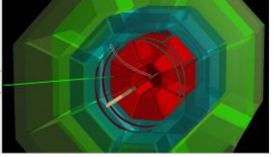
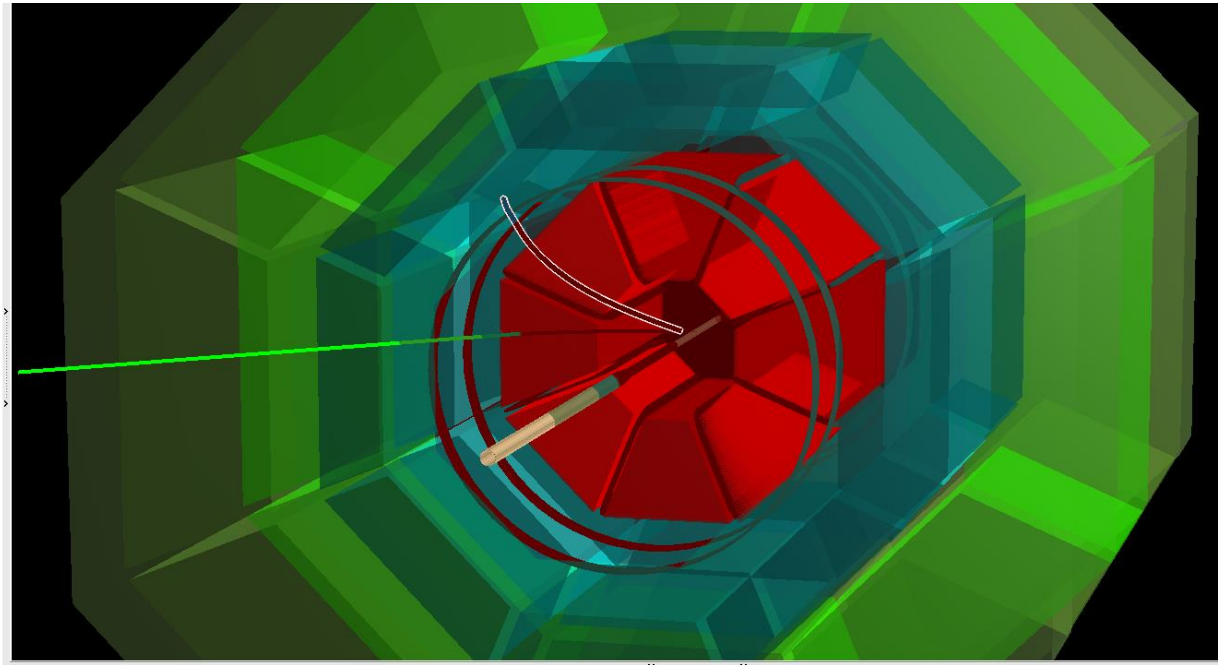
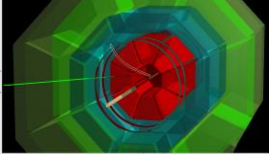


Spin-dependent event simulation

Briefly I will talk on the following topics:

- **Longitudinal double spin asymmetries (A_{LL})**
- **Transverse double spin asymmetries (A_{TT})**
- **Transverse singe spin asymmetries (A_N)**



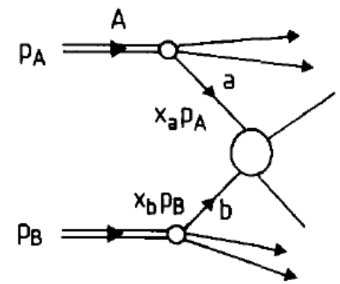


Longitudinal double spin asymmetries I

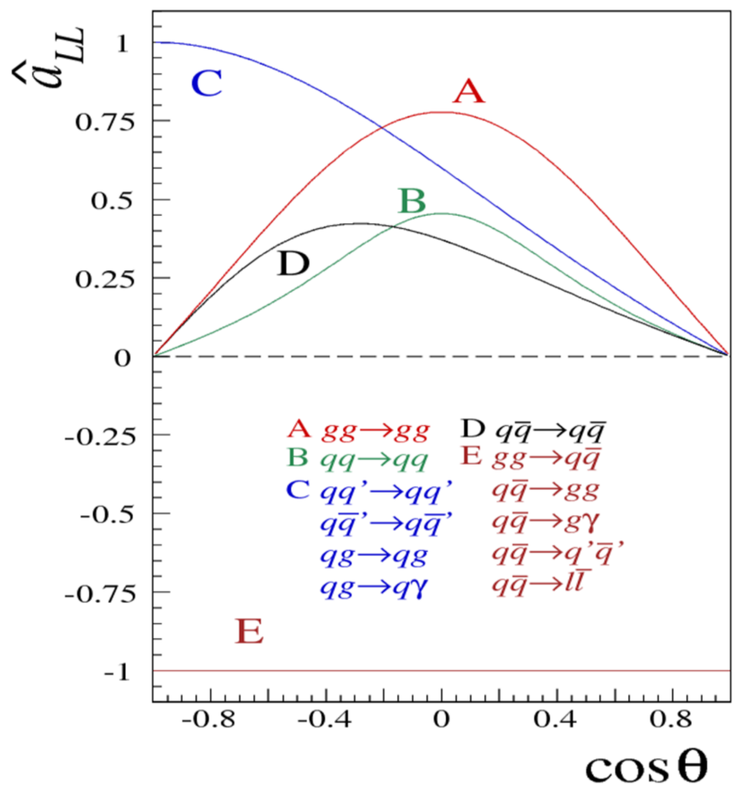
$$d\sigma^{(AB)}(P_A;P_B)=\sum_{a,b}\int dx_A dx_B f_a^A(x_A,\mu^2) f_b^B(x_B,\mu^2) d\hat\sigma_{a,b}(x_A P_A, x_B P_B, \mu)$$

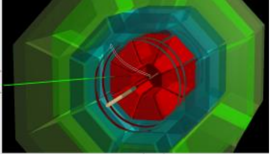
$$\hat s=(x_A P_A + x_B P_B)^2\,, \quad \hat t=(x_A P_A - k_1)^2\,, \text{ and } \quad \hat u=(x_A P_A - k_2)^2$$

$$A_{LL}^{(AB)}(x_A,x_B,\hat s,\hat t,\hat u,\mu^2)=\frac{\Delta f_a^A(x_A,\mu)}{f_a^A(x_A,\mu)}\frac{\Delta f_b^B(x_B,\mu)}{f_b^B(x_B,\mu)}\frac{\Delta\hat\sigma_{a,b}(\hat s,\hat t,\hat u,\mu^2)}{\hat\sigma_{a,b}(\hat s,\hat t,\hat u,\mu^2)}$$



