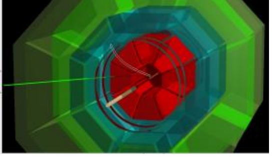
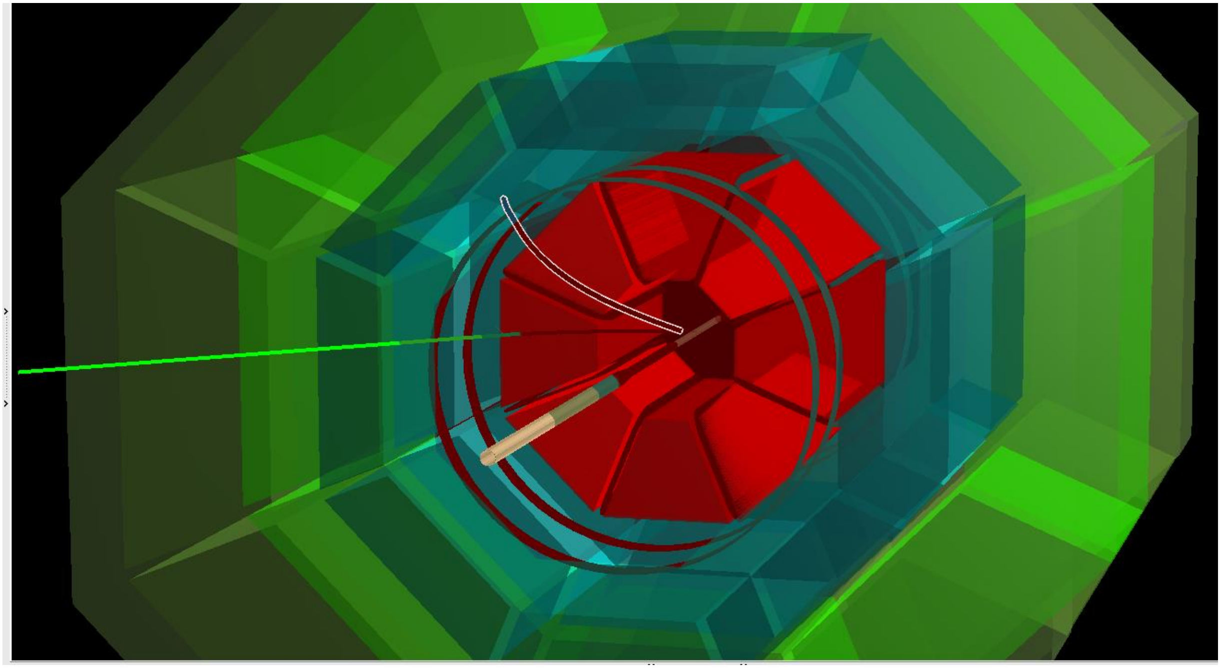


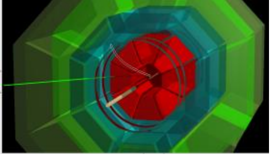
Polarized event generators

Briefly I will talk on the following topics:

- ❑ **Why do one need "polarized" event generators**
- ❑ **"Available" generators**
- ❑ **Other options**
- ❑ **Final state $\Lambda(\bar{\Lambda})$ hyperons polarization**



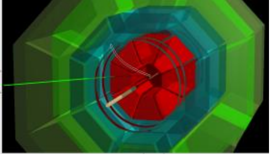
V. Alexakhin LHEP JINR 25.01.2023 SPD Physics & MC meeting



Why polarized event generator?

Various considerations:

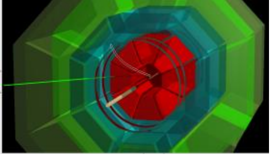
- **Obviously people are curious which asymmetry one will have for a certain setup for a certain process and how this depends on various variables**
- **Detector acceptance might depend on the variables which are not physics “invariants”, so not so simple to implement details in calculations.**
- **Background processes or effects can influence observed values.**
- **Final state particle polarization usually not easily calculatable (spin-dependent fragmentation), some phenomenological MC based models are needed.**



What is “available”?

It depends on the process:

- **There is a number of polarized generators for DIS (PEPSI, DJANGOH etc.), normally for the longitudinally polarized beams.**
- **For the pp process there was SPHINX generator, PYTHIA6 based, developed some 20-25 years ago. It was used mainly for BNL spin physics program preparation in 90s. SPHINX had many subprocesses implemented both in longitudinal and transverse modes (two codes actually, SPHINX-TT for transverse mode)**
- **Final state particle polarization in my practice was done by a private add-on, namely a code which was run over DIS Lepto generator final state particles, having all event history recorded.**



SPHINX, SPINX-TT

Some history:

- **First reference:**

SPHINX, MONTE CARLO PROGRAM FOR POLARISED NUCLEON-NUCLEON COLLISIONS. S. GULLENSTERN, P. GORNICKI, L. MANKIEWICZ, A. SCHAFER, COMP. PHYS. COMMUN. 87 (1995) 416

- **Last developments were done by O. Martin (Regensburg University, A. Shafer supervision) around 1999**
- **Homepage was lost. Only intermediate versions of SPHINX v 1.1 and SPHINX-TT from late 1996 are in hands. As well as initial version from CPC. Also PhD Thesis from O.Martin might contain details.**

The SPHINX Home Page

The SPHINX project started in the early 90's with the aim to develop a Monte Carlo Simulation for polarized nucleon-nucleon collisions. As a basis for the program Pythia 5.6 and Jetset 7.3 were chosen.The new versions Pythia 6.1 can be obtained from Torbjorn Sjostrand or from CERN.

