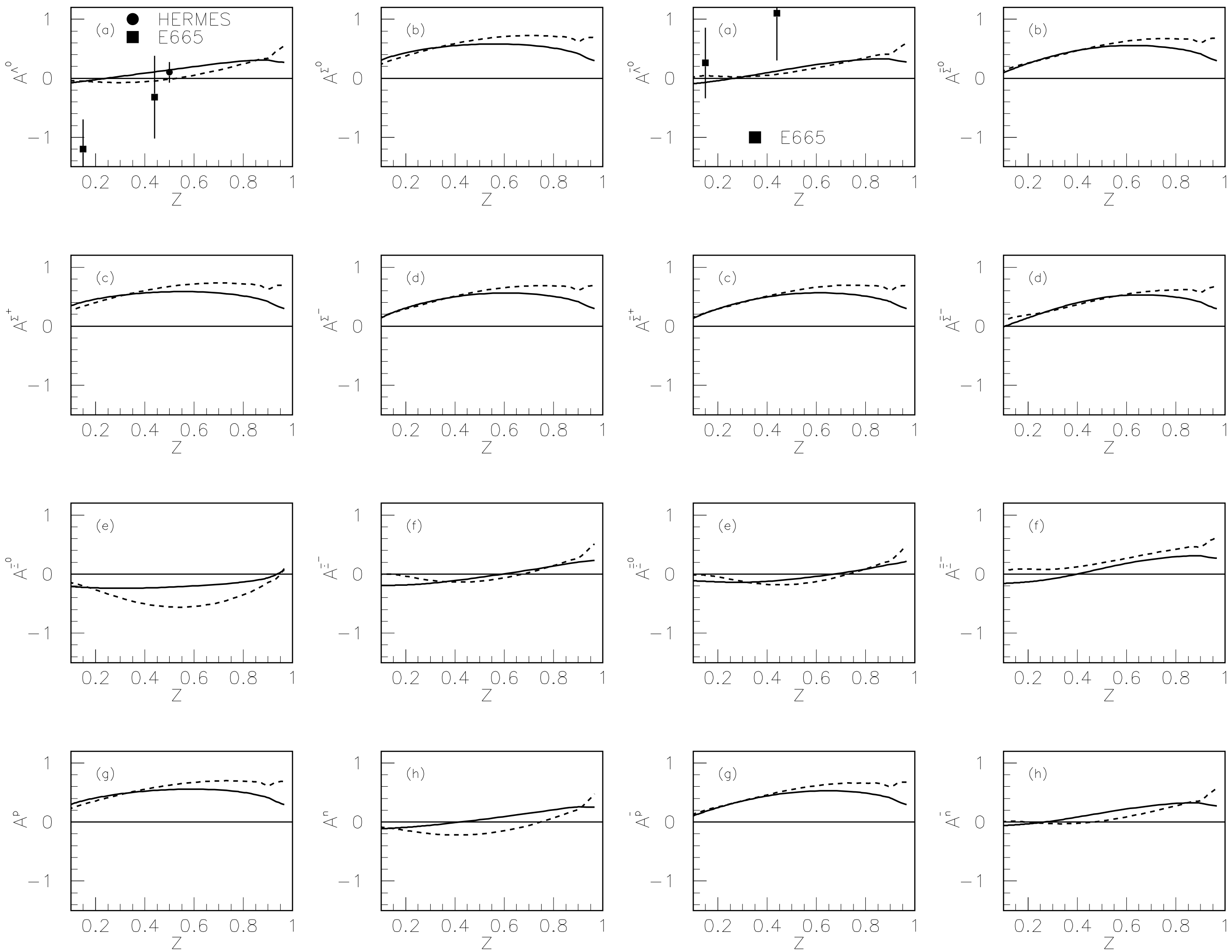


dotted line (pure valence), solid line (asymmetric sea), dashed line (symmetric sea)

