Transverse Λ polarization at high energy colliders

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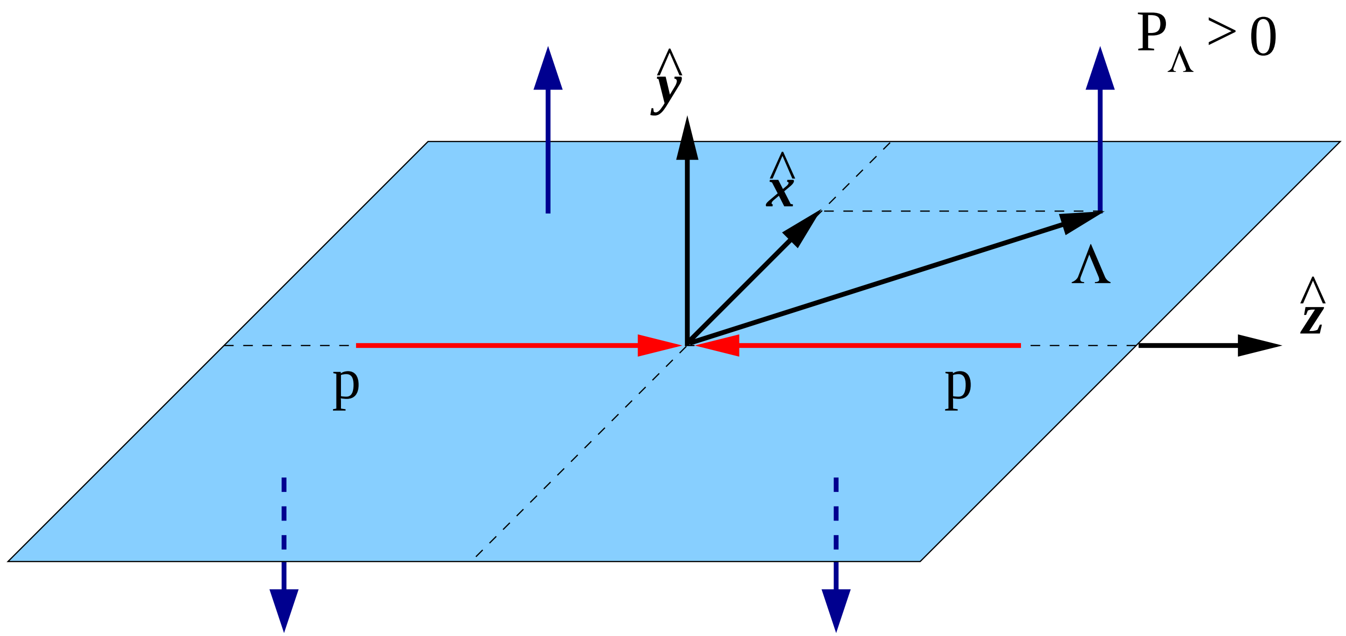
Outline

- Brief review of transverse Λ polarization in $p + p \to \Lambda^{\uparrow} + X$
- Possible underlying mechanism in the intermediate to high $\boldsymbol{p}_T$ region:
  transverse momentum and spin dependence in the fragmentation process
- Suggestions for investigations at high energy colliders:
  - $p + p/\bar{p} \to \Lambda^{\uparrow} + \text{jet} + X$ at midrapidity
  - $p + p/A \to \Lambda^{\uparrow} + X$ at forward rapidity
- Comments on high energy hadron collider data and the role of gluons

