IV Sardinian Workshop on Spin
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Modeling baryon production in polarized string fragmentation

Albi Kerbizi
Lund University, INFN Trieste

in collaboration with Xavier Artru (IP2I, Lyon)

Funded by the European Union

MARIE CURIE ACTIONS
SPINFRAG

LUND UNIVERSITY

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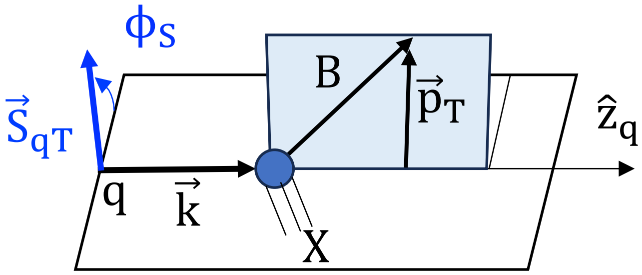
Istituto Nazionale di Fisica Nucleare

Introduction: spin effects in baryon production

- Production of spin 1/2 baryons, many interesting effects
  - **Collins effect** Collins, NPB 396, 161 (1993)



Collins FF

T polarized q
unpolarized B

$z = p^+/k^+$

$$D_{q^\uparrow \to B+X}(z, \vec{p}_T) = D_{1q}^{B}(z, p_T^2) + \frac{H_{1q}^{B\perp}(z, p_T^2)}{z M_B} \vec{S}_{qT} \cdot \hat{z}_q \times \vec{p}_T$$

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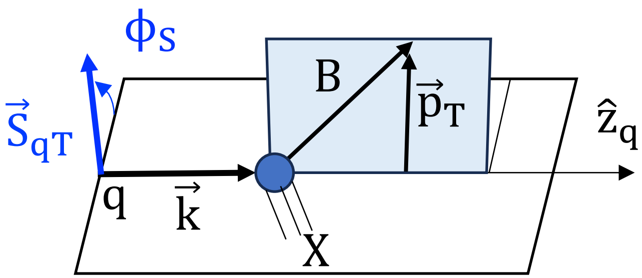

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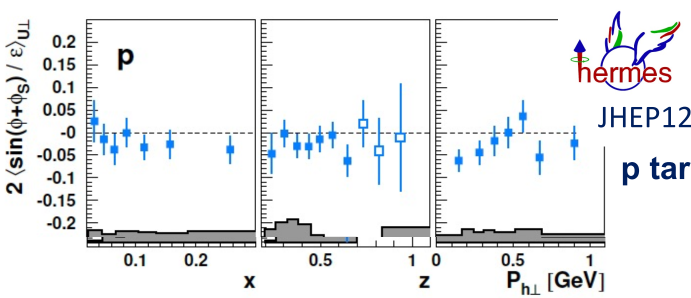
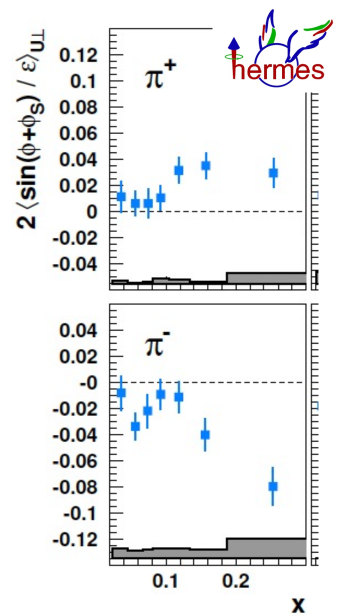


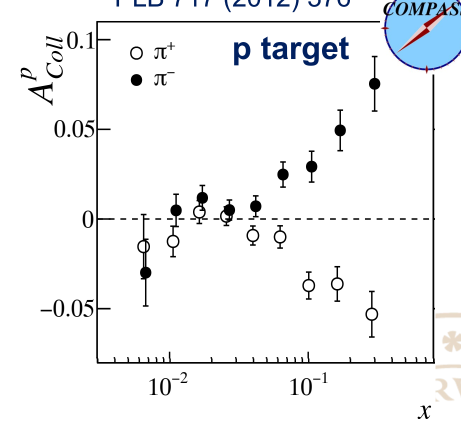
JHEP12 (2020) 010

p target

- Limited data
- Indication for a small effect (opposite to π^+)?