Importance of neutrino DIS

ν and $\bar{\nu}$ DIS allow a quark flavor separation
B.-Q. Ma and J.S., Phys. Rev. Lett. 82,2250 (1999)
With four reactions $\nu p \to \mu \Lambda X$, $\bar{\nu} p \to \mu \Lambda X$, $\nu p \to \mu \bar{\Lambda} X$ and $\bar{\nu} p \to \mu \bar{\Lambda} X$ can extract four independent FF, D_u^Λ, $D_{\bar{u}}^\Lambda$, ΔD_u^Λ and $\Delta D_{\bar{u}}^\Lambda$.
A very powerful tool!

Spin transfer for B(right) and $\bar{B}$(left)



The PDF statistical model of C. Bourrely, F. Buccella and J.S.

- A Statistical Approach for Polarized Parton Distributions
  Euro. Phys. J. C23, 487 (2002)
- Recent Tests for the Statistical Parton Distributions
  Mod. Phys. Letters A 18, 771 (2003)
- The Statistical Parton Distributions: status and prospects
  Euro. Phys. J. C41, 327, (2005)

Basic procedure for the PDF

Use a simple description of the PDF, at input scale Q_0^2, proportional to $[\exp[(x - X_{0p})/\bar{x}] \pm 1]^{-1}$, *plus* sign for quarks and antiquarks, corresponds to a Fermi-Dirac distribution and *minus* sign for gluons, corresponds to a Bose-Einstein distribution. X_{0p} is a constant which plays the role of the *thermodynamical potential* of the parton *p* and $\bar{x}$ is the *universal temperature*, which is the same for all partons.

Explicit construction

(C.Bourrely and J. S., Phys. Rev. D 68, 014003 (2003))
For the quarks $q = u, s, d$ the FF $D_q^B(x, Q_0^2)$ are expressed as

$$D_q^B(x, Q_0^2) = \frac{A_q^B X_q^B x^b}{\exp[(x - X_q^B)/\bar{x}] + 1},$$

where X_q^B is the potential corresponding to the fragmentation $q \to B$ and Q_0^2 is an initial scale.

The heavy quark FF $D_Q^B(x, Q_0^2)$ for $Q = c, b, t$, which are expected to be large only in the small x region ($x \leq 0.1$ or so), are parametrized by a diffractive term with a vanishing potential

$$D_Q^B(x, Q_0^2) = \frac{\tilde{A}_Q^B x^{\tilde{b}}}{\exp(x/\bar{x}) + 1}.$$

First we have the obvious constraints, namely, $D_u^B = D_d^B$ for $B = p, \Lambda$. Moreover we assume that we need only four potentials, two for the proton $X_u^p = X_d^p$ and X_s^p and two for the hyperons $X_u^Y = X_d^Y$ and X_s^Y where $Y = \Lambda, \Sigma^{\pm}, \Xi^{-}$.

Finally for the gluon to baryon FF $D_g^B(x, Q^2)$, which is hard to determine precisely, we take a Bose-Einstein expression with a vanishing potential

$$D_g^B(x, Q_0^2) = \frac{A_g^B x^{\tilde{b}+1}}{\exp(x/\bar{x}) - 1}.$$

We assume it has the same small x behavior as the heavy quarks and it is the same for all baryons.

Table 1: Values of the normalization constants of the FF for the octet baryons

Baryon	q_1	q_2	$A^B_{q_1}$	$A^B_{q_2}$	$\tilde{A}^B_Q$
$p(uud)$	$u=d$	s	0.264	1.168	2.943
$\Lambda(uds)$	$u=d$	s	0.428	1.094	0.720
$\Sigma^+(uus)$	u	s	0.033	0.462	0.180
$\Sigma^-(dds)$	d	s	0.030	0.319	0.180
$\Xi^-(dss)$	d	s	0.023	0.082	0.072