Transverse Λ polarization in unpolarized scattering

Large asymmetries have been observed in $p + p \to \Lambda^{\uparrow} + X$

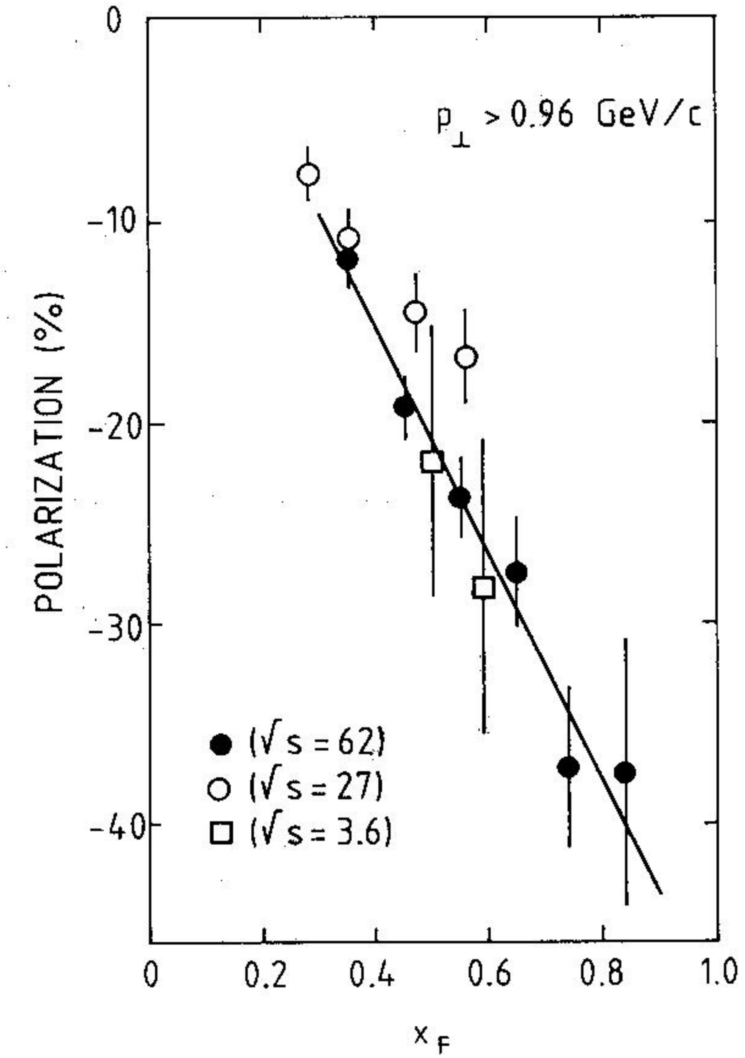
G. Bunce *et al.*, PRL 36 (1976) 1113



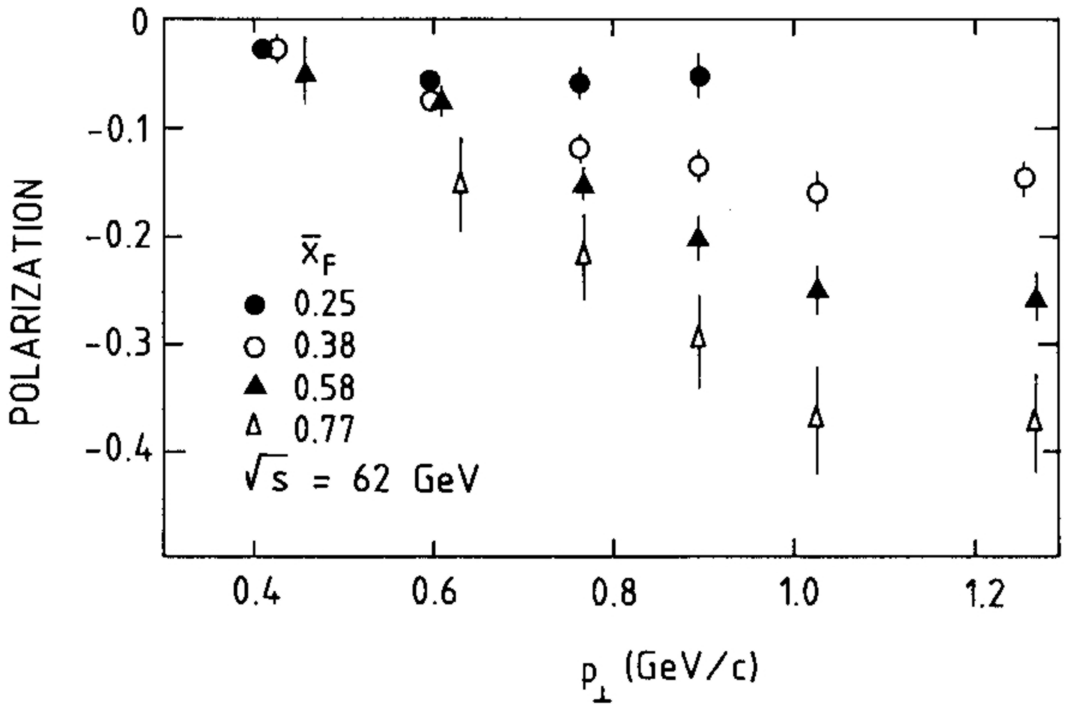
Blue arrows indicate the direction of positive transverse (w.r.t. production plane) polarization P_Λ, in the four quadrants