Parton process $ab \to cd$	Spin Average Cross Section — σ_{ab}^{cd}	Helicity Dependent Cross Section — $\Delta\sigma_{ab}^{cd}$
$q\bar q \to\to \ell\bar\ell$	$\frac{\hat u^2+\hat t^2}{\hat s^2}$	$-\frac{\hat u^2+\hat t^2}{\hat s^2}$
$qq \to qq$	$\frac{\hat s^2+\hat u^2}{\hat t^2}+\frac{\hat s^2+\hat t^2}{\hat u^2}-\frac{2}{3}\frac{\hat s^2}{\hat u\hat t}$	$\frac{\hat s^2-\hat u^2}{\hat t^2}+\frac{\hat s^2-\hat t^2}{\hat u^2}-\frac{2}{3}\frac{\hat s^2}{\hat u\hat t}$
$qq' \to qq'$	$\frac{\hat s^2+\hat u^2}{\hat t^2}$	$\frac{\hat s^2-\hat u^2}{\hat t^2}$
$q\bar q \to q\bar q$	$\frac{\hat s^2+\hat u^2}{\hat t^2}+\frac{\hat u^2+\hat t^2}{\hat s^2}-\frac{2}{3}\frac{\hat u^2}{\hat s\hat t}$	$\frac{\hat s^2-\hat u^2}{\hat t^2}-\frac{\hat u^2+\hat t^2}{\hat s^2}+\frac{2}{3}\frac{\hat u^2}{\hat s\hat t}$
$q\bar q \to q'\bar q'$	$\frac{\hat u^2+\hat t^2}{\hat s^2}$	$-\frac{\hat u^2+\hat t^2}{\hat s^2}$
$q\bar q' \to q\bar q'$	$\frac{\hat s^2+\hat u^2}{\hat t^2}$	$\frac{\hat s^2-\hat u^2}{\hat t^2}$
$q\bar q \to gg$	$\frac{8}{3}\frac{\hat t^2+\hat u^2}{\hat t\hat u}-6\frac{\hat t^2+\hat u^2}{\hat s^2}$	$-\frac{8}{3}\frac{\hat t^2+\hat u^2}{\hat t\hat u}+6\frac{\hat t^2+\hat u^2}{\hat s^2}$
$qg \to qg$	$\frac{9}{4}\frac{\hat s^2+\hat u^2}{\hat t^2}-\frac{\hat s^2+\hat u^2}{\hat u\hat s}$	$\frac{9}{4}\frac{\hat s^2-\hat u^2}{\hat t^2}-\frac{\hat s^2-\hat u^2}{\hat u\hat s}$
$gg \to gg$	$\frac{81}{8}(3-\frac{\hat s\hat u}{\hat t^2}-\frac{\hat s\hat t}{\hat u^2}-\frac{\hat u\hat t}{\hat s^2})$	$\frac{81}{8}(-3+2\frac{\hat s^2}{\hat u\hat t}+\frac{\hat u\hat t}{\hat s^2})$
$gg \to q\bar q$	$\frac{9}{8}(\frac{1}{3}\frac{\hat u^2+\hat t^2}{\hat u\hat t}-\frac{3}{4}\frac{\hat t^2+\hat u^2}{\hat s^2})$	$-\frac{9}{8}(\frac{1}{3}\frac{\hat u^2+\hat t^2}{\hat u\hat t}-\frac{3}{4}\frac{\hat t^2+\hat u^2}{\hat s^2})$
$qg \to \gamma q$	$\frac{1}{3}\frac{\hat s^2+\hat t^2}{\hat s\hat t}$	$\frac{1}{3}\frac{\hat s^2-\hat t^2}{\hat s\hat t}$
$q\bar q \to g\gamma$	$\frac{8}{9}\frac{\hat t^2+\hat u^2}{\hat t\hat u}$	$-\frac{8}{9}\frac{\hat t^2+\hat u^2}{\hat t\hat u}$





Longitudinal double spin asymmetries II

PYTHIA6 based event generator exists:

- **Sphinx v1.1 - Monte Carlo Program for Polarized Nucleon-Nucleon Collisions arXiv:hep-ph/9612278**
- **Developed some 20-25 years ago. It was used mainly for BNL spin physics program preparation in 90s. Sources were found on webarchive.**

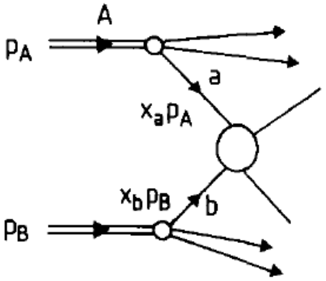
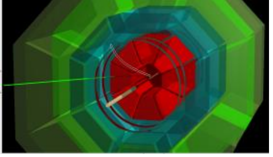


Table 1: List of processes implemented in the polarized mode.

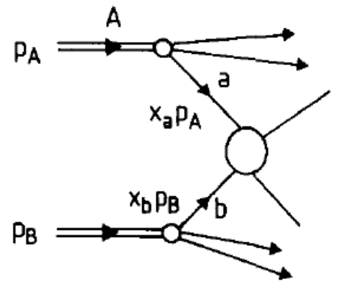
ISUB	Process	Comment
1	$q_i\bar{q}_j \to \gamma^*/Z^0$	quark-antiquark annihilation into virtual γ^*/Z^0
2	$q_i\bar{q}_j \to W^\pm$	annihilation into charged vector boson
11	$q_i q_j \to q_i q_j$	(anti-)quark – (anti-)quark scattering; annihilation diagram not included
12	$q_i\bar{q}_i \to q_k\bar{q}_k$	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	$q_i g \to q_i g$	(anti-)quark – gluon scattering
29	$q_i g \to q_i\gamma$	prompt γ production in (anti-)quark – gluon scattering
30	$q_i g \to q_i Z^0$	Z^0 production in (anti-)quark – gluon scattering
31	$q_i g \to q_j W^\pm$	$W^\pm$ production in (anti-)quark – gluon scattering
53	$gg \to q_k\bar{q}_k$	gluon fusion
68	$gg \to gg$	gluon – gluon scattering