PLB 717 (2012) 376



pions

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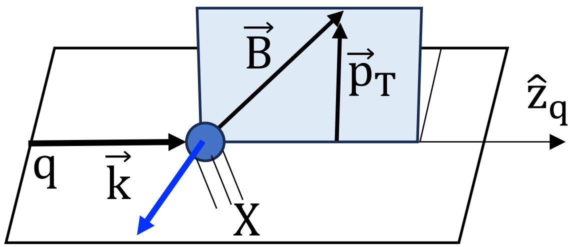
  - **Spontaneous polarization of hyperons**

Mulders, Tangerman, NPB 484, 538-540 (1997)
Anselmino et al., PRD 63 054029 (2001)



$\vec{S}_{BT} \propto \hat{z}_q \times \vec{p}_T$

Polarizing FF

unpolarized q
T polarized B

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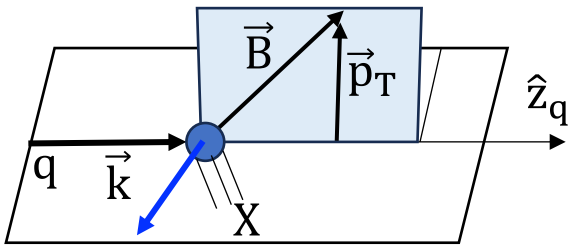

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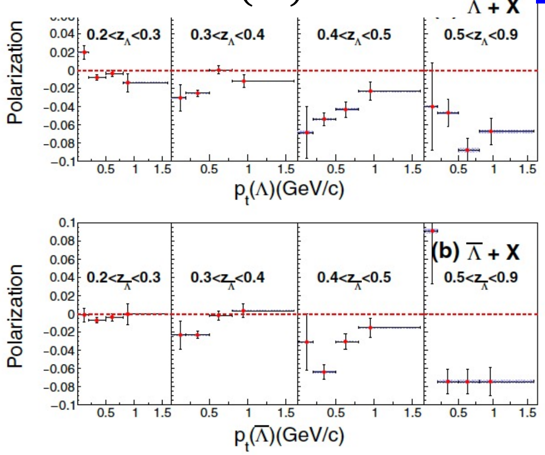
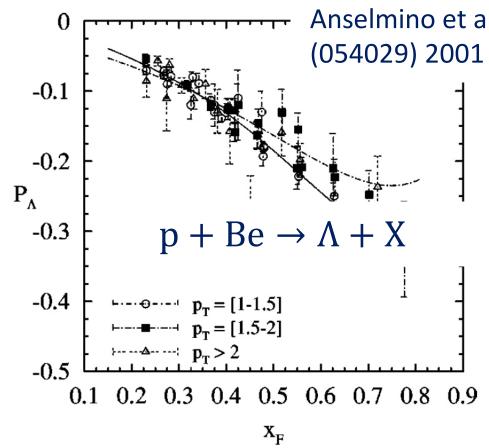
$e^+e^- \to \Lambda^\uparrow(\bar{\Lambda}^\uparrow) + X$

PRL 122, 042001 (2019)



Anselmino et al., PRD63 (054029) 2001



Sizeable effects both in hadronic collisions and e^+e^- annihilation

Many phenomenological studies
- Anselmino et al., PRD63 (054029) 2001
- D'Alesio, Murgia, Zaccheddu, PRD 102, 054001 (2020)
- D'Alesio, Gamberg, Murgia, Zaccheddu, JHEP12 (2022) 074; PRD 108, 094004 (2023); PLB 851 (2024) 138552
- Kang et al., PRD 105, 094303 (2022)