For symmetry reasons $P_\Lambda = 0$ at midrapidity

Generic $p\,p$ data - x_F and p_T dependence

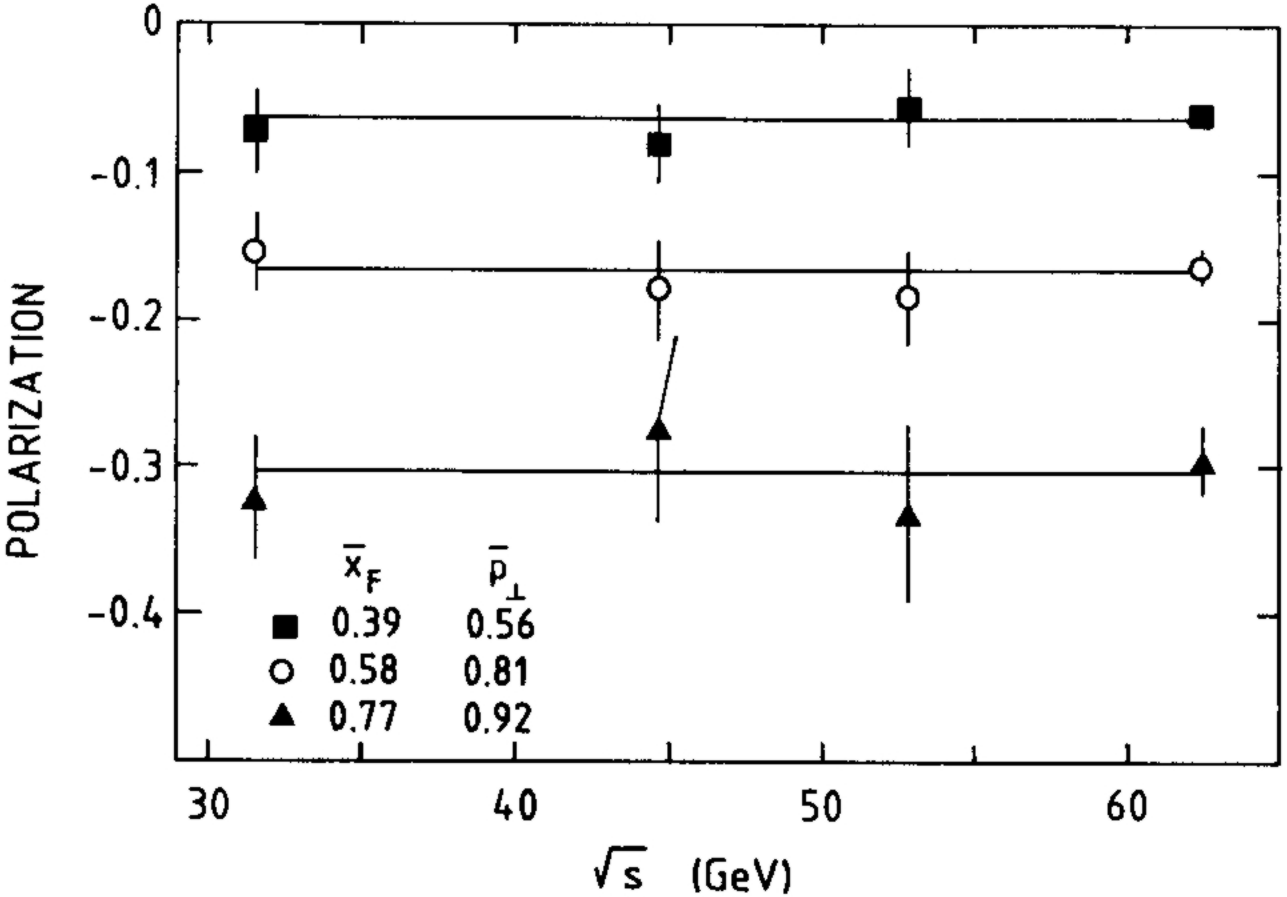


P_Λ turns out to be negative



For p_T above 1 GeV/c P_Λ becomes flat (measured up to $p_T \sim 4$ GeV/c)

Generic $p\,p$ data - $\sqrt{s}$ (in)dependence



Comprehensive review of data by A.D. Panagiotou (Int.J.Mod.Phys.A 5 (1990) 1197)

Theoretical considerations

Most models give qualitative descriptions of the data for $p_T \lesssim 1 - 2\,\text{GeV}/c$

E.g. the DeGrand-Miettinen model
PRD 23 (1981) 1227 & 24 (1981) 2419

P_Λ stays large at least until the highest measured $p_T \sim 4$ GeV$/c$

For large p_T perturbative QCD and collinear factorization should apply

pQCD conserves helicity, which leads to $P_\Lambda \sim \alpha_s m_q/\sqrt{\hat{s}}$ (= small)
Kane, Pumplin & Repko, PRL 41 (1978) 1689

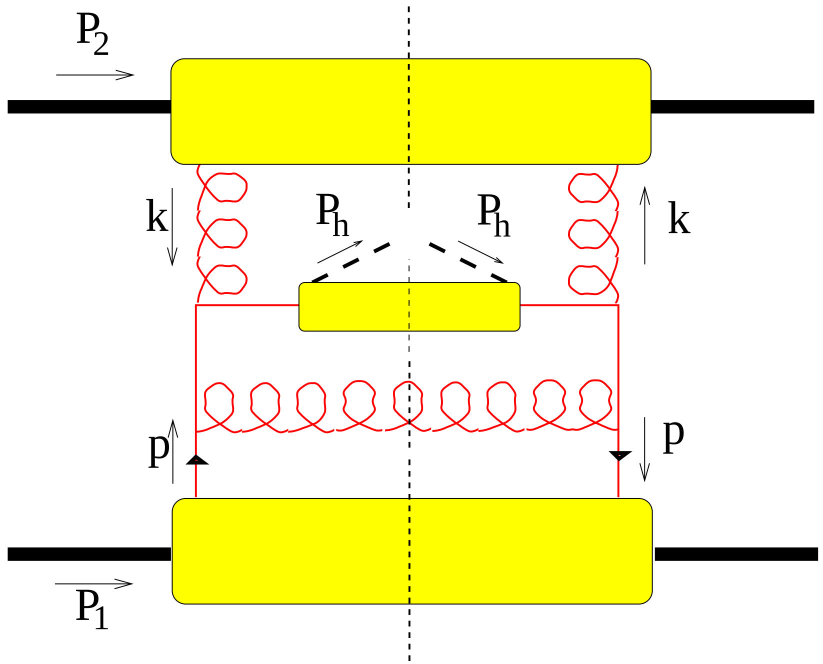
Collinear factorization

Consider for example the $qg \to qg$ subprocess

$$\sigma \sim q(x_1) \otimes g(x_2) \otimes \hat{\sigma}_{qg\to qg} \otimes D_{\Lambda/q}(z)$$

$$q(x_1) = \text{quark density}$$
$$g(x_2) = \text{gluon density}$$
$$D_{\Lambda/q}(z) = \Lambda \text{ fragmentation function}$$

$$P_\Lambda \sim q(x_1) \otimes g(x_2) \otimes \hat{\sigma}_{qg\to qg} \otimes ?$$

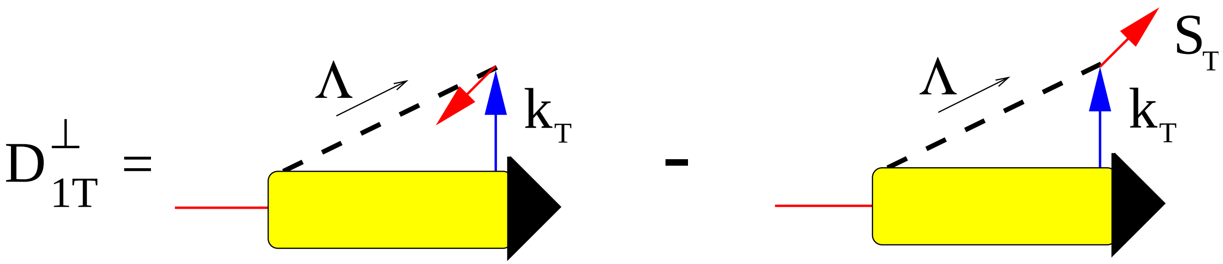


No leading twist collinear fragmentation function exists for $q \to \Lambda^\uparrow X$
(due to symmetry reasons)

Would be necessarily higher twist, which leads to a fall-off as $1/p_T$

Noncollinear factorization

Dropping the requirement of *collinear* factorization, does allow for a solution



Mulders & Tangerman, NPB 461 (1996) 197

- Transverse momentum dependent: $D_{1T}^{\perp}(z, \boldsymbol{k}_T)$
- A nonperturbative $\boldsymbol{k}_T \times \boldsymbol{S}_T$ dependence in the fragmentation process
- Allowed by the symmetries (parity and time reversal)

