TRANSVERSE Λ POLARIZATION IN SEMI-INCLUSIVE DIS

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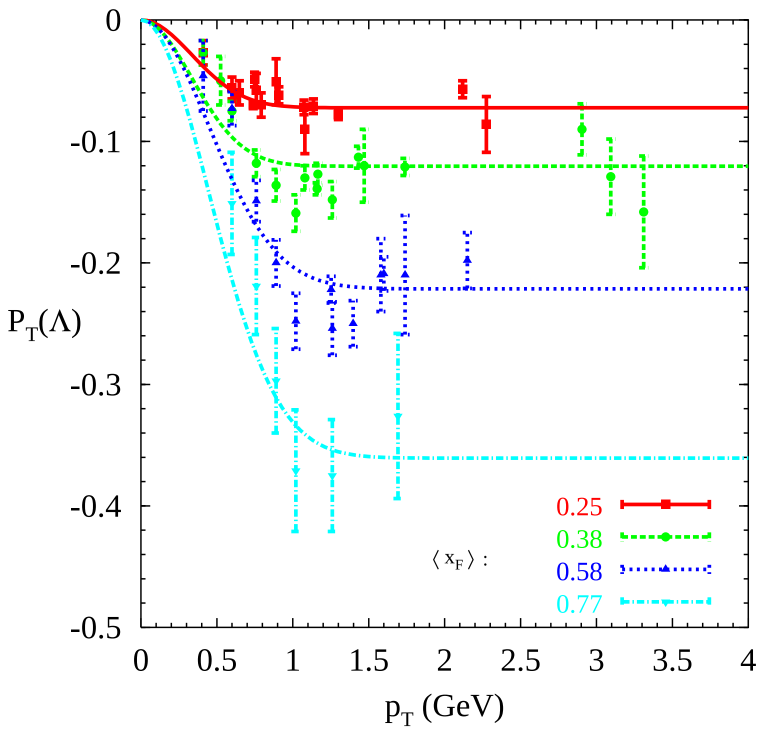
Outline:

- Transverse Λ polarization in unpolarized hadron collisions, $p\,p(A) \to \Lambda^\uparrow X$;
- The *polarizing fragmentation funct.* $\Delta^N D_{\Lambda^\uparrow/q}(z, k_T) = D_{\Lambda^\uparrow/q} - D_{\Lambda^\downarrow/q}\,[\,D_{1T}^\perp\,]$: a simple (gaussian) model for its explicit $\boldsymbol{k}_T$ - dependence;
- Applications: (preliminary) predictions for transv. Λ polarization in unpolarized (NC, CC) semi-inclusive DIS: $\ell(\nu)\,p \to \ell'\,\Lambda^\uparrow X, \quad \nu\,p \to \nu\,\Lambda^\uparrow X$;
- $P_T(\Lambda)$ with transversely polarized protons: access to $\Delta_T q\,(x)\,[\,h_1,\,\delta q\,]$;
- Conclusions and outlook;

Ref.s : M. Anselmino, D. Boer, UD, F. Murgia, PRD63 (2001) 054029; work in progress

pA - data: main features



A partial collection of experimental data for $P_T(\Lambda)$ in $p\,p(Be) \to \Lambda^{\uparrow} X$ vs. p_T and for different bins of x_F. The curves are just to guide the eye.

$|P_T(\Lambda)|$:

- is LARGE
- increases up to $p_T \sim 1$ GeV, where it flattens up to the highest measured p_T
- in this plateau regime increases linearly with x_F