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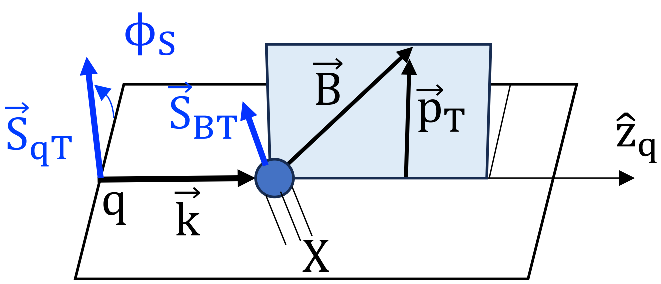

«transversity» FF — T polarized q, T polarized B

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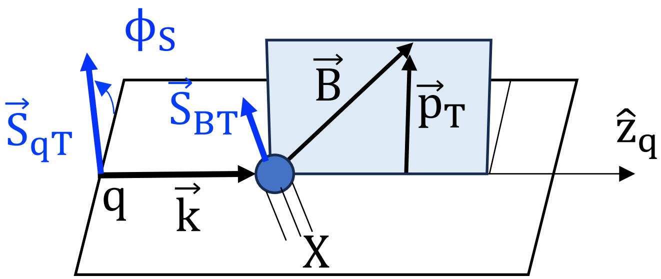

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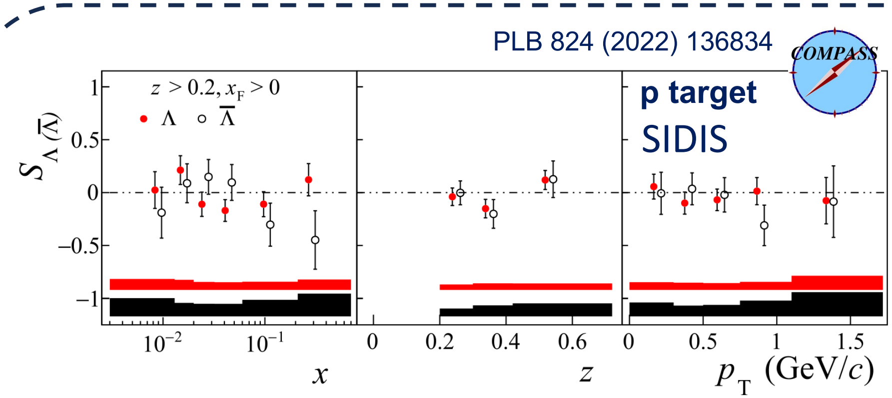
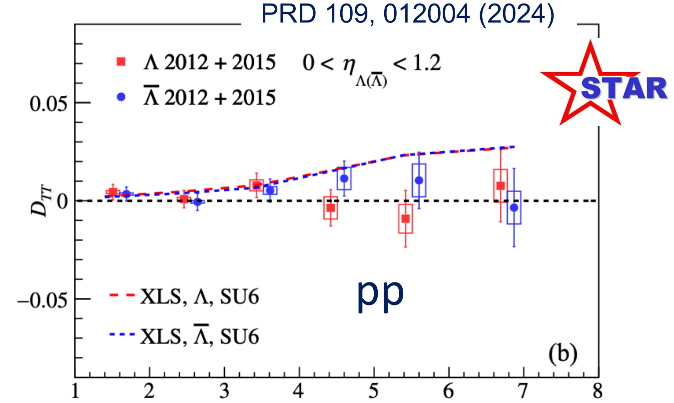
PLB 824 (2022) 136834



PRD 109, 012004 (2024)



The spin transfer to $\Lambda, \bar{\Lambda}$ is small?

Introduction: spin effects in baryon production

- Production of spin 1/2 baryons, many interesting effects
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  - Transverse spin transfer to hyperons
  - Longitudinal spin transfer etc..