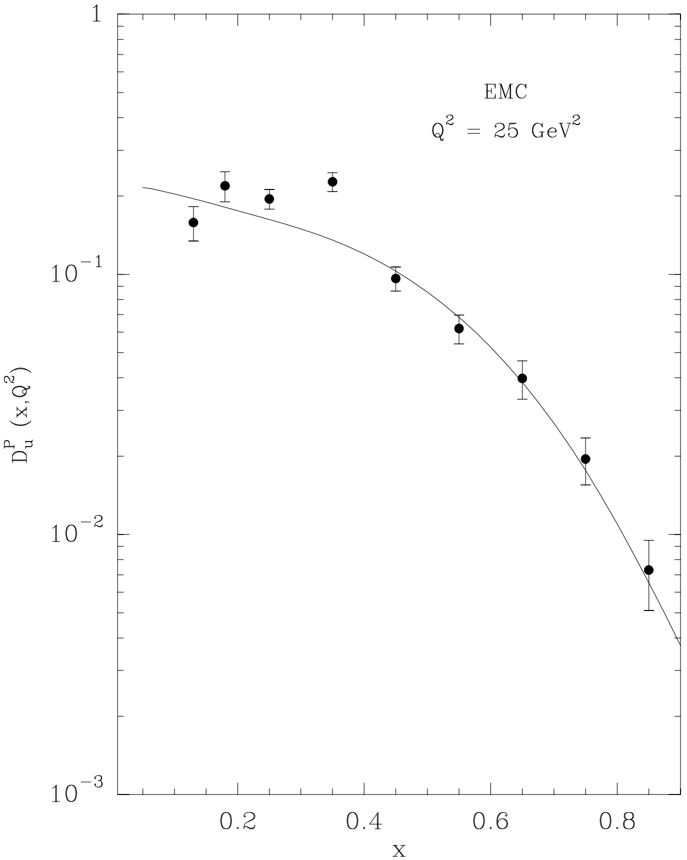
We took $\bar{x} = 0.099$ as determined earlier for the nucleon PDF

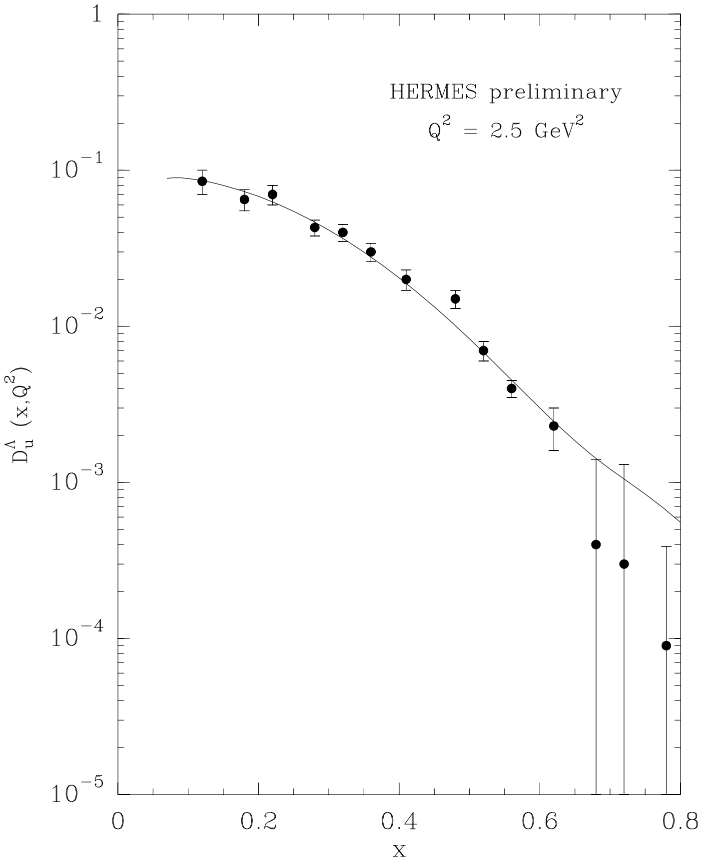
The values of the free parameters obtained from the NLO fit are

$$X_u^p = 0.648, \quad X_s^p = 0.247, \quad X_u^\Lambda = 0.296, \quad X_s^\Lambda = 0.476$$
$$b = 0.200, \quad \tilde{b} = -0.472, \quad A_g^B = 0.051.$$