$P_T(\bar{\Lambda})$ is compatible with zero

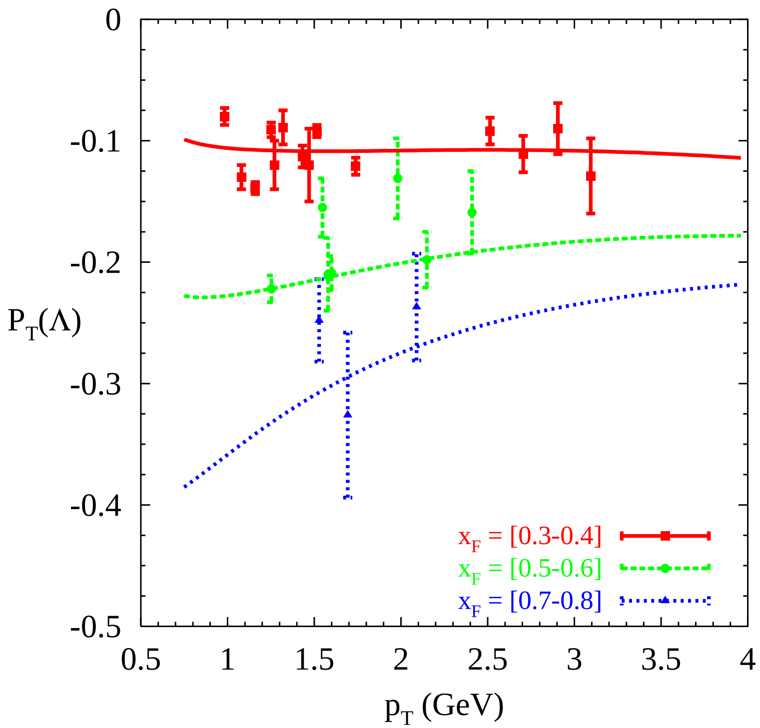
$P_T(\Lambda)$ in $p\,p(A) \to \Lambda^\uparrow\, X$

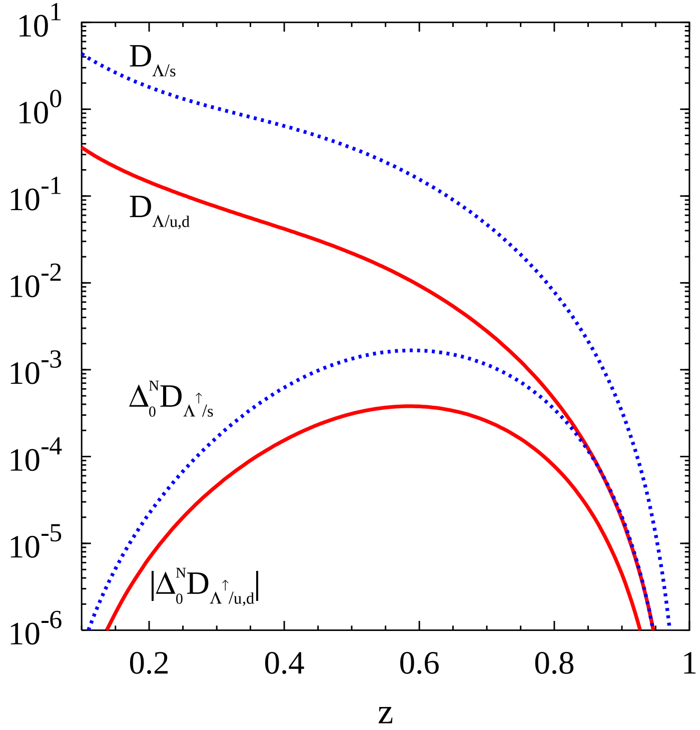
$$P_T^\Lambda(x_F, p_T) = \frac{d\sigma^{p\,p\to\,\Lambda^\uparrow\,X} - d\sigma^{p\,p\to\,\Lambda^\downarrow\,X}}{d\sigma^{p\,p\to\,\Lambda^\uparrow\,X} + d\sigma^{p\,p\to\,\Lambda^\downarrow\,X}}$$

$$= \frac{\sum \int dx_a\, dx_b \int d^2\boldsymbol{k}_{\perp c}\, f_{a/p}(x_a)\, f_{b/p}(x_b)\, d\hat\sigma(x_a, x_b; \boldsymbol{k}_{\perp c})\, \Delta^N D_{\Lambda^\uparrow/c}(z, \boldsymbol{k}_{\perp c})}{\sum \int dx_a\, dx_b \int d^2\boldsymbol{k}_{\perp c}\, f_{a/p}(x_a)\, f_{b/p}(x_b)\, d\hat\sigma(x_a, x_b; \boldsymbol{k}_{\perp c})\, D_{\Lambda/c}(z, \boldsymbol{k}_{\perp c})}$$

- Λ polarization entirely generated in the fragm. process, $q \to \Lambda^\uparrow + X$;
- Effective, inclusive Λ PFF (consistent with available sets of unpol. FF);
- $\int d^2\boldsymbol{k}_\perp F(\boldsymbol{k}_\perp) \Rightarrow F(k_\perp^0)$, where $k_\perp^0(z) \sim K\, z^a (1-z)^b$;
- Fit to exp. data $\Rightarrow$ parameterizations for $k_\perp^0(z)$ and $\Delta^N D_{\Lambda^\uparrow/q_v}(z, k_\perp^0)$;
  e.g. $k_\perp^0(z) = 0.66 z^{0.32}(1-z)^{0.5}$