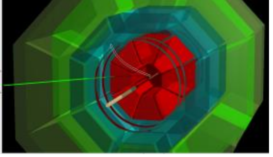
The first part of the project was the development of an event generator for collisions of longitudinally polarized hadrons, which was called SPHINX (Simulation for Polarized Hadronic INteract(X)ions).The main authors of this program are Stefan Güllenstern and Axel Saalfeld. The photoproduction part was programmed by Oliver Martin.

News about SPHINX:

- 02 Dec 1996: Release of SPHINX version 1.1. New parametrizations of polarized and unpolarized parton distribution functions are available now. A new interface to pdflib 4.0 and higher versions is also provided. A severe error in the initial state shower subroutine was corrected (the bug basically turned off initial state showering after several hundred events).
- 3 Mar 1997: error in common block in JETSET 7.3 fixed , did not effect results
- 7 Apr 1997: SPHINX version 1.2 can be downloaded. The new features include polarized electrons or photons as beam particles, a choice of two model parton distributions of the polarized photon and the necessary partonic subprocesses for photoproduction of jets.
- 18 Apr 1997: error in PYSSPA corrected which caused an infinite loop after several million events. The version of the corrected code is 1.201 .
- 20 May 1997: Glueck, Reya, Stratmann, Vogelsang leading order and next to leading order parametrizations of polarized pdfs of the proton included (Phys. Rev. D53 (1996) 4775). The version of the new code is 1.202 .
- 24 August 1998: SPHINX might be used as polarized event generator for the preparation of the Spin Program at the polarized RHIC collider. Starting mid-september 1998, a workshop will be held at Brookhaven National Lab with the aim to further enhance SPHINX, upgrade it to PYTHIA 6.1 and compare results to NLO QCD calculations.

News about SPHINX TT:

- 12 Nov 1996: The first official SPHINX TT version is available. A new interface to pdflib 4.0 and higher versions is included now.
- 3 Mar 1997: error in common block in JETSET 7.3 fixed , did not effect results



SPHINX

Processes and example event list (note polarization of IS interaction) :

Table 1: List of processes implemented in the polarized mode.

ISUB	Process	Comment
1	$q_i\bar{q}_j \to \gamma^*/Z^0$	quark-antiquark annihilation into virtual γ^*/Z^0
2	$q_i\bar{q}_j \to W^\pm$	annihilation into charged vector boson
11	$q_iq_j \to q_iq_j$	(anti-)quark – (anti-)quark scattering; annihilation diagram not included
12	$q_i\bar{q}_i \to q_k\bar{q}_k$	annihilation process
13	$q_i\bar{q}_i \to gg$	annihilation into gluon pair
14	$q_i\bar{q}_i \to g\gamma$	annihilation into gluon and prompt γ
15	$q_i\bar{q}_i \to gZ^0$	annihilation into gluon and Z^0
16	$q_i\bar{q}_i \to gW^\pm$	annihilation into gluon and $W^\pm$
18	$q_i\bar{q}_i \to \gamma\gamma$	annihilation into γ pair
19	$q_i\bar{q}_i \to \gamma Z^0$	annihilation into γ and Z^0
20	$q_i\bar{q}_i \to \gamma W^\pm$	annihilation into γ and $W^\pm$
28	$q_ig \to q_ig$	(anti-)quark – gluon scattering
29	$q_ig \to q_i\gamma$	prompt γ production in (anti-)quark – gluon scattering
30	$q_ig \to q_iZ^0$	Z^0 production in (anti-)quark – gluon scattering
31	$q_ig \to q_jW^\pm$	$W^\pm$ production in (anti-)quark – gluon scattering
53	$gg \to q_k\bar{q}_k$	gluon fusion
68	$gg \to gg$	gluon – gluon scattering

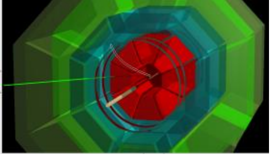
```
==================================================================
I                                          I                     I
I ISUB Subprocess name                     I   Maximum value     I
I                                          I                     I
==================================================================
I                                          I                     I
I  28  f + g -> f + g                      I     4.7736E+00      I
I  96  Semihard QCD 2 -> 2                 I     1.9598E+02      I
I                                          I                     I
==================================================================

**************** PYINIT: initialization completed ***************

                       Event listing (summary)

I  particle/jet KF      p_x     p_y     p_z        E        m

1  !p+!        2212+    0.000   0.000  99.996  100.000   0.938
2  !p+!        2212+    0.000   0.000 -99.996  100.000   0.938
==========================================================================
3  !d~!          -1+   -0.279  -0.107  12.583   12.587   0.000
4  !u!            2+   -0.132   0.469  -3.602    3.634   0.000
5  !g!           21-   -2.214  -1.299   7.340    7.776   0.000
6  !u!            2+   -0.096   0.342  -2.626    2.649   0.000
7  !g!           21    -5.168  -1.523   5.182    7.476   0.000
8  !u!            2     2.857   0.566  -0.467    2.950   0.006
==========================================================================
```