- Modeling these effects is challenging → need amplitudes not probabilities

- The model should be suitable for inclusion in Pythia → we want it to be useful for present and future experiments (EIC, JLAB22, LHCSpin,..)

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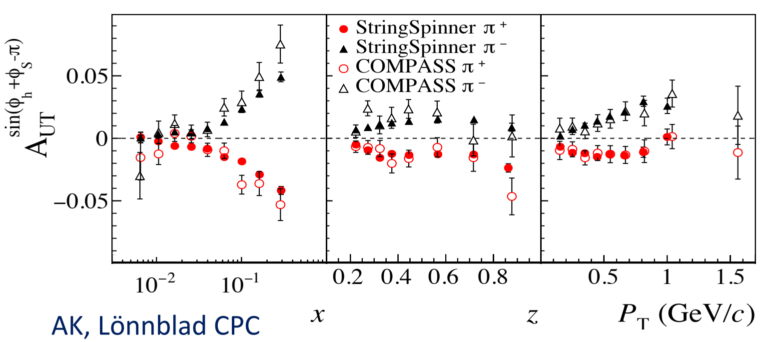
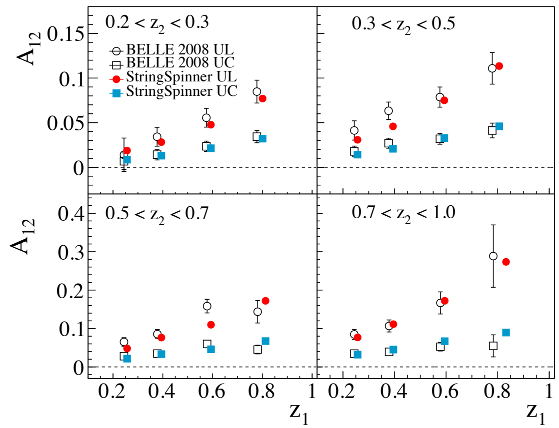
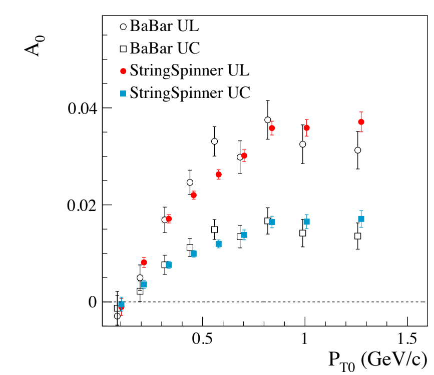
- Extend the string+$^3P_0$ model → shown to reproduce transverse spin effects in SIDIS, e^+e^- [StringSpinner]



AK, Lönnblad CPC **292** (2023) 108886





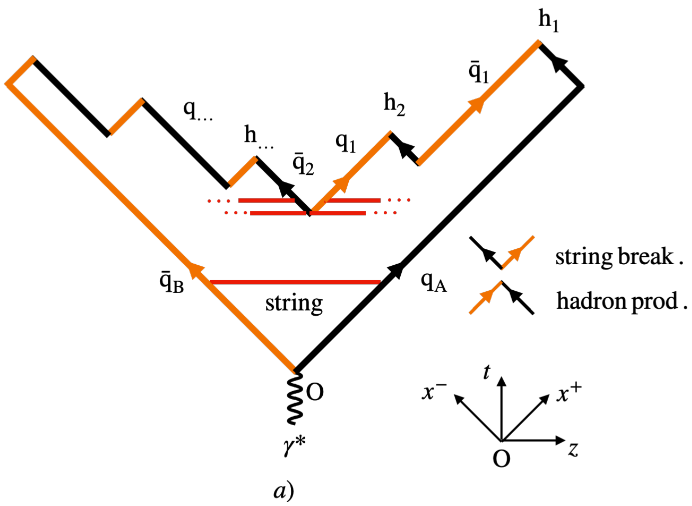
AK, L. Lönnblad, A. Martin, PRD 110 (2024) 7, 074029