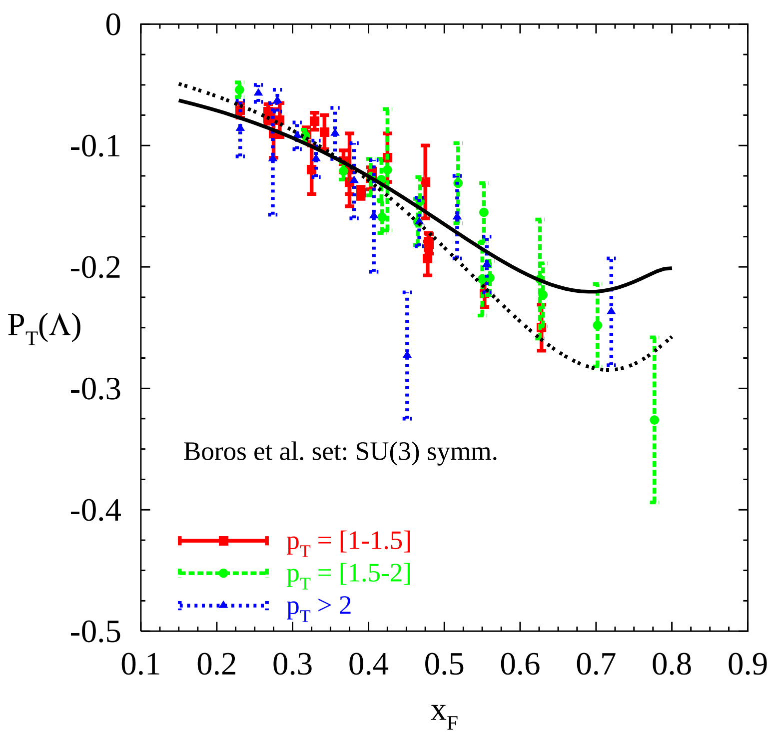
[Indumathi *et al.* and Boros *et al.* sets for unp. FF];

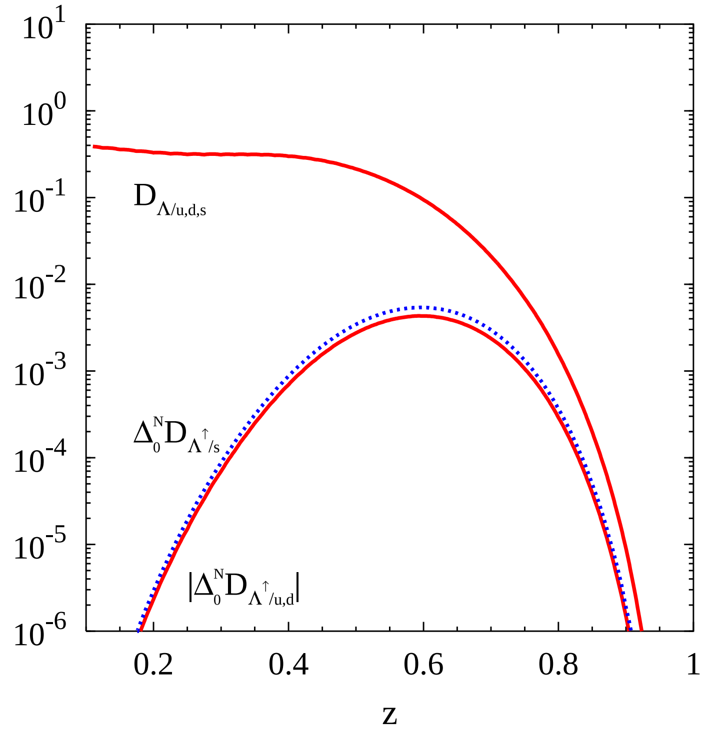




Best fit, obtained with a $SU(3)$ symmetry broken FF set (see plot on the right), to $P_T(\Lambda)$ data from $p-Be$ reactions, vs. p_T and for various x_F bins, at the c.m. energy $\sqrt{s} = 80$ GeV.

$|\Delta_0^N D_{\Lambda^\uparrow/u,d}|$ and $\Delta_0^N D_{\Lambda^\uparrow/s}$, as given by our best fit parameters, compared to the Indumathi *et al.* unpolarized FF, $D_{\Lambda/u,d}$ and $D_{\Lambda/s}$. Notice that $\Delta_0^N D_{\Lambda^\uparrow/u,d}$ is negative.