Processes and example event list:

ISUB	Process	Comment
11	$q_i q_j \to q_i q_j$	(anti-)quark – (anti-)quark scattering; annihilation is not included
12	$q_i \bar{q}_i \to q_k \bar{q}_k$	annihilation process
13	$q_i \bar{q}_i \to gg$	annihilation into gluon pair
14	$q_i \bar{q}_i \to g\gamma$	annihilation into gluon and prompt γ
18	$q_i \bar{q}_i \to \gamma\gamma$	annihilation into γ-pair
28	$q_i g \to q_i g$	(anti-)quark – gluon scattering
29	$q_i g \to q_i \gamma$	prompt γ-production in (anti-)quark – gluon scattering
53	$gg \to q_k \bar{q}_k$	gluon fusion
68	$gg \to gg$	gluon – gluon scattering
191	$q_i \bar{q}_i \to f_k \bar{f}_k$	annihilation into lepton-pair or quark – (anti-)quark pair (Drell-Yan process); this process is new and equivalent to the γ-piece of ISUB=1 in PYTHIA

Table 1: List of processes implemented in the polarized mode

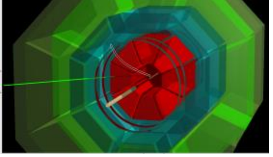
```
==========================================================
I                                       I                I
I  ISUB  Subprocess name                I  Maximum value I
I                                       I                I
==========================================================
I                                       I                I
I  191   f + f~ -> f + f~               I    6.5589E-05  I
I                                       I                I
==========================================================

*************** PYINIT: initialization completed ****************


                    Event listing (summary)


   I  particle/jet  KF orig   p_x     p_y     p_z      E       m

   1  !p+!       2212^   0   0.000   0.000  99.996  100.000  0.938
   2  !p+!       2212v   0   0.000   0.000 -99.995  100.000  0.938
==================================================================
   3  !u!           2^   1  -0.414  -0.069  25.831   25.835  0.000
   4  !u~!         -2v   2  -0.207  -0.420   0.321    0.568  0.000
   5  !u!           2^   3  -0.414  -0.069  25.831   25.835  0.000
   6  !u~!         -2v   4  -0.207  -0.420   0.321    0.568  0.000
   7  !u!           2    0  -1.025   0.598  23.197   23.227  0.006
   8  !u~!         -2    0   0.404  -1.087   2.956    3.175  0.006
==================================================================
```

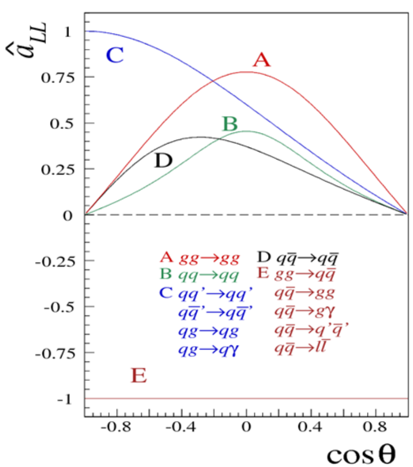


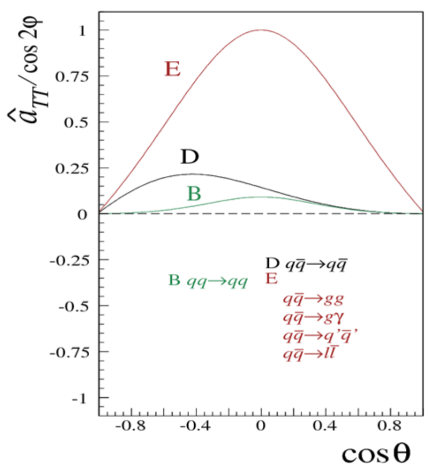
“Polarized” PYTHIA

Another option to take into account polarization (based on STAR endcap ECAL proposal procedure):

- **Generate events as usual, but recording event history, all lines plus some kinematics (generator truth GT).**
- **Optionally pass through the setup and reconstruct, keeping GT. Or apply some cuts to make the sample close to what setup can detect.**
- **Calculate asymmetry (do not forget Q2 evolution of PDFs)**

$$A_{LL} \sim P_1 P_2 \hat{a}_{LL} = \frac{\Delta f_1(x_1,Q^2)}{f_1(x_1,Q^2)} \frac{\Delta f_2(x_2,Q^2)}{f_2(x_2,Q^2)} \hat{a}_{LL}(\hat{s},\hat{t},\hat{u})$$