Λ polarization arises in the fragmentation of an *unpolarized* quark

Hence, the suggested name "polarizing fragmentation function"

Polarizing fragmentation functions

$D_{1T}^{\perp}$ has been extracted from fixed target $p + p(Be) \to \Lambda^{\uparrow}(\bar{\Lambda}^{\uparrow}) + X$ data

Anselmino, D.B., D'Alesio & Murgia, PRD 63 (2001) 054029

Unpolarized FF used include:

- De Florian, Stratmann, Vogelsang [DSV] (PRD 57 (1998) 5811)
- Indumathi, Mani, Rastogi [IMR] (PRD 58 (1998) 094014)

Both use e^+e^- data only and IMR includes $SU(3)$ breaking

Resulting $D_{1T}^{\perp}$ has opposite signs for u, d versus s quarks; the latter is larger

This leads to cancellations in order that $P_{\bar{\Lambda}} \approx 0$

Extraction done under the restriction of $p_T > 1$ GeV$/c$ to exclude the soft regime

Whether this is sufficient to ensure the validity of the description is a matter of concern

Despite that reasonable functions are obtained

High energy hadron collider data?

Validity of factorized description depends on a proper cross section description
This requires data at higher energies and higher p_T

Available data is from experiments with $\sqrt{s} \leq 62$ GeV, requiring large K factors

Why no $\Lambda^\uparrow$ data from high energy hadron colliders, such as RHIC or Tevatron?

Capabilities to measure Λ polarization via $\Lambda \to p\,\pi^-$ are usually restricted to the midrapidity region, where the degree of transverse polarization is very small

$P_\Lambda = 0$ at $\eta = 0$ in $p\,p$ collisions in cms

Alternative: consider jet+Λ production: $p\,p \to (\Lambda^\uparrow \text{jet})\ \text{jet}\,X$
Such an asymmetry does not need to vanish at $\eta = 0$

D.B., Bomhof, Hwang & Mulders, PLB 659 (2008) 127; D.B., arXiv:0907.1610

Jet+Λ production

Consider two jets, with momenta K_j and $K_{j'}$, such that $K_j \cdot K_{j'} = \mathcal{O}(\hat{s})$

The Λ is part of one of the two jets, and has momentum K_Λ and polarization S_Λ

An asymmetry can arise that is proportional to:

$$\epsilon_{\mu\nu\alpha\beta} K_j^\mu K_{j'}^\nu K_\Lambda^\alpha S_\Lambda^\beta$$

In principle, it is not power suppressed, nor needs to vanish at $\eta = 0$

In the center of mass frame of the two jets the asymmetry is of the form:

$$\text{SSA} = \frac{d\sigma(+\boldsymbol{S}_\Lambda) - d\sigma(-\boldsymbol{S}_\Lambda)}{d\sigma(+\boldsymbol{S}_\Lambda) + d\sigma(-\boldsymbol{S}_\Lambda)} = \frac{\hat{\boldsymbol{K}}_j \cdot (\boldsymbol{K}_\Lambda \times \boldsymbol{S}_\Lambda)}{z\, M_\Lambda} \frac{d\sigma_T}{d\sigma_U}$$

$d\sigma_T / d\sigma_U$ depends on $D_{1T}^\perp$

Jet+Λ production

The process $p\,p \to (\Lambda^{\uparrow}\text{jet})\ \text{jet}\,X$ can be studied at RHIC and LHC

For instance, ALICE can measure Λ's over a wide p_T range,

in a typical yearly run at least up to 16 GeV/c

Rapidity coverage of ALICE: $-0.9 \leq \eta \leq +0.9$

For jet rapidities in this kinematic region, the cross section is dominated by gluon-gluon ($gg \to gg$) scattering, *if* gluons fragmenting into Λ's are as important as quarks

This leads to

$$\frac{d\sigma_T}{d\sigma_U} \approx \frac{D_{1T}^{\perp\,g}(z, K_{\Lambda\,T}^2)}{D_1^g(z, K_{\Lambda\,T}^2)}$$

No model or fit for $D_{1T}^{\perp\,g}$ is available yet, so no predictions can be made in this case

Fit of $D_{1T}^{\perp}$ to $p\,p \to \Lambda^{\uparrow}\,X$ data not sensitive to $g \to \Lambda\,X$

Jet+Λ production at the LHC

If it happens that $D_{1T}^{\perp\, g} \ll D_{1T}^{\perp\, q}$, then one finds for $\eta_{j'} \approx -\eta_j$ $(x \equiv x_1 \approx x_2)$