PYTHIA process number	partonic reaction	partonic asymmetry $\frac{\Delta\hat{\sigma}}{\hat{\sigma}}$	remark
11	$qq' \to qq'$	$\left(\hat{s}^2-\hat{u}^2\right)/\left(\hat{s}^2+\hat{u}^2\right)$	
	$q\bar{q}' \to q\bar{q}'$	$\left(\hat{s}^2-\hat{u}^2\right)/\left(\hat{s}^2+\hat{u}^2\right)$	
	$q\bar{q} \to q\bar{q}$	$\left[\hat{s}\left(\hat{s}^2-\hat{u}^2\right)+\frac{2}{3}\mathcal{I}\hat{t}\hat{u}^2/\mathcal{K}\right]/\left[\hat{s}\left(\hat{s}^2+\hat{u}^2\right)-\frac{2}{3}\mathcal{I}\hat{t}\hat{u}^2/\mathcal{K}\right]$	$\hat{t}$- and $\hat{u}$-channel only
	$qq \to qq$	$\left(\hat{s}^2-\hat{u}^2\right)/\left(\hat{s}^2+\hat{u}^2\right)$	colour flow scenario 1
		$\left[\hat{t}\left(\hat{s}^2-\hat{t}^2\right)-\frac{2}{3}\mathcal{I}\hat{s}^2\hat{u}\right]/\left[\hat{t}\left(\hat{s}^2+\hat{t}^2\right)-\frac{2}{3}\mathcal{I}\hat{s}^2\hat{u}\right]$	colour flow scenario 2
12	$q\bar{q} \to q\bar{q}$	-1	$\hat{s}$-channel only
	$q\bar{q} \to q'\bar{q}'$	-1	
13	$q\bar{q} \to gg$	-1	
14	$q\bar{q} \to g\gamma$	-1	
18	$q\bar{q} \to \gamma\gamma$	-1	
28	$qg \to qg$	-1	colour flow scenario 1
		1	colour flow scenario 2
29	$qg \to q\gamma$	$\left(\hat{s}^2-\hat{u}^2\right)/\left(\hat{s}^2+\hat{u}^2\right)$	
53	$gg \to q\bar{q}$	-1	
68	$gg \to gg$	$-\left[\hat{t}^2+2\hat{s}\hat{t}\left(\hat{s}^2+\hat{t}^2\right)+3\hat{s}^2\hat{t}^2\right]/\left[\hat{s}^2+\hat{t}^2+2\hat{s}\hat{t}\left(\hat{s}^2+\hat{t}^2\right)+3\hat{s}^2\hat{t}^2\right]$	colour flow scenario 1
		$-\left[\hat{u}^2+2\hat{s}\hat{u}\left(\hat{s}^2+\hat{u}^2\right)+3\hat{s}^2\hat{u}^2\right]/\left[\hat{s}^2+\hat{u}^2+2\hat{s}\hat{u}\left(\hat{s}^2+\hat{u}^2\right)+3\hat{s}^2\hat{u}^2\right]$	colour flow scenario 2
		$2\left[\hat{t}\hat{u}\left(\hat{t}^2+\hat{u}^2\right)+3\hat{t}^2\hat{u}^2\right]/\left[\hat{t}^2+\hat{u}^2+2\hat{t}\hat{u}\left(\hat{t}^2+\hat{u}^2\right)+3\hat{t}^2\hat{u}^2\right]$	colour flow scenario 3

$\Delta G(x,\mu^2)$ **from jet and prompt photon production at RHIC** O. Martin and A. Schäfer

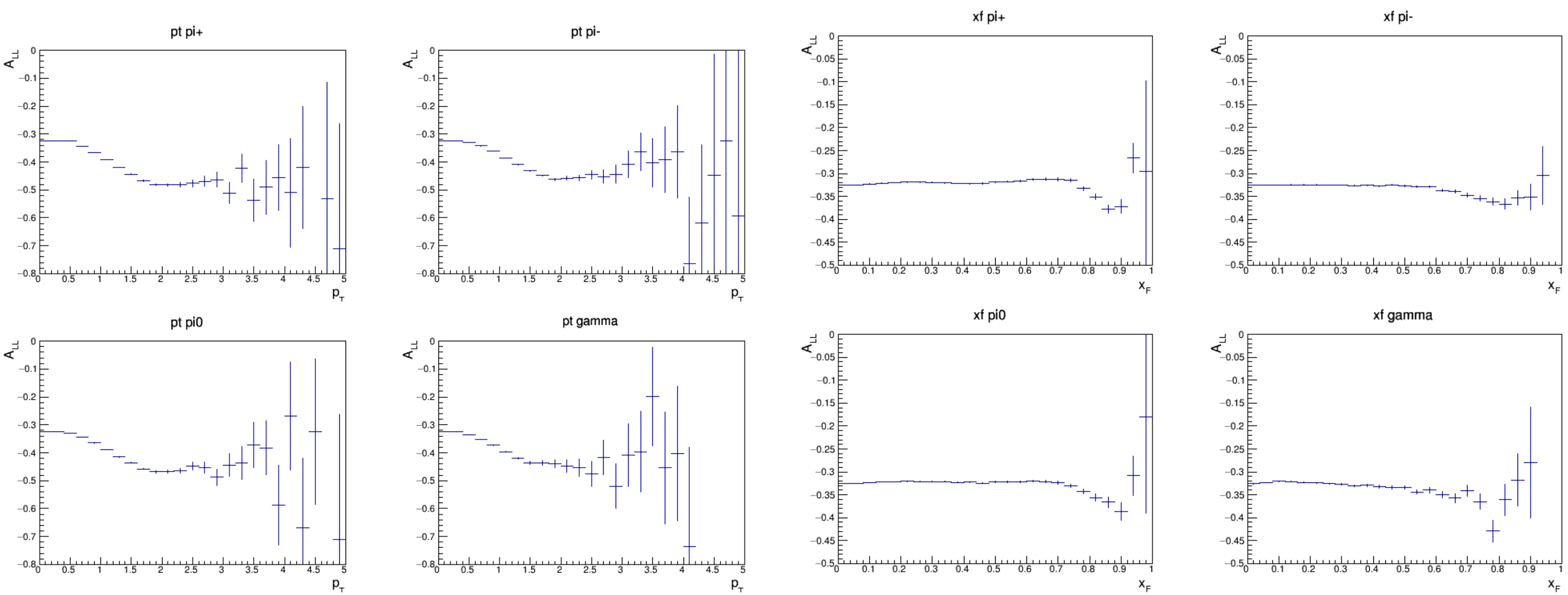


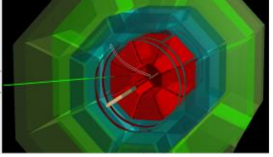
Longitudinal double spin asymmetries III



First A_{LL} simulation results with SPHINX

fake polarization, built up from unpolarized distribution according to $\Delta q = \frac{\mathtt{MSTP(178)}}{100} q$