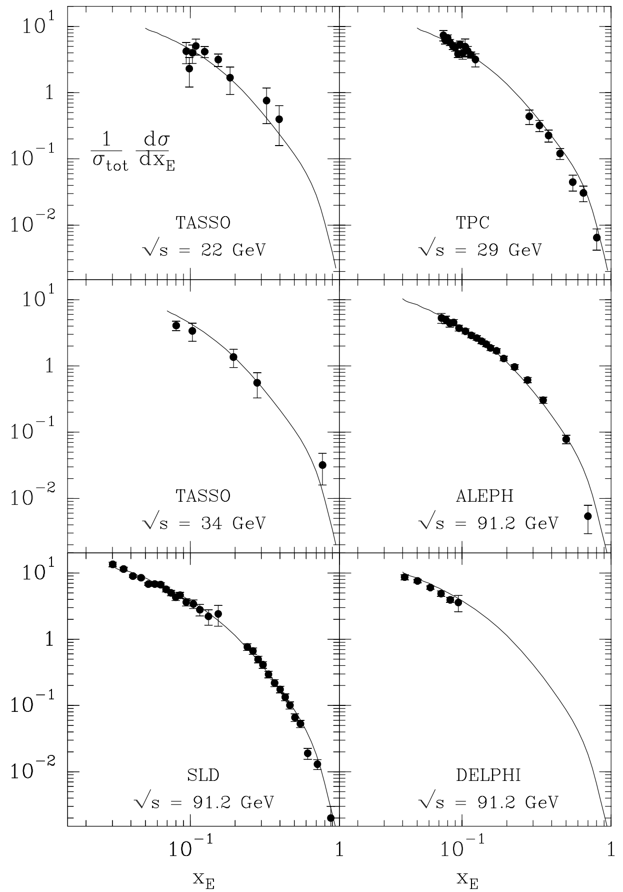
Notice that in the nucleon PDF the u quark which is dominant has the larger potential and here we have analogously, $X_u^p > X_s^p$ and $X_s^\Lambda > X_u^\Lambda$, a situation which is natural to expect. So the intrinsic properties of the quarks when observed in DIS or in fragmentation processes seem to be preserved.

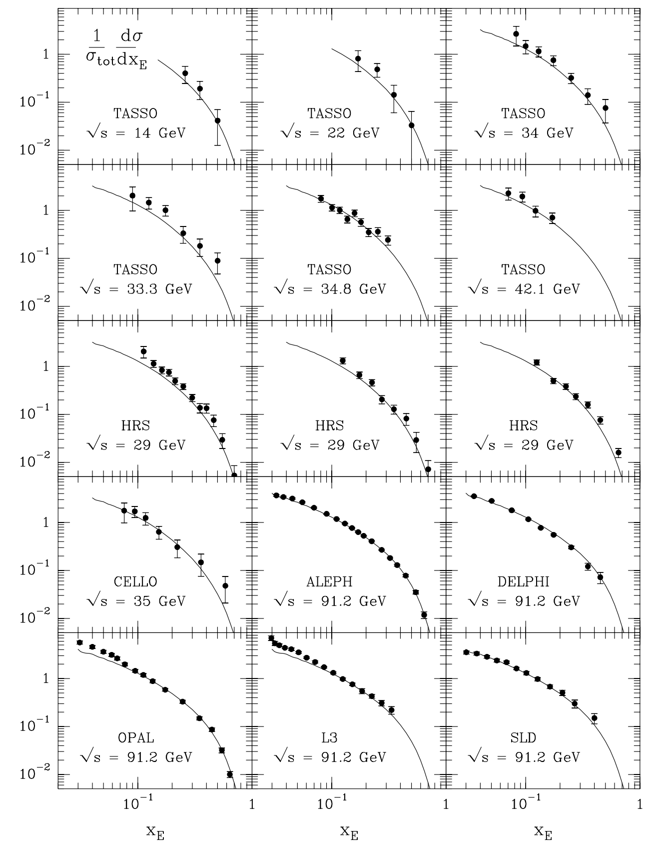
The FF for $u \to p$ and for $u \to \Lambda$ (versus x)