Best fit, obtained with a $SU(3)$ symmetric FF set (see plot on the right), to $P_T(\Lambda)$ data from $p-Be$ reactions, vs. x_F and for various p_T bins, at $\sqrt{s} = 80$ GeV. The two theoretical curves correspond to $p_T = 1.5$ GeV (dotted) and $p_T = 3$ GeV (solid).

$|\Delta_0^N D_{\Lambda^\uparrow/u,d}|$ and $\Delta_0^N D_{\Lambda^\uparrow/s}$, as given by our best fit parameters, compared to the Boros *et al.* unpolarized FF, $D_{\Lambda/u,d} = D_{\Lambda/s}$. Notice that $\Delta_0^N D_{\Lambda^\uparrow/u,d}$ is negative.

$D_{\Lambda/q}(z, \boldsymbol{k}_\perp)$ and $\Delta^N D_{\Lambda^\uparrow/q}(z, \boldsymbol{k}_\perp)$: gaussian parameterizations

- Define: $D_{\Lambda/q}(z, k_\perp) = \frac{d(z)}{M^2}\, \exp\left[-\frac{k_\perp^{\,2}}{M^2 f(z)}\right]$;

  $\Delta^N D_{\Lambda^\uparrow/q}(z, \boldsymbol{k}_\perp) = \frac{\delta(z)}{M^2}\, \frac{k_\perp}{M}\, \exp\left[-\frac{k_\perp^{\,2}}{M^2 \varphi(z)}\right] \sin\phi;$

  where ϕ is the angle between the spin and $\boldsymbol{k}_\perp$ of Λ

- Require:

▶ $\int d^2k_\perp \left[k_\perp^{\,2}\right] D_{\Lambda/q}(z, k_\perp) = \left[\langle k_\perp^{\,2}(z)\rangle\right] D_{\Lambda/q}(z) \quad \Rightarrow$ fix $d(z), f(z)$;

▶ $|\Delta^N D_{\Lambda^\uparrow/q}(z, \boldsymbol{k}_\perp)| \,/\, D_{\Lambda/q}(z, k_\perp) \leq 1, \;\forall\, z$ and $\boldsymbol{k}_\perp$; $\Rightarrow \quad \varphi(z) < f(z)$;

▶ + Consistency with approx.s and parameterizations adopted for $p\,p \to \Lambda^\uparrow + X$;

$$\int d^2\boldsymbol{k}_\perp F(\boldsymbol{k}_\perp) \simeq F(k_\perp^0) \Longrightarrow \begin{array}{rl} k_\perp^0(z) & \Leftrightarrow f(z), \varphi(z) \\ \Delta_0^N D_{\Lambda^\uparrow/q}(z, k_\perp^0) & \Leftrightarrow \delta(z) \end{array}$$

More precisely we have:

- $D_{\Lambda/q}(z, k_\perp) = \frac{D_{\Lambda/q}(z)}{2\pi[k_\perp^0(z)]^2} \exp\left[-\frac{k_\perp^2}{2[k_\perp^0(z)]^2}\right];$
- $\Delta^N D_{\Lambda^\uparrow/q_v}(z, k_\perp) = \Delta_0^N D_{\Lambda^\uparrow/q_v}(z, k_\perp^0)\, \frac{2}{\sqrt{\pi}}\, \frac{k_\perp}{[k_\perp^0(z)]^3} \exp\left[-\frac{k_\perp^2}{[k_\perp^0(z)]^2}\right];$

▶ The factor 2 comes from consistency with the approach in $p\,A$ case;

▶ Simple relation between our "effective" $k_\perp^0(z)$ and the physical $\langle k_\perp^2(z)\rangle$ of the Λ inside the jet:

$$\langle k_\perp^2(z)\rangle = 2\,[k_\perp^0(z)]^2$$

▶ Positivity constraint reads:

$$|\Delta_0^N D_{\Lambda^\uparrow/q_v}(z, k_\perp^0)| \,/\, [D_{\Lambda/q}(z)/2] \leq \frac{\sqrt{e}}{2\sqrt{\pi}} \simeq 0.465$$

[fulfilled by the original parameterizations obtained in $p\,A \to \Lambda^\uparrow X$]