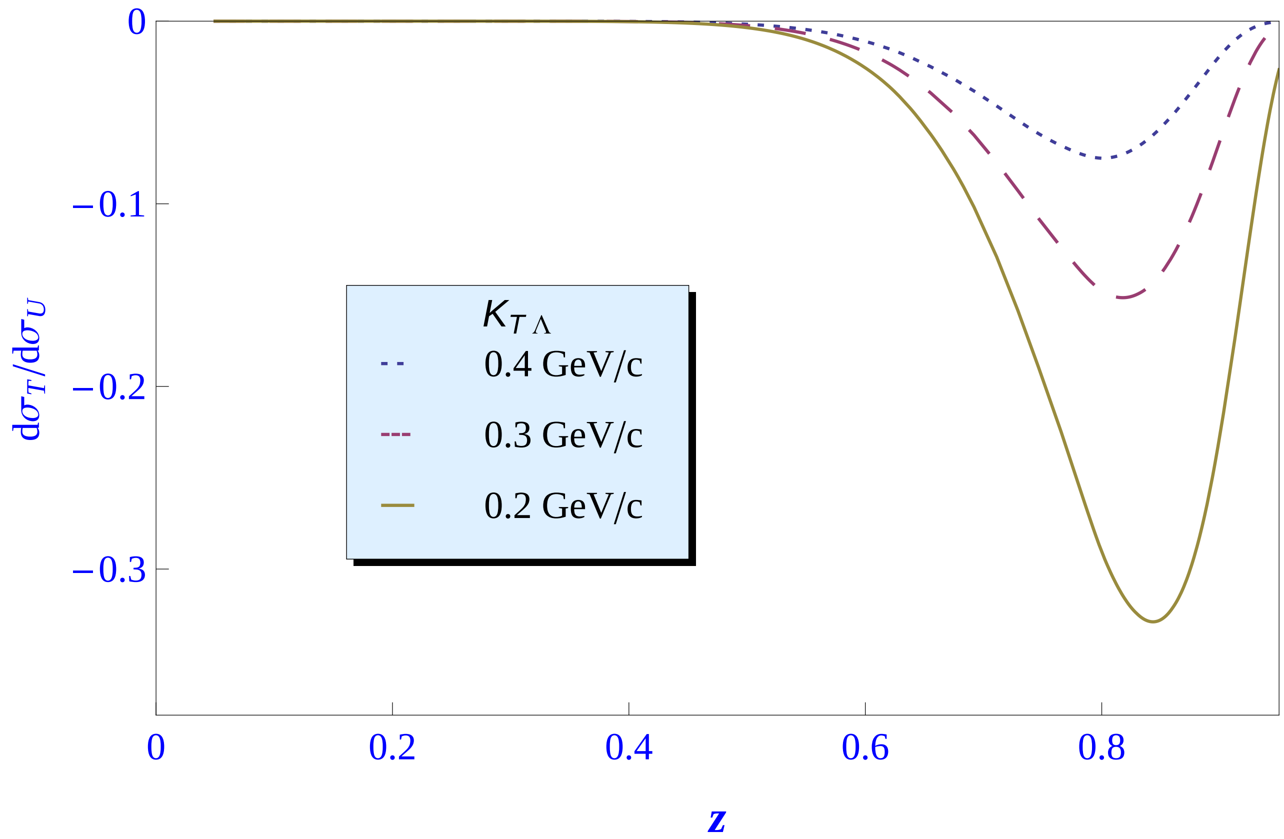
$$\frac{d\sigma_T}{d\sigma_U} \approx \frac{\sum_q f_1^q(x) D_{1T}^{\perp\, q}(z, K_{\Lambda\, T}^2)}{\sum_q f_1^q(x)(D_1^q(z, K_{\Lambda\, T}^2) + D_1^g(z, K_{\Lambda\, T}^2)) + f_1^g(x) D_1^g(z, K_{\Lambda\, T}^2)/0.8}$$

This includes also in the denominator the $qg \to qg$ subprocess

Will use extracted ratios for $D_{1T}^{\perp\, q}/D_1^q$ with DSV & IMR which have $D_1^g \ll D_1^q$

Expected to yield qualitative estimates only

Jet+Λ production at the LHC



using DSV

$\eta_j, \eta_{j'} = 0$

$|K_{\perp\,j}|, |K_{\perp\,j'}| = 70$ GeV

The asymmetry exceeds -1 for smaller $K_{T\Lambda}$ at large z, hence is overestimated

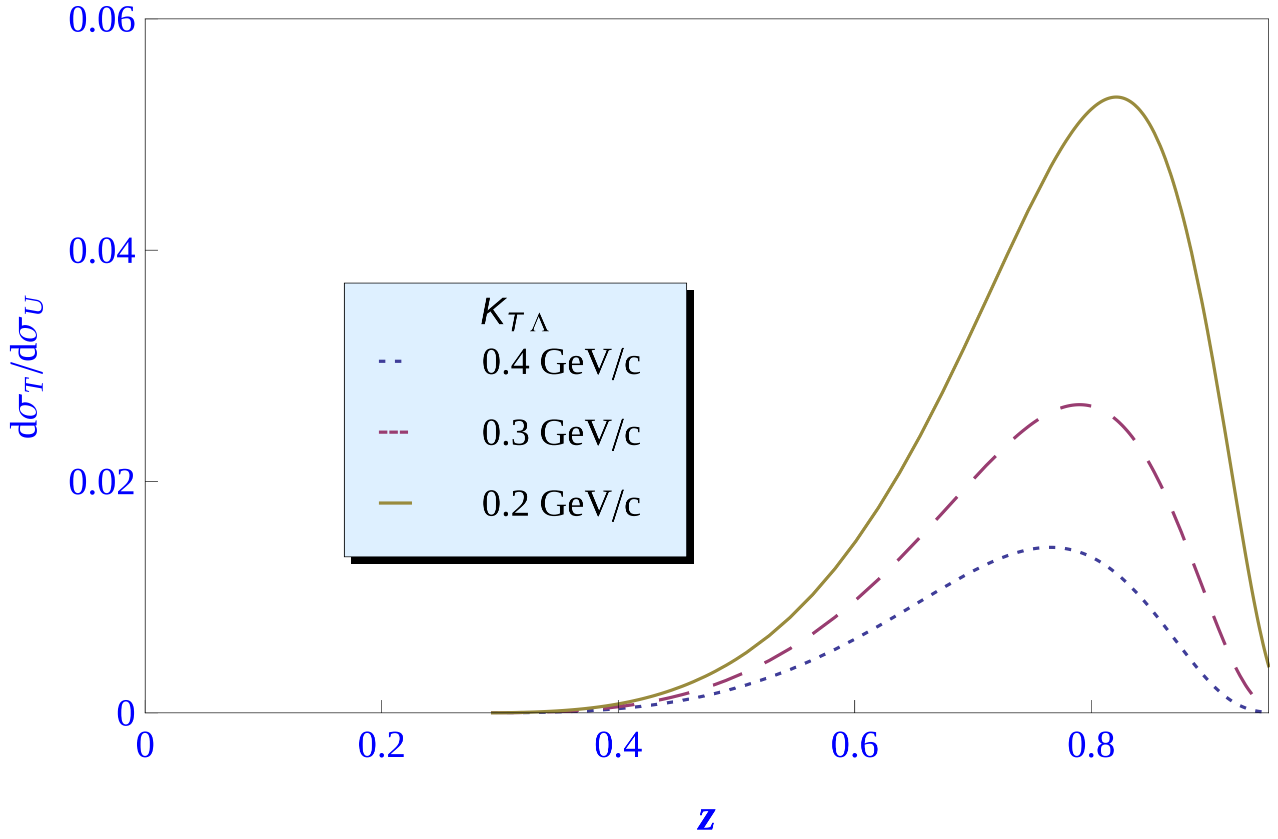
Hardly any asymmetry at smaller z due to fit to low energy data