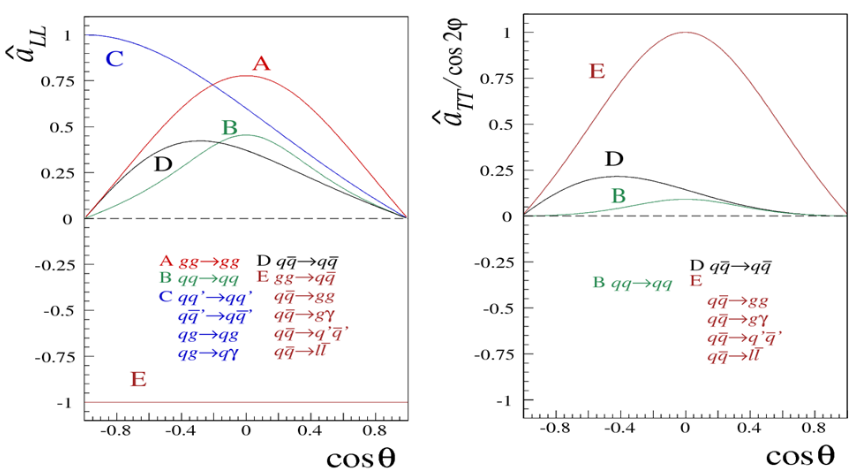


“Polarized” PYTHIA

Another option to take into account polarization is partonic a_{LL} weighting, procedure is accessible with STAR software on github:

- **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)**

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

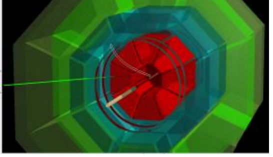


N+- random Poisson distributed (mean is average yield per bunch)

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

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

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



Transverse double spin asymmetries I

$$d\sigma^{(AB)}(P_A;P_B) = \sum_{a,b}\int dx_A dx_B f_a^A(x_A,\mu^2) f_b^B(x_B,\mu^2) d\hat{\sigma}_{a,b}(x_A P_A, x_B P_B, \mu)$$

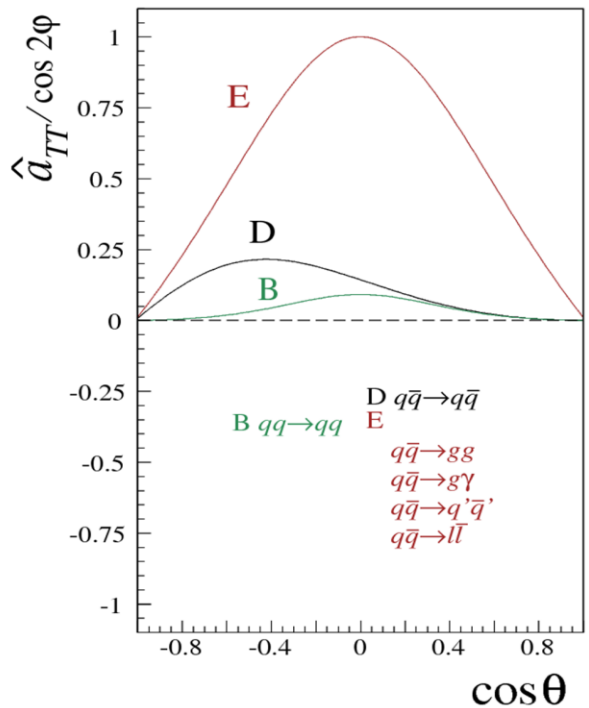
$$A^{TT} = \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}}$$

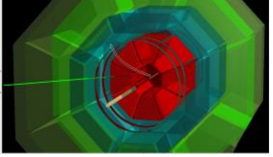
$$\hat{s} = (x_A P_A + x_B P_B)^2\,, \quad \hat{t} = (x_A P_A - k_1)^2\,, \text{ and } \quad \hat{u} = (x_A P_A - k_2)^2$$

Parton process $ab \to cd$	Spin Average Cross Section — σ_{ab}^{cd}	Helicity Dependent Cross Section — $\Delta\sigma_{ab}^{cd}$	Transversity Dependent Cross Section — $\delta\sigma_{ab}^{cd}$
$q\bar{q} \to\to \ell\bar{\ell}$	$\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}$	$-\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}$	$\frac{1}{\hat{s}^2}$
$qq \to qq$	$\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2} - \frac{2}{3}\frac{\hat{s}^2}{\hat{u}\hat{t}}$	$\frac{\hat{s}^2-\hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2-\hat{t}^2}{\hat{u}^2} - \frac{2}{3}\frac{\hat{s}^2}{\hat{u}\hat{t}}$	$\frac{2}{3\hat{t}\hat{u}}$
$qq' \to qq'$	$\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$	$\frac{\hat{s}^2-\hat{u}^2}{\hat{t}^2}$	—
$q\bar{q} \to q\bar{q}$	$\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2} - \frac{2}{3}\frac{\hat{u}^2}{\hat{s}\hat{t}}$	$\frac{\hat{s}^2-\hat{u}^2}{\hat{t}^2} - \frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2} + \frac{2}{3}\frac{\hat{u}^2}{\hat{s}\hat{t}}$	$\frac{2}{\hat{s}^2} - \frac{2}{3\hat{s}\hat{t}}$
$q\bar{q} \to q'\bar{q}'$	$\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}$	$-\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}$	$\frac{2}{\hat{s}^2}$
$q\bar{q}' \to q\bar{q}'$	$\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$	$\frac{\hat{s}^2-\hat{u}^2}{\hat{t}^2}$	—
$q\bar{q} \to gg$	$\frac{8}{3}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}} - 6\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$	$-\frac{8}{3}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}} + 6\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$	$\frac{16}{3\hat{t}\hat{u}} - \frac{12}{\hat{s}^2}$
$qg \to qg$	$\frac{9}{4}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} - \frac{\hat{s}^2+\hat{u}^2}{\hat{u}\hat{s}}$	$\frac{9}{4}\frac{\hat{s}^2-\hat{u}^2}{\hat{t}^2} - \frac{\hat{s}^2-\hat{u}^2}{\hat{u}\hat{s}}$	—
$gg \to gg$	$\frac{81}{8}(3 - \frac{\hat{s}\hat{u}}{\hat{t}^2} - \frac{\hat{s}\hat{t}}{\hat{u}^2} - \frac{\hat{u}\hat{t}}{\hat{s}^2})$	$\frac{81}{8}(-3 + 2\frac{\hat{s}^2}{\hat{u}\hat{t}} + \frac{\hat{u}\hat{t}}{\hat{s}^2})$	—
$gg \to q\bar{q}$	$\frac{9}{8}(\frac{1}{3}\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} - \frac{3}{4}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2})$	$-\frac{9}{8}(\frac{1}{3}\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} - \frac{3}{4}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2})$	—
$qg \to \gamma q$	$\frac{1}{3}\frac{\hat{s}^2+\hat{t}^2}{\hat{s}\hat{t}}$	$\frac{1}{3}\frac{\hat{s}^2-\hat{t}^2}{\hat{s}\hat{t}}$	—
$q\bar{q} \to g\gamma$	$\frac{8}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}$	$-\frac{8}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}$	$\frac{8}{9}\frac{2}{\hat{u}\hat{t}}$