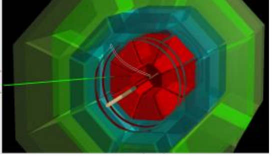


N+- random Poisson distributed (mean is average yield per bunch)

$$\mu_{\pm} = (1 \pm P_{b_1} P_{b_2} A_{LL}) N_{eff}$$

$$A_{LL}^{recon} = \frac{1}{P_{b_1} P_{b_2}} \frac{N_+ - N_-}{N_+ + N_-}$$

$$\delta A_{LL} = \frac{1}{P_{b_1} P_{b_2}} \sqrt{\frac{1 - (P_{b_1} P_{b_2} A_{LL})^2}{N_+ + N_-}}$$



“Polarized” PYTHIA 2

Example of generator truth information (taken from EIC PYTHIA):

I:	
ievent:	eventnumber running from 1 to XXX
genevent:	trials to generate this event
subprocess:	pythia subprocess (MSTI(1)), for details see table
nucleon:	hadron beam type (MSTI(12))
targetparton:	parton hit in the target (MSTI(16))
xtargparton:	x of target parton (PARI(34))
beamparton:	in case of resolved photon processes and soft VM
xbeamparton:	x of beam parton (PARI(33))
thetabeamparton:	theta of beam parton (PARI(53))
truey, trueQ2, truex, trueW2, trueNu:	are the kinematic variables of the event.
	If radiative corrections are turned on they are differ
	If radiative corrections are turned off they are the s
leptonphi:	phi of the lepton (VINT(313))
s_hat:	shat of the process (PARI(14))
t_hat:	Mandelstam t (PARI(15))
u_hat:	Mandelstm u (PARI(16))
pt2_hat:	pthat^2 of the hard scattering (PARI(18))
Q2_hat:	Q2hat of the hard scattering (PARI(22)),

nrTracks:	number of tracks in this event, includes also virtual particles

- 4th line: ==
- 5th line: Information on track-wise variables stored in the file:

I:	line index, runs from 1 to nrTracks
K(I,1):	status code KS (1: stable particles 11: particles which decay 55; radiative photon)
K(I,2):	particle KF code (211: pion, 2112:n, ...)
K(I,3):	line number of parent particle
K(I,4):	normally the line number of the first daughter; it is 0 for an undecayed particle or unfragmented parton
K(I,5):	normally the line number of the last daughter; it is 0 for an undecayed particle or unfragmented parton.
P(I,1):	px of particle
P(I,2):	py of particle
P(I,3):	pz of particle
P(I,4):	Energy of particle
P(I,5):	mass of particle
V(I,1):	x vertex information
V(I,2):	y vertex information
V(I,3):	z vertex information

Longitudinal spin transfer to hyperons in pp

Hyperon production with high pT:

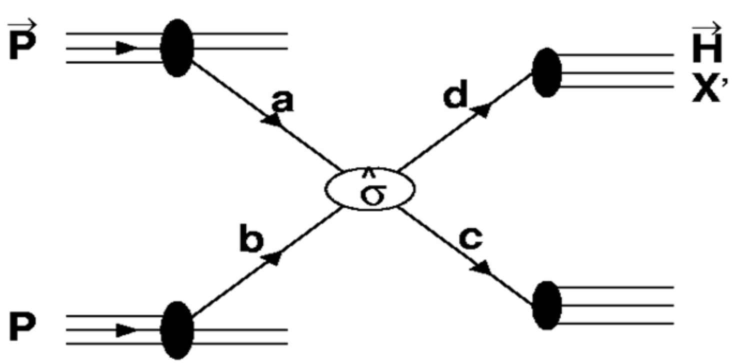
- (Un)Polarised PDFs, (un)polarized fragmentation functions,
- QCD crossections 2->2 (spin-dependent and not)
- Transmitted asymmetries give degree of final quark polarisation

$$\frac{d^2\sigma^{pp\to HX}}{dp_T\,d\eta} = \sum_{abcd}\int dx_a dx_b dz_c\, f_a(x_a,\mu^2)\, f_b(x_b,\mu^2)\,\frac{d\hat{\sigma}(ab\to cd)}{dp_T\,d\eta}\, D_c^H(z_c,\mu^2)$$

$$\frac{d^2\Delta\sigma}{dp_T\,d\eta} = \sum_{abcd}\int dx_a dx_b dz_c\,\Delta f_a(x_a,\mu^2)\, f_b(x_b,\mu^2)\,\frac{d\Delta\hat{\sigma}^{(\vec{a}b\to\vec{c}d)}}{dp_T\,d\eta}\,\Delta D_c^H(z_c,\mu^2)$$

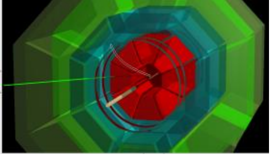
Spin-dependent PDF

Spin dependent fragmentation function



$$\vec{p}p \to HX$$

$$D_{LL} \equiv \frac{\sigma_{p^+p\to\bar{\Lambda}^+X} - \sigma_{p^+p\to\bar{\Lambda}^-X}}{\sigma_{p^+p\to\bar{\Lambda}^+X} + \sigma_{p^+p\to\bar{\Lambda}^-X}} = \frac{d\Delta\sigma}{d\sigma}$$