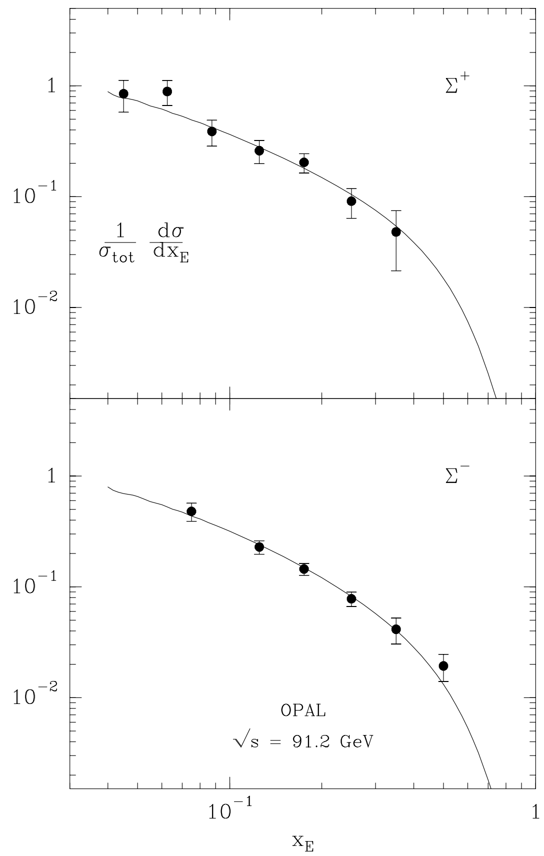


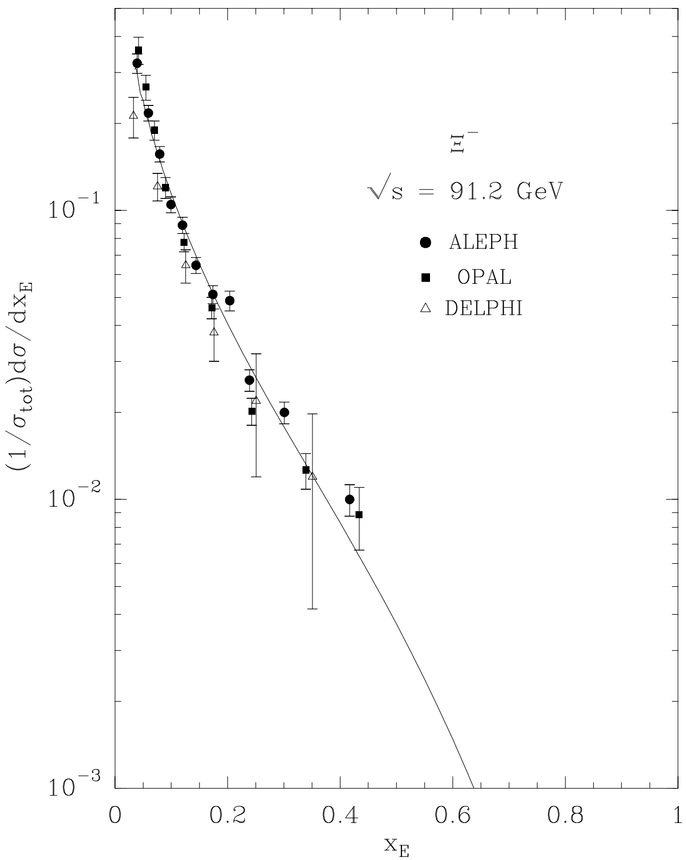
Cross sections for p and Λ production in e^+e^- annihilation