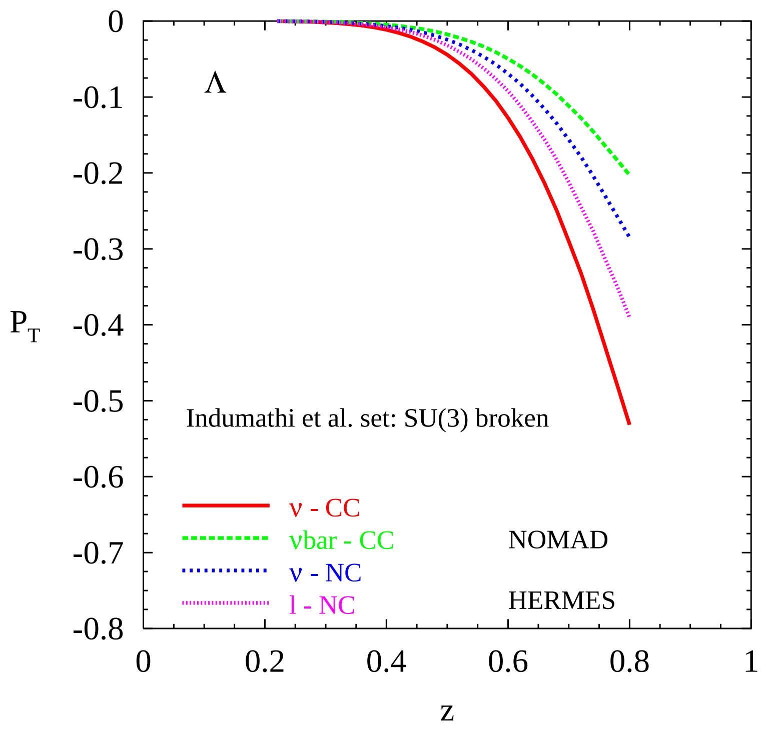
$P_T^\Lambda(x, y, z, \boldsymbol{p}_T)$ in unpolarized semi-inclusive DIS $(x_F > 0)$

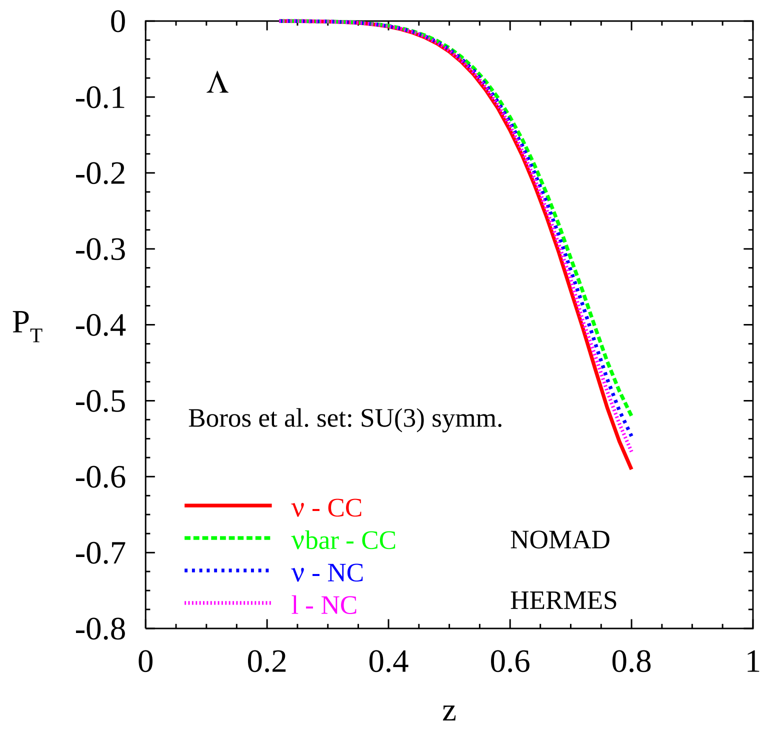
In the virtual boson - proton c.m. frame [$\hat{z}$-axis along the virt. boson direction; $\hat{x}$-axis along the hadron $\boldsymbol{k}_\perp \equiv \boldsymbol{p}_T$; $\uparrow$ along the $+\hat{y}$-axis and $\phi = \pi/2$]

In the region $z > 0.2$ where $D_{\Lambda/\bar{q}} \simeq 0$ and $\Delta^N D_{\Lambda^\uparrow/\bar{q}} \simeq 0$ (= 0 in our model), we have:

- $\nu\, p \to \ell^-\, \Lambda^\uparrow\, X \qquad P_T^\Lambda \simeq \dfrac{(d+R\,s)\,\Delta^N D_{\Lambda^\uparrow/u}}{(d+R\,s)\,D_{\Lambda/u}}$
- $\bar{\nu}\, p \to \ell^+\, \Lambda^\uparrow\, X \qquad P_T^\Lambda \simeq \dfrac{(1-y)^2 u\,(\Delta^N D_{\Lambda^\uparrow/u} + R\,\Delta^N D_{\Lambda^\uparrow/s})}{(1-y)^2 u\,(D_{\Lambda/u} + R\,D_{\Lambda/s})}$
- $\nu\, p \to \nu\, \Lambda^\uparrow\, X \qquad P_T^\Lambda \simeq \dfrac{(K\,u+d)\,\Delta^N D_{\Lambda^\uparrow/u} + s\,\Delta^N D_{\Lambda^\uparrow/s}}{(K\,u+d)\,D_{\Lambda/u} + s\,D_{\Lambda/s}}$
- $\ell\, p \to \ell'\, \Lambda^\uparrow\, X \qquad P_T^\Lambda \simeq \dfrac{(4u+d)\,\Delta^N D_{\Lambda^\uparrow/u} + s\,\Delta^N D_{\Lambda^\uparrow/s}}{(4u+d)\,D_{\Lambda/u} + s\,D_{\Lambda/s}}$

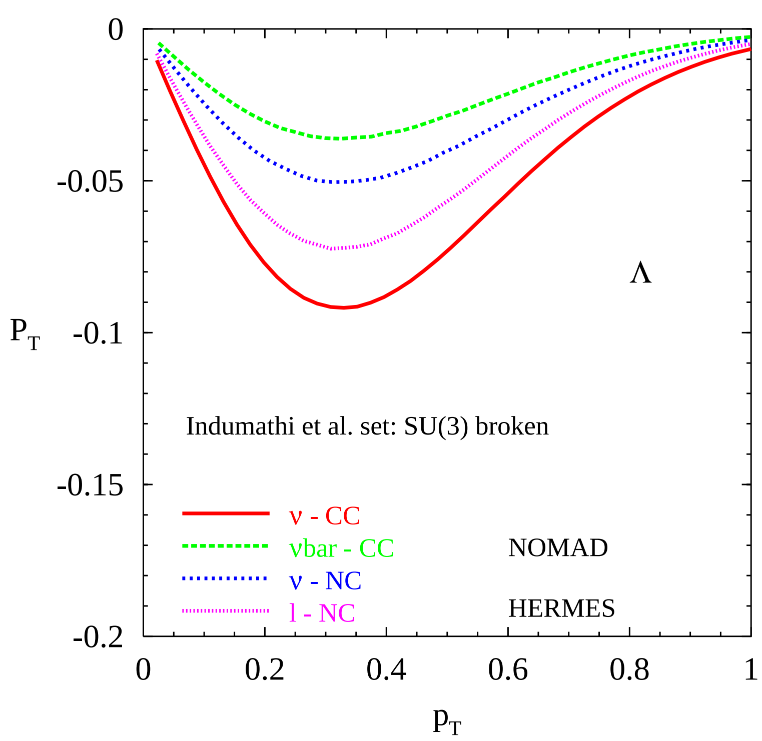
where $R = \tan^2\theta_c \simeq 0.056$ and $K \simeq 0.555$.