Table iii: Parton cross sections and asymmetries. Each entry multiplies a factor of $\frac{4\pi\alpha_s^2}{9\hat{s}^2}$, except for the first (Drell-Yan) which multiplies $\frac{4\pi\alpha_{em}^2 e_q^2}{3\hat{s}^2}$, and the last (prompt γ production) which multiplies $\frac{\pi\alpha_s\alpha_{em}e_q^2}{\hat{s}^2}$. In addition, helicity entries multiply ± 1 according to whether the beam helicities are equal (+**1**) or opposite (-**1**), and transversity entries multiply the kinematic factor $\{\hat{u}\hat{t}S_a\cdot S_b - \hat{s}(S_a\cdot k_a S_b\cdot k_b + S_b\cdot k_a S_a\cdot k_b)\}$, which is proportional to $\sin^2\theta\cos 2\phi$ in the parton-parton center of mass frame.

$$A_{DY}^{TT} = \frac{\sin^2\hat{\theta}\cos 2\hat{\phi}}{1+\cos^2\hat{\theta}}\,\frac{\sum_i e_i^2 \delta q_i(x_A,Q^2)\,\delta\bar{q}_i(x_B,Q^2) + A\leftrightarrow B}{\sum_i e_i^2 q_i(x_A,Q^2)\,\bar{q}_i(x_B,Q^2) + A\leftrightarrow B}$$





Transverse double spin asymmetries II

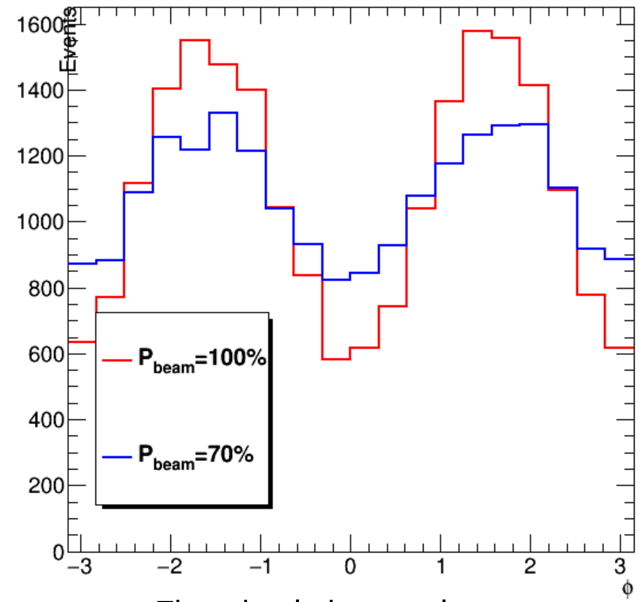
SPHINX TT - Monte Carlo Program for Nucleon-Nucleon Collisions with Transverse Polarization
arXiv:hep-ph/9612305

$$A^{TT} = \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}}$$

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

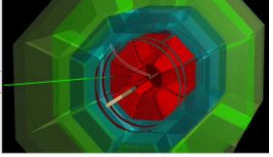
Table 1: List of processes implemented in the polarized mode

$$A^{TT}_{DY} = \frac{\sin^2\hat{\theta}\cos 2\hat{\phi}}{1+\cos^2\hat{\theta}} \frac{\sum_i e_i^2 \delta q_i(x_A, Q^2)\, \delta\bar{q}_i(x_B, Q^2) + A \leftrightarrow B}{\sum_i e_i^2 q_i(x_A, Q^2)\, \bar{q}_i(x_B, Q^2) + A \leftrightarrow B}$$



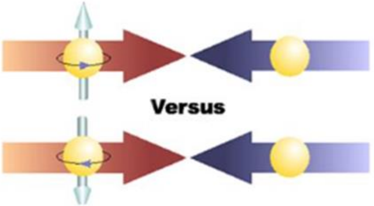
First simulation result with SPHINX-TT

MC-Simulation of the Transverse Double Spin Asymmetry for RHIC
arXiv:hep-ph/9607470



Transverse single spin asymmetries I

Transverse single spin asymmetry, also called left-right asymmetry (observed using certain azimuthal angle range)



$$p(P, S_T) + p(P') \rightarrow \pi(P_h) + X$$

$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$

$$A_N \equiv \frac{d\Delta\sigma(S_T)}{d\sigma}, \quad \text{where} \quad d\Delta\sigma(S_T) \equiv \frac{1}{2}\left[d\sigma(S_T) - d\sigma(-S_T)\right], \quad \text{and} \quad d\sigma \equiv \frac{1}{2}\left[d\sigma(S_T) + d\sigma(-S_T)\right]$$

L. Gamberg, Zh. Kang, D. Pitonyak, A. Prokudin JLAB-THY-17-2405

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[4] A. V. Efremov and O. V. Teryaev, Phys. Lett. **B150**, 383 (1985).
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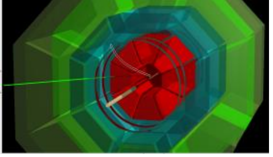
$$E_h \frac{d\sigma}{d^3\vec{P}_h} = \frac{\alpha_S^2}{S} \sum_i \sum_{a,b,c} \int_0^1 \frac{dz}{z^2} \int_0^1 \frac{dx'}{x'} \int_0^1 \frac{dx}{x}\, \delta(\hat{s} + \hat{t} + \hat{u})\, f_1^a(x)\, f_1^b(x')\, D_1^{\pi/c}(z)\, S_U^i$$

$$E_h \frac{d\Delta\sigma(S_T)}{d^3\vec{P}_h} = E_h \frac{d\Delta\sigma^{QS}(S_T)}{d^3\vec{P}_h} + E_h \frac{d\Delta\sigma^{Frag}(S_T)}{d^3\vec{P}_h}$$