Need not be realistic at high energies

Jet+Λ production at the LHC

$D_{1T}^{\perp}$ extracted using $SU(3)$ breaking unpolarized FFs [IMR] yields very different result

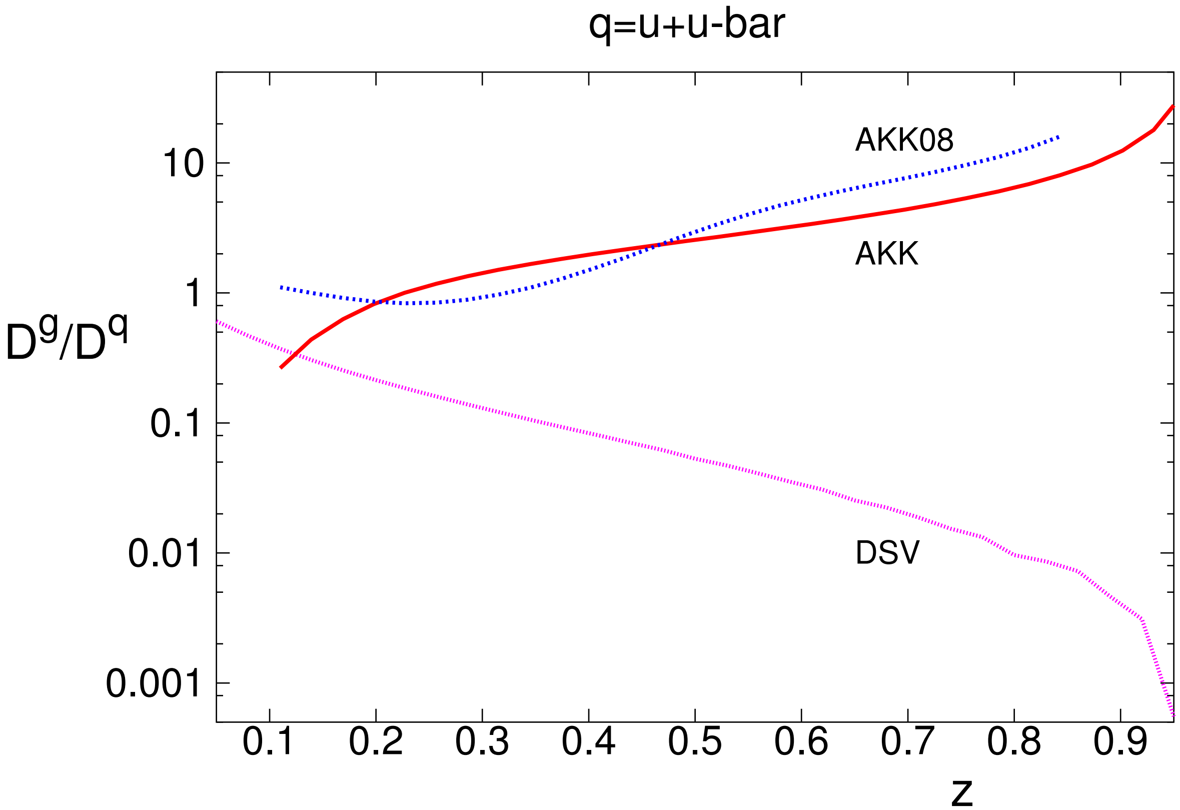
Indumathi *et al.*, PRD 58 (1998) 094014



Asymmetry is very sensitive to the cancellation between u, d and s contributions

Future jet+Λ production data hopefully will allow more solid extraction of $D_{1T}^{\perp}$