Hyperon polarization MC model

Developed for DIS but might be possible to adapt for pp:

Longitudinal Polarization of Λ and $\bar{\Lambda}$ Hyperons in Lepton-Nucleon Deep-Inelastic Scattering

John Ellis[1], Aram Kotzinian[2,3,4], Dmitry Naumov[2,5], and Mikhail Sapozhnikov[2]

– **Model A**: Restrict spin transfer in (di-)quark fragmentation to hyperons with ($R_{qq} = 1, R_q \neq 1$) $R_{qq} \neq 1, R_q = 1$.
– **Model B**: Allow spin transfer in (di-)quark fragmentation to hyperons with ($R_{qq} < R_q$) $R_{qq} > R_q$.

The polarization of Λ and $\bar{\Lambda}$ hyperons produced promptly or via the decay of a strange baryon Y in quark fragmentation is assumed to be related to the quark polarization P_q by:

$$P^q_\Lambda(Y) = -C^\Lambda_q(Y)P_q, \qquad P^{\bar{q}}_{\bar{\Lambda}}(\bar{Y}) = -C^{\bar{\Lambda}}_{\bar{q}}(\bar{Y})P_{\bar{q}}, \quad (2)$$

Table 1. *Spin correlation coefficients in the SU(6) and BJ models.*

Λ's parent	C_u^Λ		C_d^Λ		C_s^Λ	
	SU(6)	BJ	SU(6)	BJ	SU(6)	BJ
quark	0	-0.18	0	-0.18	1	0.63
Σ^0	-2/9	-0.12	-2/9	-0.12	1/9	0.15
Ξ^0	-0.15	0.07	0	0.05	0.6	-0.37
Ξ^-	0	0.05	-0.15	0.07	0.6	-0.37
$\Sigma^\star$	5/9	–	5/9	–	5/9	–

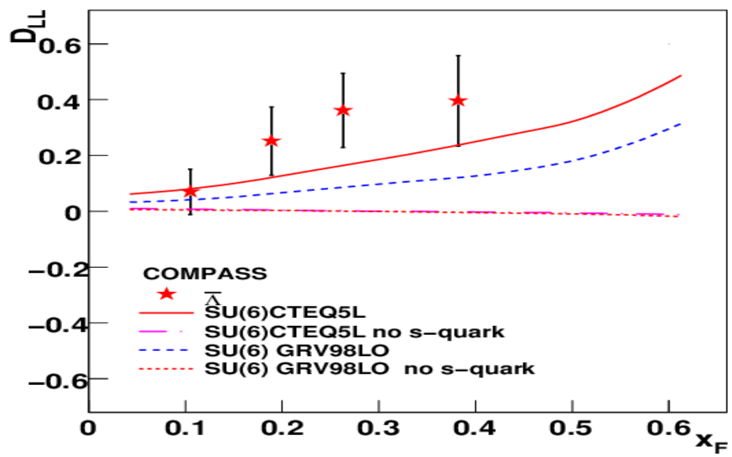
2.3.2 Spin Transfer from the Remnant Diquark

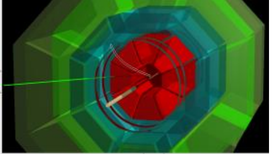
We parametrize a possible sea-quark polarization as a *correlation* between the polarization of the sea quark and that of the struck quark, described by the spin-correlation coefficients C_{sq}:

$$P_s = C_{sq}P_q, \quad (3)$$

where P_q and P_s are the polarizations of the initial struck quark and the strange quark. The values of the C_{sq} parameters (one for scattering on a valence quark, the other for scattering on a sea quark) were found in a fit to NOMAD data [25]:

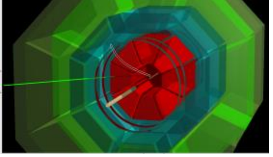
Model A:
$$C_{sq_{val}} = -0.35 \pm 0.05, C_{sq_{sea}} = -0.95 \pm 0.05. \quad (4)$$
Model B:
$$C_{sq_{val}} = -0.25 \pm 0.05, \quad C_{sq_{sea}} = 0.15 \pm 0.05.$$





Conclusion

- There are some options for the polarization asymmetry calculation on the event basis
- My opinion that it might be useful to have some of them implemented and ready for use for SPD
- Hyperon polarization generator would require some development