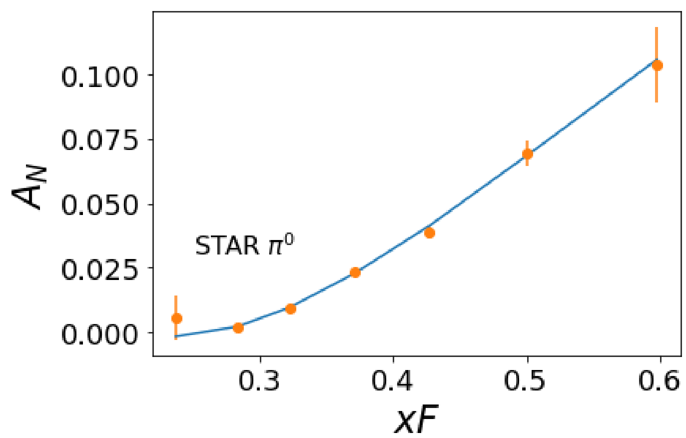
Transverse single spin asymmetries II

$$E_h \frac{d\Delta\sigma^{QS}(S_T)}{d^3\vec{P}_h} = -\frac{4\alpha_S^2 M}{S}\,\epsilon^{P'PP_hS_T}\sum_i\sum_{a,b,c}\int_0^1\frac{dz}{z^3}\int_0^1 dx'\int_0^1 dx\;\delta(\hat{s}+\hat{t}+\hat{u})\frac{\pi}{\hat{s}\hat{u}}$$
$$\times\, f_1^b(x')\,D_1^{\pi/c}(z)\left[F_{FT}^a(x,x) - x\frac{dF_{FT}^a(x,x)}{dx}\right]S^i_{F_{FT}}\,,$$

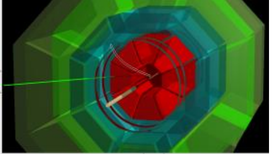
$$E_h \frac{d\Delta\sigma^{Frag}(S_T)}{d^3\vec{P}_h} = -\frac{4\alpha_s^2 M_h}{S}\,\epsilon^{P'PP_hS_T}\sum_i\sum_{a,b,c}\int_0^1\frac{dz}{z^3}\int_0^1 dx'\int_0^1 dx\;\delta(\hat{s}+\hat{t}+\hat{u})\frac{1}{\hat{s}\,(-x'\hat{t}-x\hat{u})}$$
$$\times\, h_1^a(x)\,f_1^b(x')\left\{\left[H_1^{\perp(1),\pi/c}(z) - z\frac{dH_1^{\perp(1),\pi/c}(z)}{dz}\right]S^i_{H_1^\perp} + \frac{1}{z}H^{\pi/c}(z)\,S^i_H + \frac{2}{z}\int_z^\infty\frac{dz_1}{z_1^2}\frac{1}{\left(\frac{1}{z}-\frac{1}{z_1}\right)^2}\hat{H}_{FU}^{\pi/c,\Im}(z,z_1)\,S^i_{\hat{H}_{FU}}\right\}$$

L. Gamberg, M. Malda, J. Miller, D. Pitonyak, A. Prokudin, N.Sato JLAB-THY-22-3604 TMD fit

Observable	Reactions	Non-Perturbative Function(s)
$A_{UT}^{\sin(\phi_h-\phi_S)}$	$e+(p,d)^\uparrow \to e+(\pi^+,\pi^-,\pi^0)+X$	$f_{1T}^\perp(x,\vec{k}_T^2)$
$A_{UT}^{\sin(\phi_h+\phi_S)}$	$e+(p,d)^\uparrow \to e+(\pi^+,\pi^-,\pi^0)+X$	$h_1(x,\vec{k}_T^2), H_1^\perp(z,z^2\vec{p}_T^2)$
$^*A_{UT}^{\sin\phi_S}$	$e+p^\uparrow \to e+(\pi^+,\pi^-,\pi^0)+X$	$h_1(x), \tilde{H}(z)$
$A_{UC/UL}$	$e^++e^- \to \pi^+\pi^-(UC,UL)+X$	$H_1^\perp(z,z^2\vec{p}_T^2)$
$A_{T,\mu^+\mu^-}^{\sin\phi_S}$	$\pi^-+p^\uparrow \to \mu^+\mu^-+X$	$f_{1T}^\perp(x,\vec{k}_T^2)$
$A_N^{W/Z}$	$p^\uparrow+p \to (W^+,W^-,Z)+X$	$f_{1T}^\perp(x,\vec{k}_T^2)$
A_N^π	$p^\uparrow+p \to (\pi^+,\pi^-,\pi^0)+X$	$h_1(x), F_{FT}(x,x)=\frac{1}{\pi}f_{1T}^{\perp(1)}(x), H_1^{\perp(1)}(z), \tilde{H}(z)$
Lattice g_T	——	$h_1(x)$

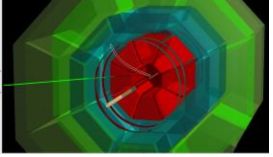


TMDs, $\sqrt{s}$, x_F , p_T , product (π^+, π^-, π^0, γ) $\rightarrow A_N$
can be tried for PYTHIA event weighting



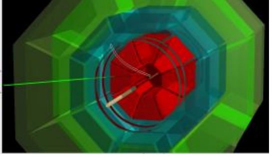
Conclusion

- There are some options for the polarization asymmetry calculation on the event basis
- My opinion that it might be useful to start with event weighting approach
- There is preparatory work on hyperon polarization (D_{LL} , D_{TT}) estimator



Backup

Thank you



“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 diffe
	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:

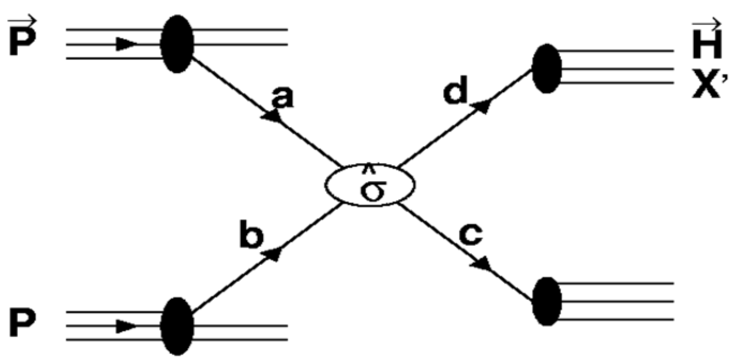
- (Un)Polarised PDFs, (un)polarized fragmentation functions,
- QCD crossections 2->2 (spin-dependent and not)
- Transmitted asymmetries give degree of final quark polarisation