Role of $g \to \Lambda X$



$D_1^g / D_1^{u+\bar{u}}$ at LO

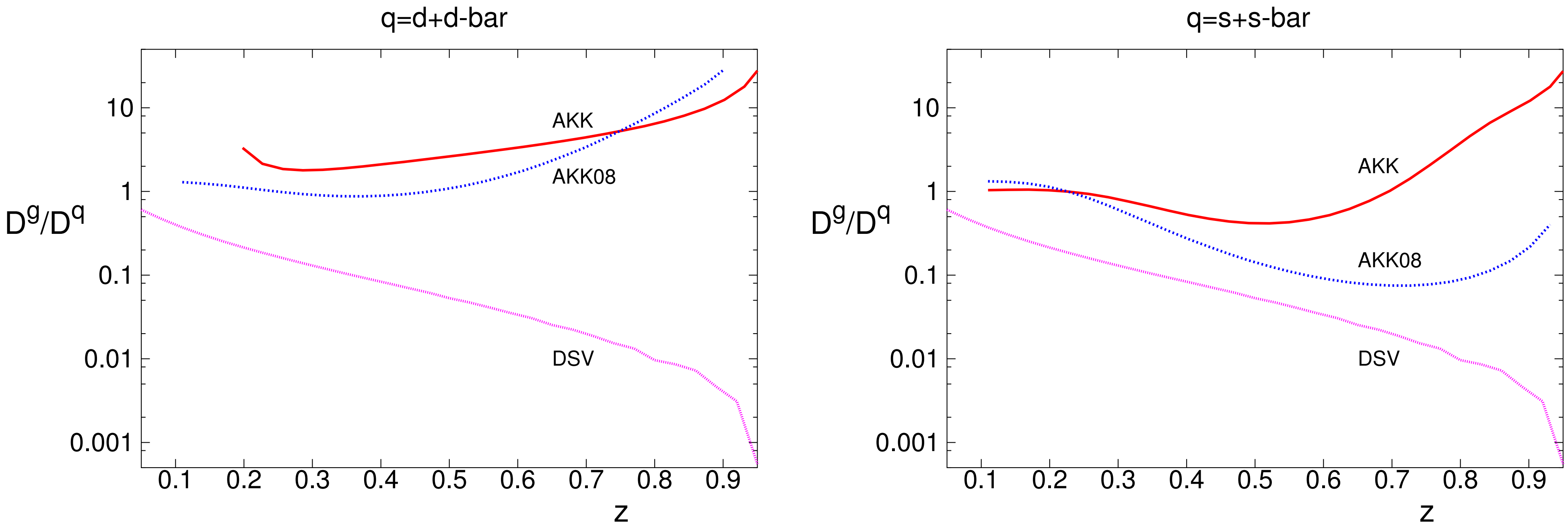
$Q = 10$ GeV

De Florian, Stratmann, Vogelsang [DSV] (PRD 57 (1998) 5811) (e^+e^- data only)

Albino, Kniehl, Kramer [AKK] (NPB 734 (2006) 50)

AKK update [AKK08] (NPB 803 (2008) 42)

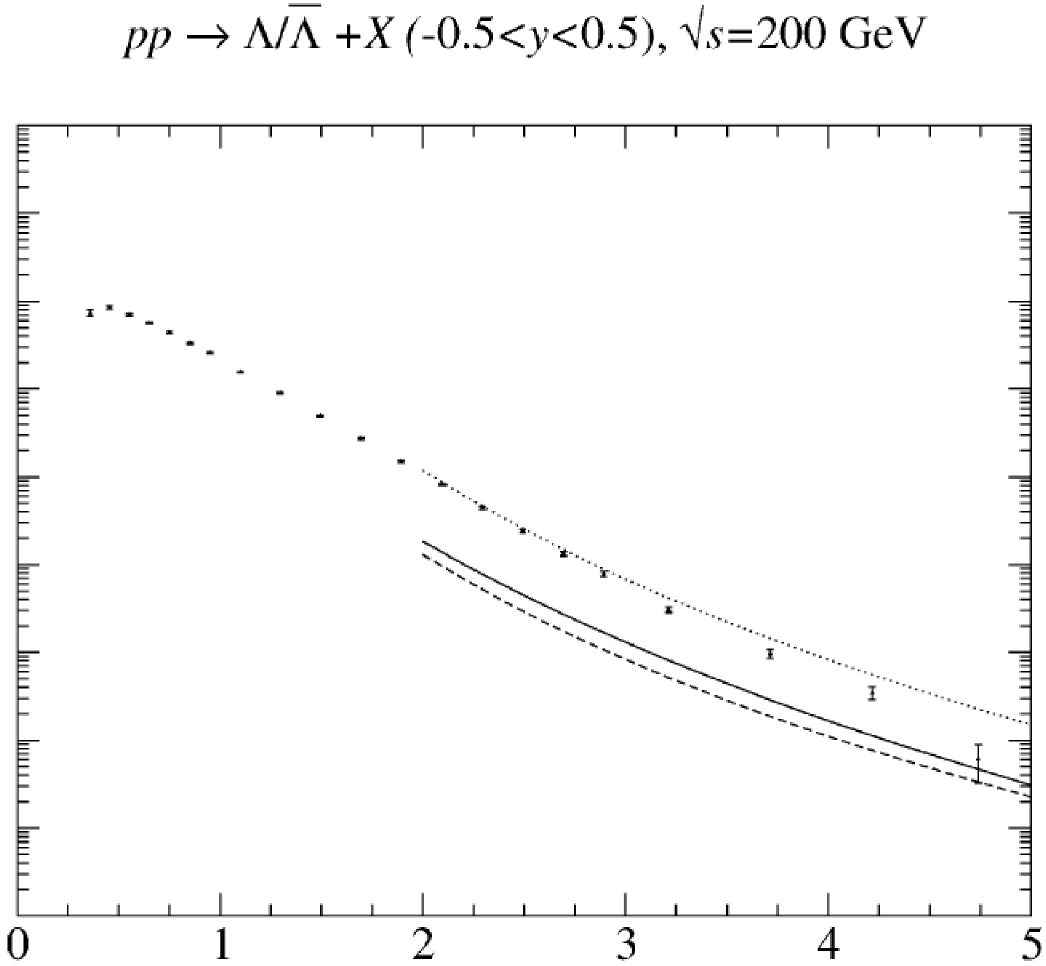
Role of $g \to \Lambda X$



Fits of D_1 to only $e^+e^- \to \Lambda X$ data not sensitive to $g \to \Lambda X$

Should we use the latest AKK08 then? Also problematic!

Λ fragmentation function problem



p_T distribution

solid: AKK08

dotted: AKK

dashed: DSV

data: STAR

"a possible inconsistency between the pp and e^+e^- reaction data for $\Lambda/\overline{\Lambda}$ production"

AKK, NPB 803 (2008) 42

Forward rapidity data

Λ polarization is also very interesting in $p\,A$ reactions at very high $\sqrt{s}$, large A and η

In this kinematic regime of small x, saturation of the gluon density is expected

The saturation scale Q_s and even its evolution with x could be probed in this way

D.B. & Dumitru, PLB 556 (2003) 33; D.B., Utermann & Wessels, PLB 671 (2009) 91

However, in the forward direction often protons cannot be identified, which hampers the measurement of Λ polarization

None of the existing data is in the saturation regime

Suggestion:

Use neutral decays $\Lambda \to n\,\pi^0$ (B.R. $\frac{1}{3}$) to measure Λ polarization at forward rapidities