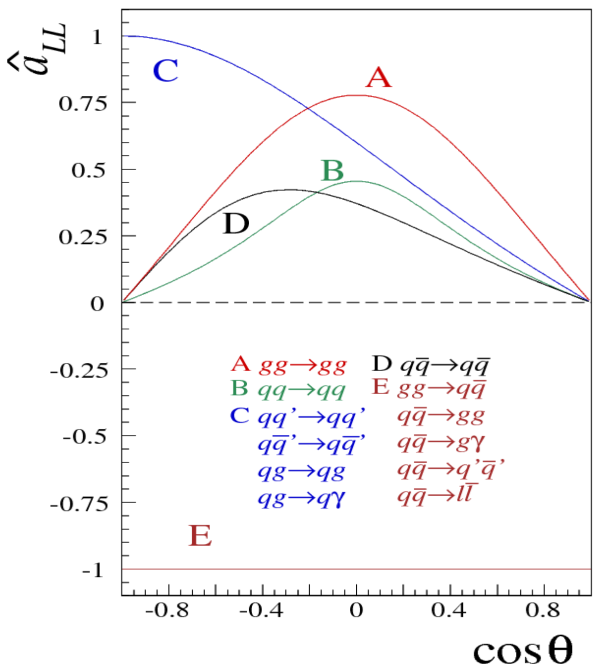


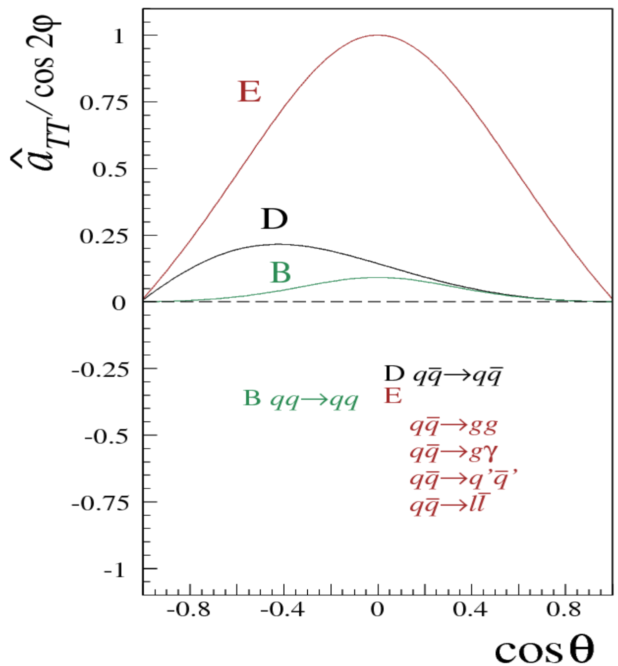
Backup

Thank you

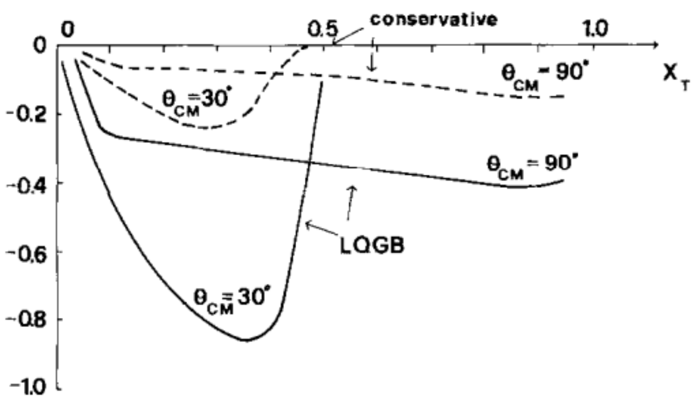
Spin transfer to hyperons in pp

Transmitted asymmetries:

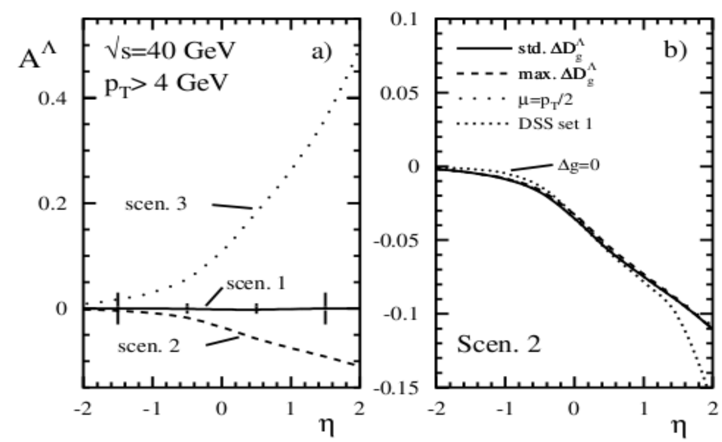




$$A^{\Lambda} \equiv \frac{d\Delta\sigma^{p\vec{p} \to \vec{\Lambda} X}/d\eta}{d\sigma^{pp \to \Lambda X}/d\eta}$$

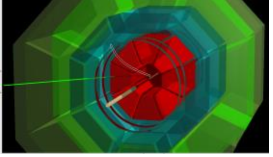


$$x_T = \frac{2p_{\Lambda T}}{\sqrt{s}}.$$



N.S. Craigie P.Ratcliffe 1983

De Florian et al 1998



D_{LL} extraction technics

$$\frac{dN}{d\cos\theta} = \frac{N_{tot}}{2} A(\cos\theta)(1 + \alpha P \cos\theta)$$

A(cosθ) - acceptance, needs MC. However using beam polarization reversal (and setup symmetry in η is suitable) it is possible to extract Λ polarization without MC, or without direct acceptance determination.