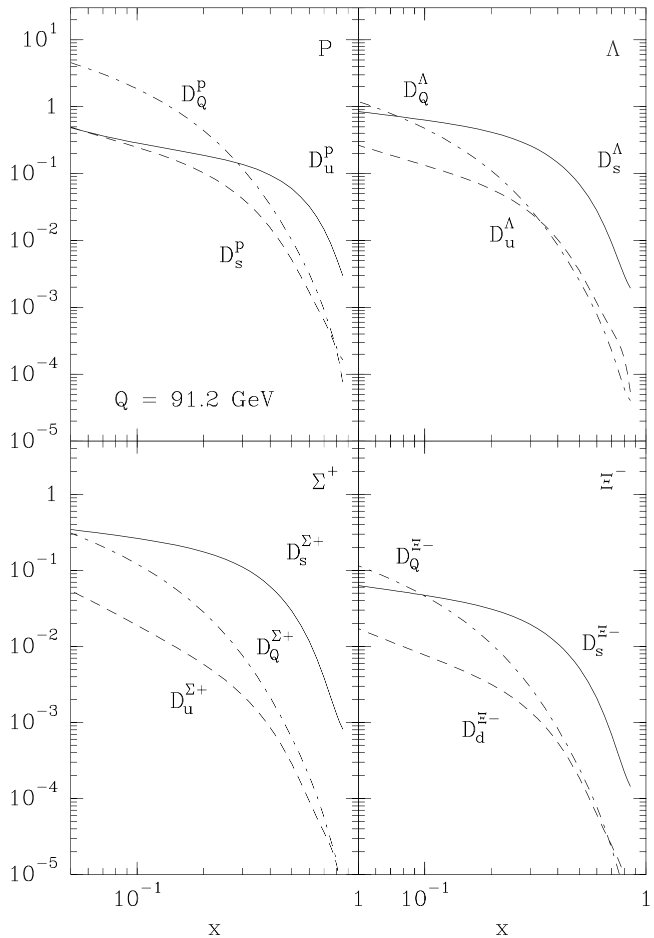


Cross sections for $\Sigma^\pm$ and Ξ^- production in e^+e^- annihilation





The quark to baryons FF $D_q^B(x,Q^2)$ and $D_Q^B(x,Q^2)$



Some comments

For all hyperons the strange quark FF dominates over the u, d quarks. For Λ, we agree with a model for SU(3) symmetry breaking (Indumathi et al.) which gives $D_u^\Lambda \sim 0.07 D_s^\Lambda$. In Boros et al. one also finds $D_u^\Lambda << D_s^\Lambda$ and $D_{\bar{q}}^\Lambda$ is strongly suppressed. This contrasts with De Florian et al. where u, d and s are assumed to be equal. However the heavy quarks have a pattern similar to De Florian et al., with a sizeable contribution only for $x \leq 0.1$ and a fast dropping off for large x.

Comments (cont.)

This is also at variance with J.J. Yang, where $D_u^\Lambda / D_s^\Lambda$ decreases from 1 to 0.2 when x goes from 0 to 1. For the proton it is surprizing to see that the u-quark FF dominates only at large x, whereas the strange and heavy quarks contribute substantially for $x \leq 0.3$ or so.

Conclusions

- FF are very relevant for better understanding of baryon structure
- Importance of semi-inclusive DIS to improve quark flavor separation
- Present situation: Λ unpolarized FF is known but need more data. Polarized FF poorly known
- Future prospects from Hermes, HERA, Compass and RHIC-BNL.