Cork *et al.*, PR 120 (1960) 1000; Olsen *et al.*, PRL 24 (1970) 843

Hadron production in the saturation regime

The cross section of forward hadron production in the (near-)saturation regime:

pdf $\otimes$ dipole cross section $\otimes$ FF

Dumitru & Jalilian-Marian, PRL 89 (2002) 022301

Since $D_{1T}^{\perp}$ is $\boldsymbol{k}_T$-odd, it essentially probes the derivative of the dipole cross section

At transverse momenta of $\mathcal{O}(Q_s)$ the dipole cross section changes much

This leads to a Q_s-dependent peak in the Λ polarization

First demonstrated for the McLerran-Venugopalan model, which has constant Q_s

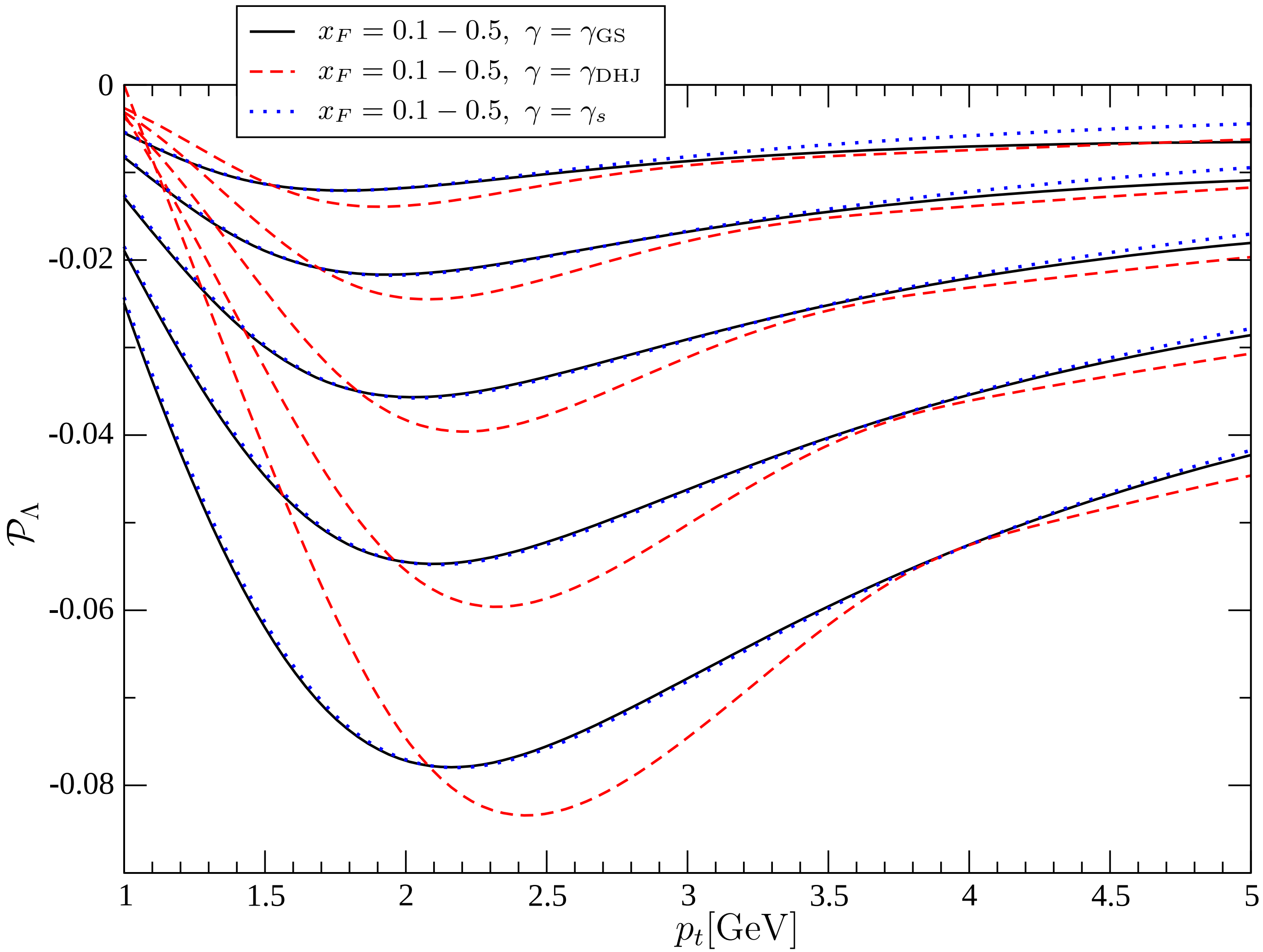
D.B. & Dumitru, PLB 556 (2003) 33

For an x-dependent Q_s it is *a priori* not clear whether this signature remains

But various CGC models lead to same conclusion about peak of Λ polarization:

Its x_F dependence is to very good approximation the x dependence of Q_s!

Λ polarization in $p + Pb \to \Lambda^{\uparrow} + X$ at $\sqrt{s} = 8.8$ TeV



D.B., Utermann & Wessels, PLB 671 (2009) 91

Conclusions

- At medium to high p_T, $p\,p \to \Lambda^\uparrow X$ may be described using $D_{1T}^\perp$
- $D_{1T}^\perp \Rightarrow$ unsuppressed $\boldsymbol{K}_j \cdot (\boldsymbol{K}_\Lambda \times \boldsymbol{S}_\Lambda)$ asymmetry in $p\,p \to \big(\Lambda^\uparrow \text{jet}\big)$ jet X at midrapidity
- Future jet$+\Lambda$ production data hopefully will allow more solid extraction of $D_{1T}^\perp$

  This can also clarify the role of gluons

  It may shed light on the inconsistency between $p\,p$ and e^+e^- data
- The k_T-odd nature of $D_{1T}^\perp$ can be of use to small-x physics
- x_F dependence of the peak of Λ polarization directly probes the x dependence of Q_s
- In principle possible at LHC (at RHIC the peak is likely at too low p_T)
- Λ polarization studies at high energy colliders could prove very interesting!