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

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

Spin-dependent PDF

Spin dependent fragmentation function

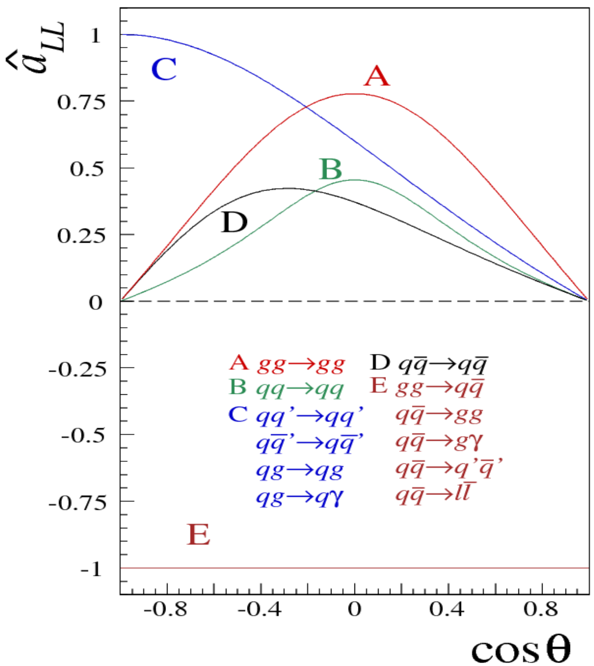


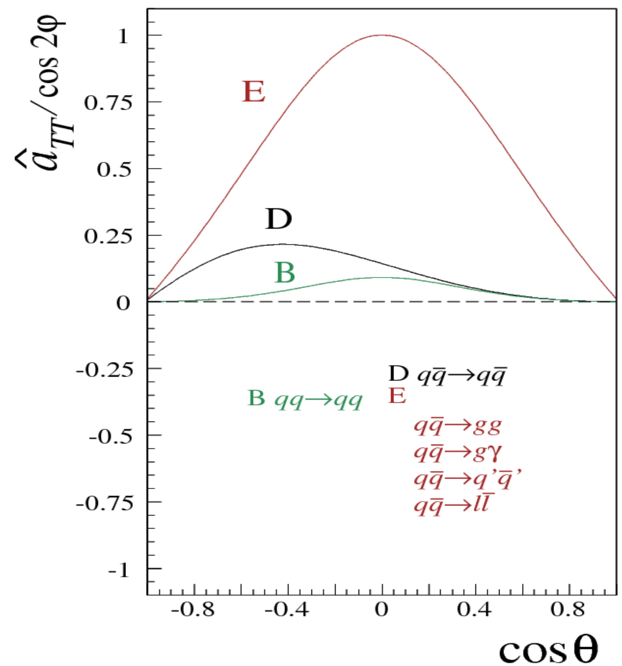
$$\vec{p}p \to HX$$

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

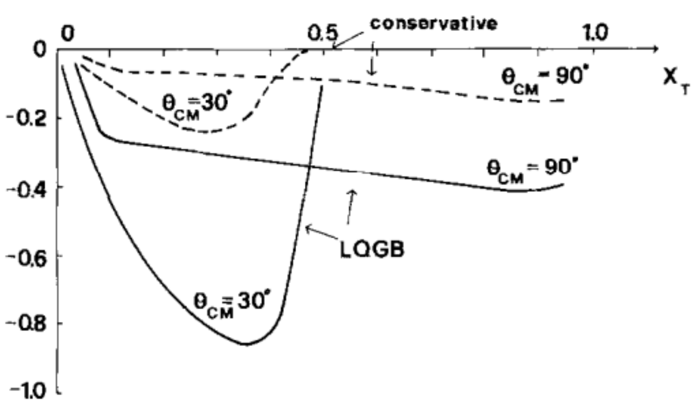
Spin transfer to hyperons in pp

Transmitted asymmetries:

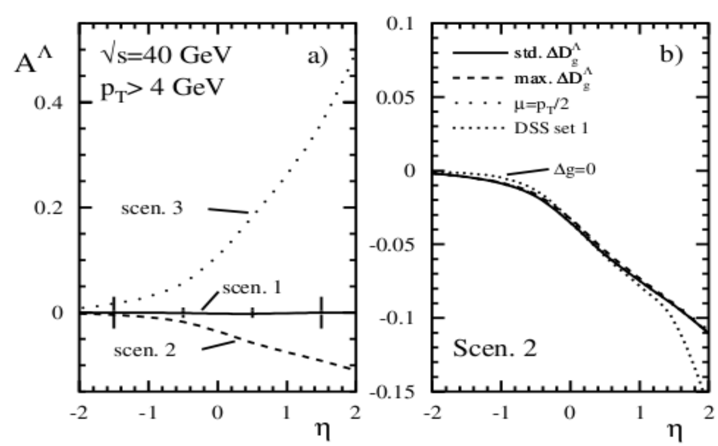




$$A^{\Lambda} \equiv \frac{d\Delta\sigma^{p\vec{p} \to \vec{\Lambda} X}/d\eta}{d\sigma^{pp \to \Lambda X}/d\eta}$$

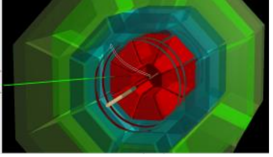


$$x_T = \frac{2p_{\Lambda T}}{\sqrt{s}}.$$



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

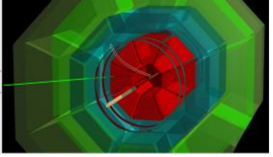
$$D_{LL} = \frac{1}{\alpha \cdot P_{beam} < \cos\theta^* >} \cdot \frac{N^+ - N^-}{N^+ + N^-}$$

, where the acceptance cancels.

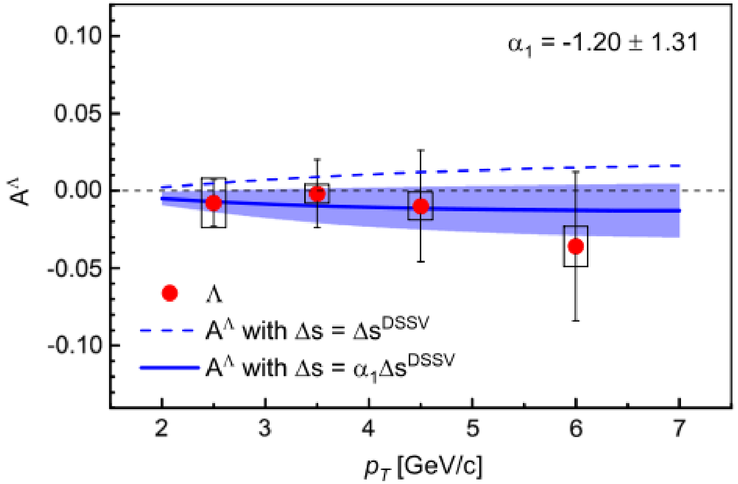
$$N^+_\Lambda = N^{++} \frac{L_{--}}{L_{++}} + N^{+-} \frac{L_{--}}{L_{+-}}$$