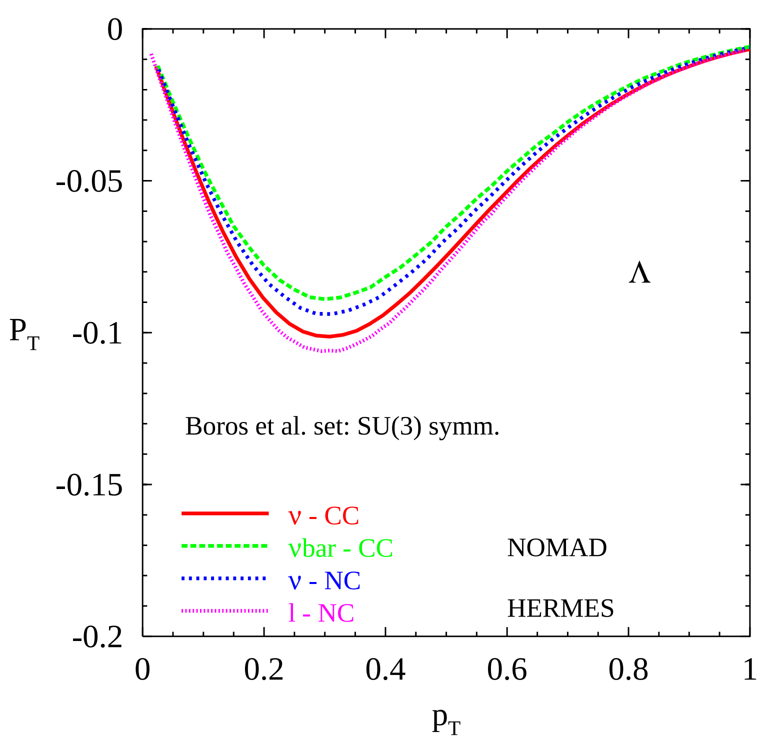




Preliminary predictions for $P_T(\Lambda)$ vs. z, integrated over p_T, with a $SU(3)$ symmetry broken (on the left) and a $SU(3)$ symmetric (on the right) set of unpolarized and polarizing FF for different semi-inclusive DIS processes.

HERMES kin.: $0.023 \leq x \leq 0.8$, $y \leq 0.85$, $1 \leq Q^2 \leq 24$ (in GeV^2), $W^2 \geq 4$ GeV^2;
NOMAD kin.: $\langle E_\nu \rangle = 48.8$ GeV; $\langle Q^2 \rangle \simeq 9$ GeV^2; $\langle x \rangle = 0.22$.





Preliminary predictions for $P_T(\Lambda)$ vs. p_T, integrated over $0.4 < z < 0.8$, with a $SU(3)$ symmetry broken (on the left) and a $SU(3)$ symmetric (on the right) set of unpolarized and polarizing FF for different semi-inclusive processes.

HERMES kin.: $0.023 \leq x \leq 0.8$, $y \leq 0.85$, $1 \leq Q^2 \leq 24$ (in GeV^2), $W^2 \geq 4$ GeV^2;

NOMAD kin.: $\langle E_\nu \rangle = 48.8$ GeV; $\langle Q^2 \rangle \simeq 9$ GeV^2; $\langle x \rangle = 0.22$.

$P_T^\Lambda(x, y, z, \boldsymbol{p}_T)$ in polarized semi-inclusive DIS $(x_F > 0)$

$$\ell\, p^\uparrow \to \ell' \Lambda^\uparrow(\boldsymbol{p}_T) + X \qquad P_T = \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}}$$

$$\begin{aligned} d\sigma^{\uparrow\uparrow} &= \sum_q \{ f_{q^\uparrow/p^\uparrow} [d\hat\sigma^{\ell q^\uparrow \to \ell q^\uparrow} \hat D_{\Lambda^\uparrow/q^\uparrow}(\boldsymbol{p}_T) + d\hat\sigma^{\ell q^\uparrow \to \ell q^\downarrow} \hat D_{\Lambda^\uparrow/q^\downarrow}(\boldsymbol{p}_T)] \\ &+ f_{q^\downarrow/p^\uparrow} [d\hat\sigma^{\ell q^\downarrow \to \ell q^\uparrow} \hat D_{\Lambda^\uparrow/q^\uparrow}(\boldsymbol{p}_T) + d\hat\sigma^{\ell q^\downarrow \to \ell q^\downarrow} \hat D_{\Lambda^\uparrow/q^\downarrow}(\boldsymbol{p}_T)\} \end{aligned}$$

$$\begin{aligned} [d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}](\boldsymbol{p}_T) &= \frac{1}{2} \sum_q \{ q\, d\hat\sigma\, [\Delta_T D_{\Lambda/q}(+\boldsymbol{p}_T) - \Delta_T D_{\Lambda/q}(-\boldsymbol{p}_T)] \\ &+ \Delta_T q\, \Delta_N \hat\sigma\, [\Delta_T D_{\Lambda/q}(+\boldsymbol{p}_T) + \Delta_T D_{\Lambda/q}(-\boldsymbol{p}_T)]\} \end{aligned}$$

$\Delta_T D_{\Lambda/q}(\boldsymbol{p}_T) \equiv \hat D_{\Lambda^\uparrow/q^\uparrow}(\boldsymbol{p}_T) - \hat D_{\Lambda^\downarrow/q^\uparrow}(\boldsymbol{p}_T)$ and $\Delta_T q \equiv f_{q^\uparrow/p^\uparrow} - f_{q^\downarrow/p^\uparrow}$

$d\hat\sigma \equiv d\hat\sigma^{q^\uparrow \to q^\uparrow} + d\hat\sigma^{q^\uparrow \to q^\downarrow}$; $\Delta_N \hat\sigma \equiv d\hat\sigma^{q^\uparrow \to q^\uparrow} - d\hat\sigma^{q^\uparrow \to q^\downarrow}$.