- **HERMES method**

Helicity balanced data sample →

$$D_{LL'} = \frac{\sum_{i=1}^{N} P_{b,i} D(y_i) \cos\theta^i_{pL'}}{\alpha \| P_b^2 \| \sum_{i=1}^{N} D^2(y_i) \cos^2\theta^i_{pL'}}$$

- **RHIC method**

D_{LL} has been extracted from Λ counts with opposite beam polarization within a small interval of cosθ*:

-STAR, hep-ex/0512058

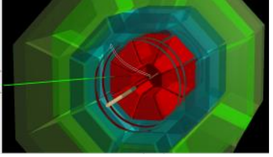
$$D_{LL} = \frac{1}{\alpha \cdot P_{beam} < \cos\theta^* >} \cdot \frac{N^+ - N^-}{N^+ + N^-}$$

, where the acceptance cancels.

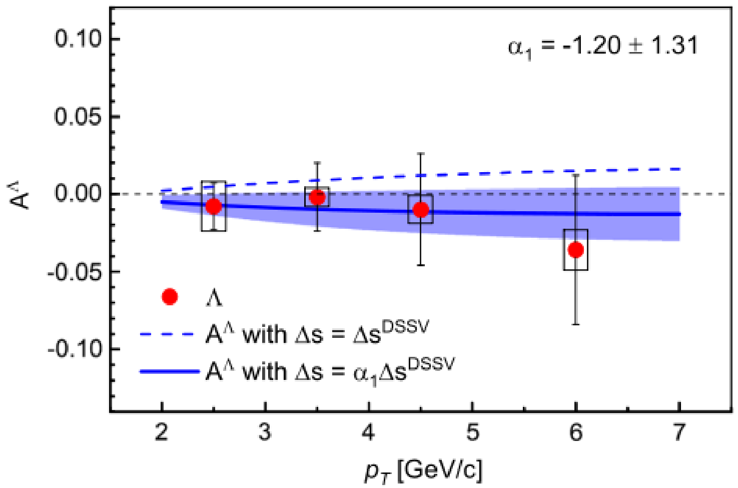
$$N_\Lambda^+ = N^{++} \frac{L_{--}}{L_{++}} + N^{+-} \frac{L_{--}}{L_{+-}}$$

$$N_\Lambda^- = N^{-+} \frac{L_{--}}{L_{-+}} + N^{--}$$

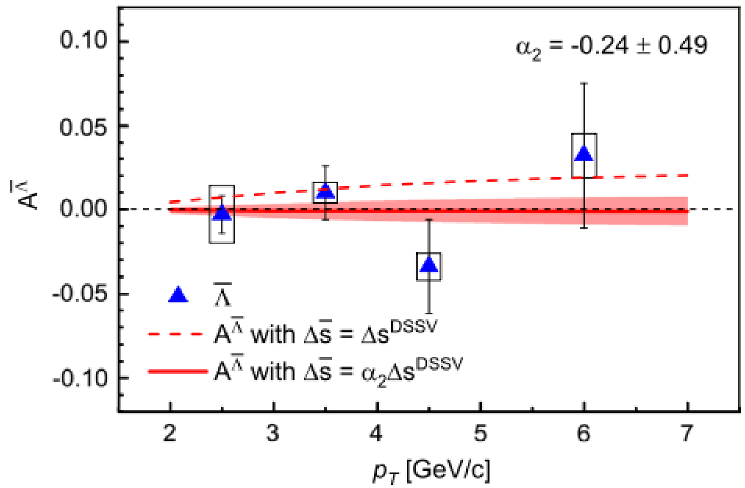
Relative luminosity ratio measured with BBC, and P_{beam} in RHIC.



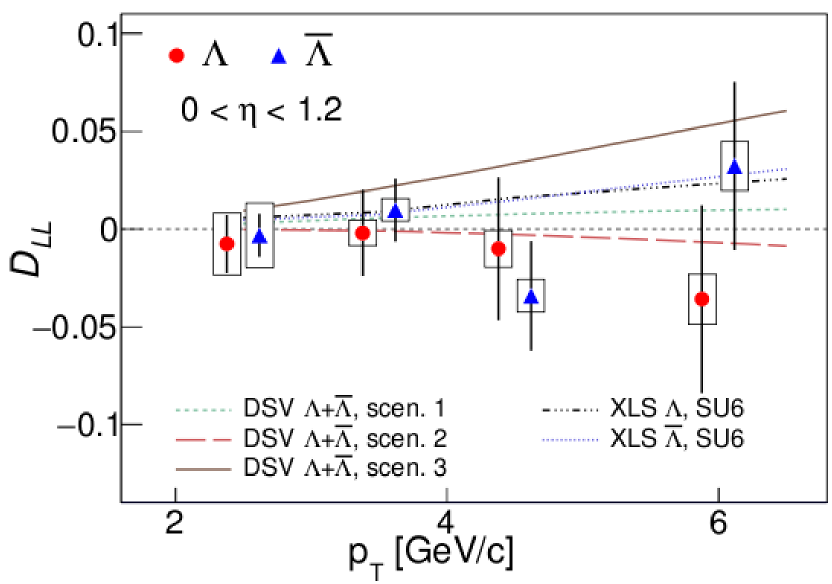
RHIC results on D_{LL}



(a) Longitudinal spin transfer to Λ.