In the following slides

- recall of string+$^3P_0$
- new amplitudes for baryon production
- predictions of the new model

The string+$^3P_0$ model

- Lund Model of string fragmentation (spinless) ⊗ $^3P_0$ mechanism at string breaking (spin)



x^- as "time" → recursive splittings $q \to h + q'$

x^+ as "time" → recursive splittings $\bar{q} \to h + \bar{q}'$

Equivalent formulations → Left-Right symmetry

Andersson, Gustafson, Söderberg,
Z Phys. C 20, 317 (1983)

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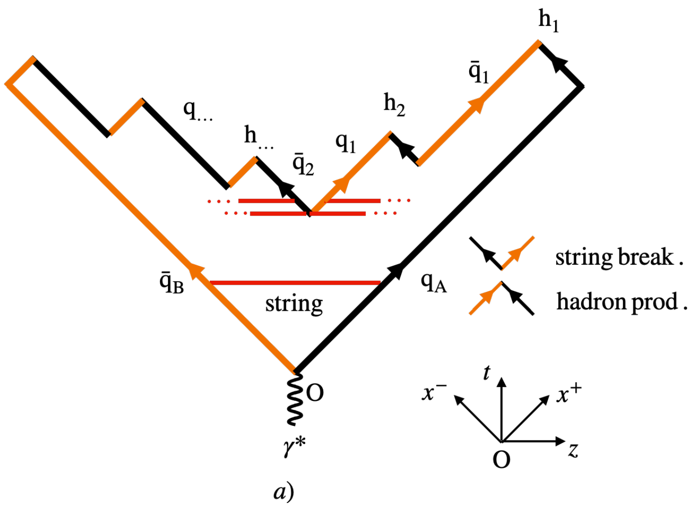

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Equivalent formulations → Left-Right symmetry

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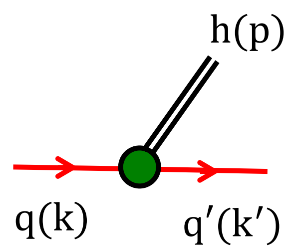
- Spinless splitting function for $q \to h + q'$



$$Z_+ = p^+/k^+$$
$$\mathbf{k}_T = \mathbf{p}_T + \mathbf{k}'_T$$
$$\varepsilon_h^2 = M^2 + \mathbf{p}_T^2$$

$$F^{LM}_{q',h,q} = \left|C_{q',h,q}\right|^2 \ |D_h(M^2)|^2 \left(\frac{1-Z_+}{Z_+}\right)^{a_{q'}} \left(\frac{Z_+}{\varepsilon_h^2}\right)^{a_q} \exp\left[-\frac{b_L \varepsilon_h^2}{2Z_+}\right] N_a^{-\frac{1}{2}}(\varepsilon_h^2)\, e^{-\frac{b_T k'^2_T}{2}}$$