On the other hand we have:

$$
\begin{aligned}
\Delta_T D_{\Lambda/q}(+\boldsymbol{p}_T) - \Delta_T D_{\Lambda/q}(-\boldsymbol{p}_T)
&= [\hat{D}_{\Lambda^\uparrow/q^\uparrow}(+\boldsymbol{p}_T) - \hat{D}_{\Lambda^\downarrow/q^\uparrow}(+\boldsymbol{p}_T)] - [\hat{D}_{\Lambda^\uparrow/q^\uparrow}(-\boldsymbol{p}_T) - \hat{D}_{\Lambda^\downarrow/q^\uparrow}(-\boldsymbol{p}_T)] \\
&= [\hat{D}_{\Lambda^\uparrow/q^\uparrow}(+\boldsymbol{p}_T) - \hat{D}_{\Lambda^\downarrow/q^\uparrow}(+\boldsymbol{p}_T)] - [\hat{D}_{\Lambda^\downarrow/q^\downarrow}(+\boldsymbol{p}_T) - \hat{D}_{\Lambda^\uparrow/q^\downarrow}(+\boldsymbol{p}_T)] \\
&= 2\,\hat{D}_{\Lambda^\uparrow/q}(\boldsymbol{p}_T) - 2\,\hat{D}_{\Lambda^\downarrow/q}(\boldsymbol{p}_T) = 2\,\Delta^N D_{\Lambda^\uparrow/q}(\boldsymbol{p}_T)
\end{aligned}
$$

▶ $$
\begin{aligned}
[d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}](\boldsymbol{p}_T) = \sum_q \{ & q\, d\hat{\sigma}\, \Delta^N D_{\Lambda^\uparrow/q}(\boldsymbol{p}_T) \\
& + \Delta_T q\, \Delta_N \hat{\sigma} [\Delta_T D_{\Lambda/q}(+\boldsymbol{p}_T) + \Delta_T D_{\Lambda/q}(-\boldsymbol{p}_T)]/2 \}
\end{aligned}
$$

- for unpolarized p $\quad \Delta_T q \equiv 0 \quad \Rightarrow \quad \sum_q q\, d\hat{\sigma}\, \Delta^N D_{\Lambda^\uparrow/q}(\boldsymbol{p}_T)$
- for ν-CC processes $\Delta_N \hat{\sigma} \equiv 0 \quad \Rightarrow \quad \sum_q q\, d\hat{\sigma}\, \Delta^N D_{\Lambda^\uparrow/q}(\boldsymbol{p}_T)$
- if integrated over $\boldsymbol{p}_T$ $\quad \Rightarrow \quad \sum_q q\, \Delta_T q\, \Delta_N \hat{\sigma}\, \Delta_T D_{\Lambda/q}$

[M. Anselmino, M. Boglione, F. Murgia, PLB 481 (2000) 253]

Conclusions and outlook

- PFF $\Delta_0^N D_{\Lambda^\uparrow/q}(z, \langle k_\perp \rangle)$: good description of transverse Λ, $\bar{\Lambda}$ polarization in $p\,A \to \Lambda^\uparrow X$;
- Parameterizations for the PFF to extrapolate a consistent, gaussian $k_\perp$- dependence for $\Delta^N D_{\Lambda^\uparrow/q}(z, k_\perp)$;
- *Preliminary* predictions for P_T^Λ in unpolarized semi-inclusive DIS ($x_F > 0$): importance of a comparison of different processes (CC vs. NC);
- P_T^Λ in polarized SI-DIS to access $\Delta_T q$ and/or to disentangle $\Delta^N D_{\Lambda^\uparrow/q}$ effects;
- Improvements (in progress) from a more detailed treatment of (not averaged) $k_\perp$- dependence in $p\,A \to \Lambda^\uparrow X$, where a large amount of data is available;
- More data on semi-inclusive DIS to test the z and $k_\perp$- dependence of PFF.