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

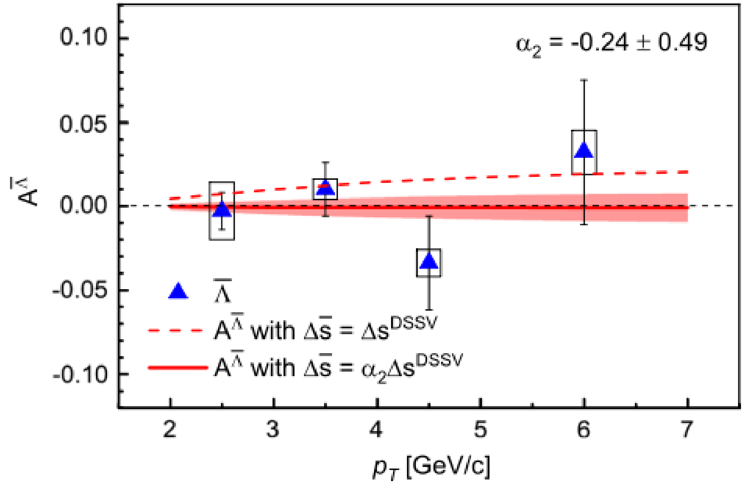
Relative luminosity ratio measured with BBC, and P_{beam} in RHIC.



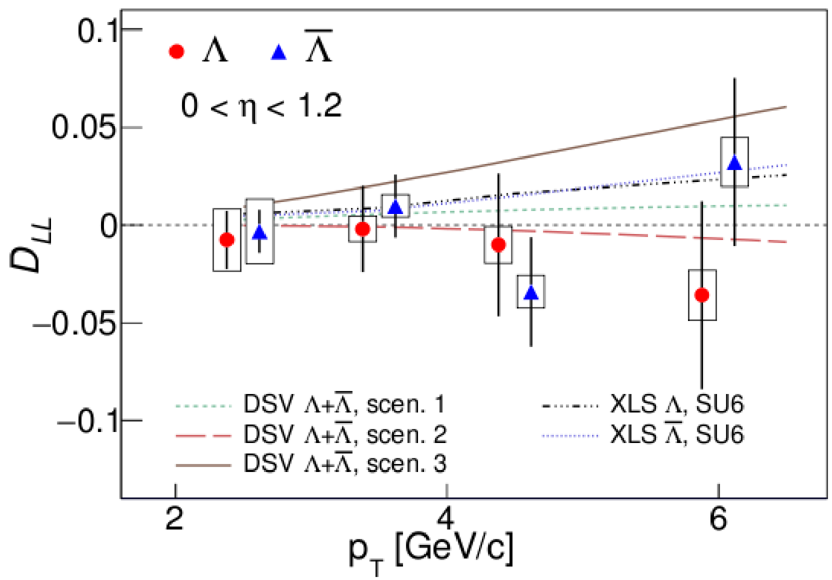
RHIC results on D_{LL}



(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

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

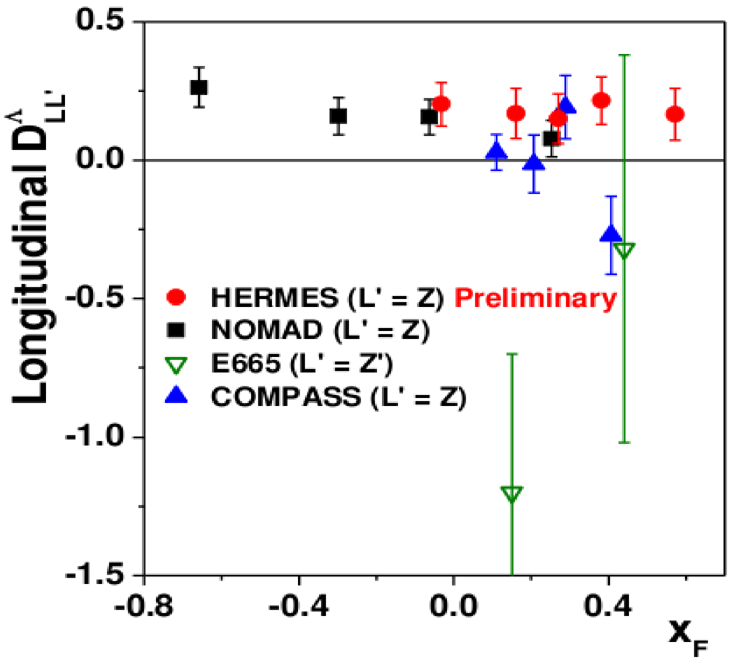
$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P_{L'}^{\Lambda} \cos\theta_{pL'})$$

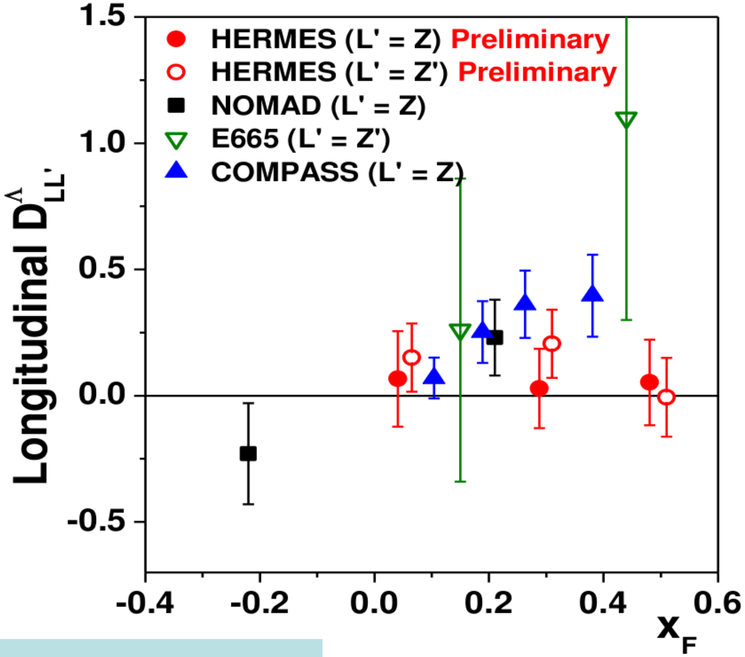
$\alpha = 0.642$ for Λ ($\alpha = -0.642$ for $\bar{\Lambda}$)

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

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

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





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