h flavour wf

mass spectrum of resonance

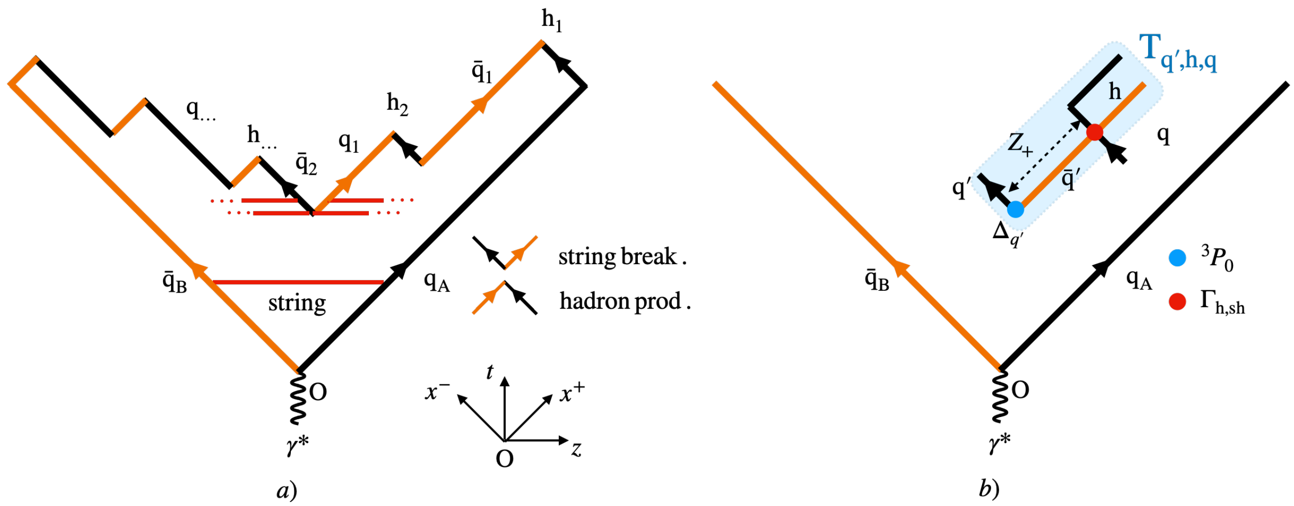
string fragmentation

transverse momentum cutoff

- Basics of string fragmentation in Pythia.. many parameters

The string+$^3P_0$ model

- Lund Model of string fragmentation (spinless) $\otimes$ $^3P_0$ mechanism at string breaking (spin)



- Spin-dependent splitting matrix (2x2)
  quarks (antiquarks) are taken to have $v_z \simeq -1(+1)$

$^3P_0$ propagator

$$T_{q',h,q} \propto \left[F^{LM}_{q',h,q}\right]^{\frac{1}{2}} \otimes \Delta_{q'}(\mathbf{k}'_T) \quad \Gamma_{h,s_h}$$

coupling

$$\chi_{q'}(\mathbf{S}_{q'}) = T_{q',h,q}\ \chi_q(\mathbf{S}_q)$$

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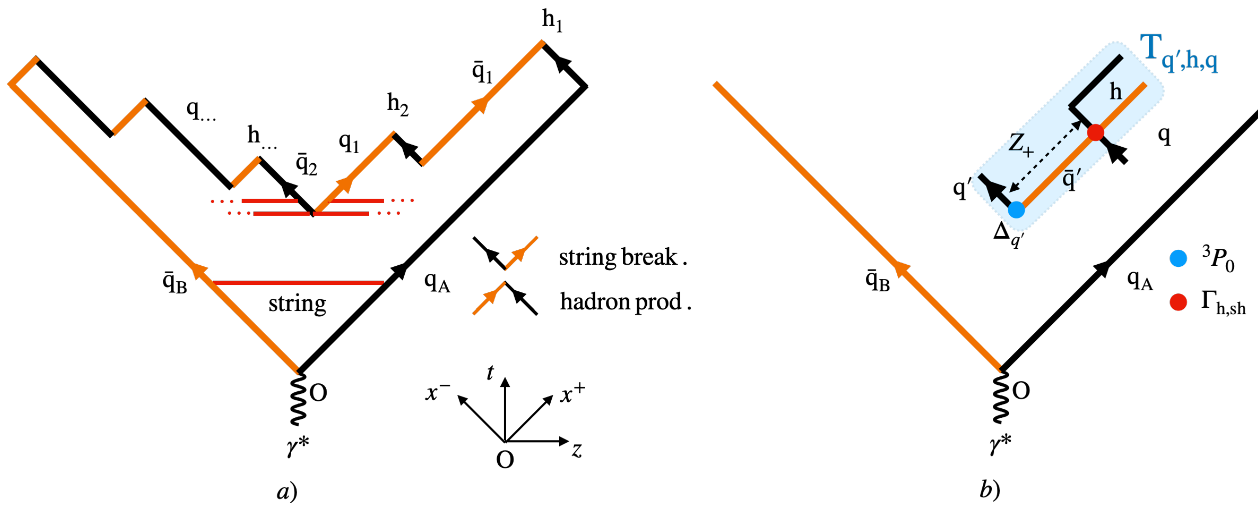