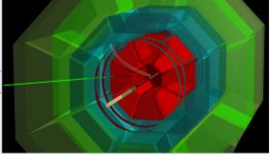
(b) Longitudinal spin transfer to $\bar{\Lambda}$.



$$x_T = \frac{2p_{\Lambda T}}{\sqrt{s}}.$$

At 200GeV/c, p_T=6GeV/c x_T=0.06

Eur. Phys. J. C (2019) 79:409



Longitudinal spin transfer to Λ in DIS

Keywords: Δs , $\Delta\bar{s}(x)$ $\Delta s \neq \Delta\bar{s}(x)$? , spin-dependent FF, intrinsic strangeness of the nucleon

$$\Lambda^0 \to p + \pi^-$$

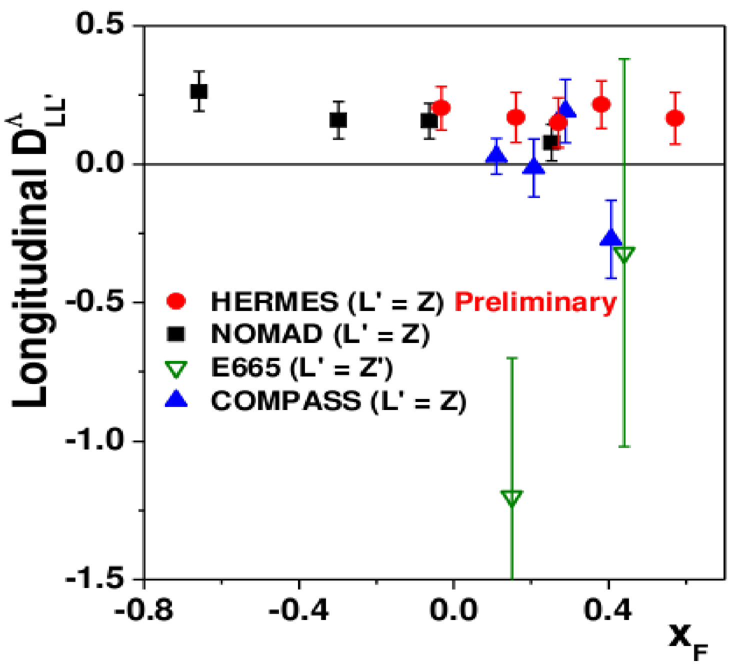
$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P^{\Lambda}_{L'} \cos\theta_{pL'})$$

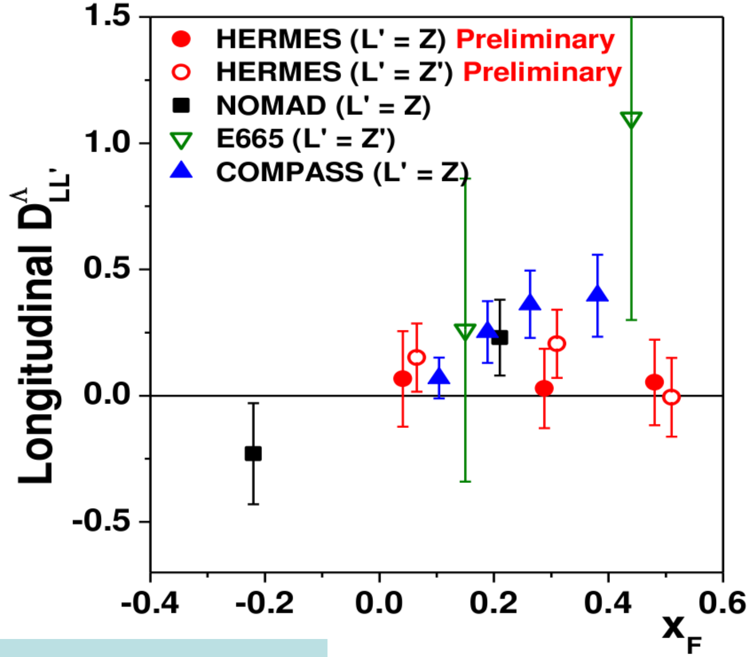
$\alpha = 0.642$ for Λ ($\alpha = -0.642$ for $\bar{\Lambda}$)

$L' \to \Lambda$ *spin direction*

$$P_\Lambda = \frac{\sum_q e_q^2 \left[P_b D(y) q(x) + P_T \Delta q(x)\right] \Delta D_q^\Lambda(z)}{\sum_q e_q^2 \left[q(x) + P_b P_T D(y) \Delta q(x)\right] D_q^\Lambda(z)}$$

$$P_L = D^\Lambda_{LL} \cdot P_b \cdot D(y)$$





S. Belostotski DSPIN12