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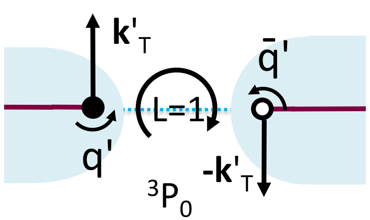


$J^{PC}=0^{++}$

$^3P_0$ pair production

$$\Delta_{q'} = \mu + \sigma_z \boldsymbol{\sigma}_T \cdot \mathbf{k}'_T$$

$\mu = [0.42 + i0.76]\ \mathrm{GeV}/c^2$

«complex quark ~~mass~~» long. momentum

$^3P_0$ propagator

$$T_{q',h,q} \propto \left[F^{LM}_{q',h,q}\right]^{\frac{1}{2}} \otimes \Delta_{q'}(\mathbf{k}'_T) \quad \Gamma_{h,s_h}$$

coupling

$$\chi_{q'}(\mathbf{S}_{q'}) = T_{q',h,q}\ \chi_q(\mathbf{S}_q)$$

$$\Gamma_{PS} = \sigma_z$$

$$\Gamma_{VM} = G_T \vec{\sigma}_T \sigma_z \cdot \vec{V}^*_T + G_L\ 1\ V^*_L$$

G_T, G_L coupling constants

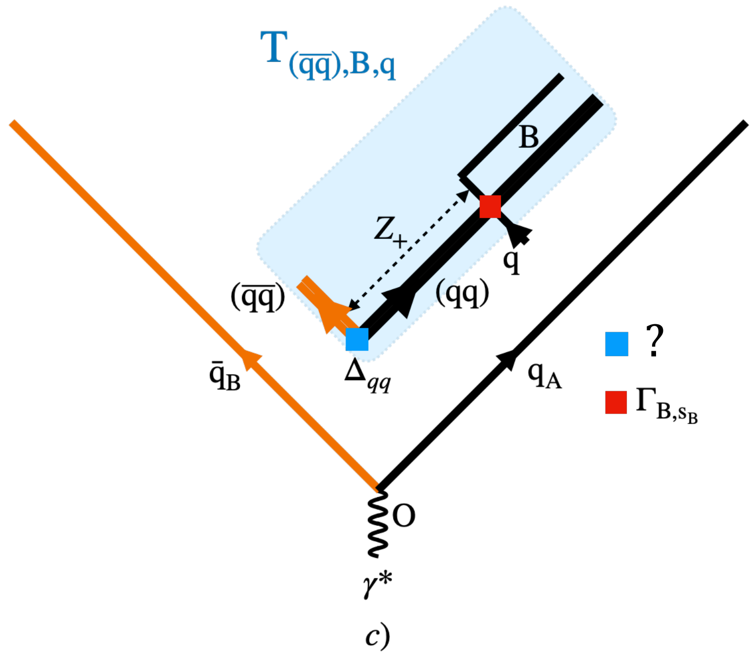
In the following slides

- recall of string+$^3P_0$
- new amplitudes for baryon production
- predictions of the new model

AK, X. Artru, in preparation

String breaking by diquark-antidiquark pairs

- We model baryons as q – qq bound states
- Assume string to break by tunneling of $(\mathrm{qq}) - (\overline{\mathrm{qq}})$ pairs
  - (spinless) model introduced by the Lund group included in Pythia — Andersson, Gustafson, Sjöstrand, NPB 197, 45 (1982)
- Distinguish between
  - scalar $(\mathrm{qq})_0$
  - pseudovector $(\mathrm{qq})_1$



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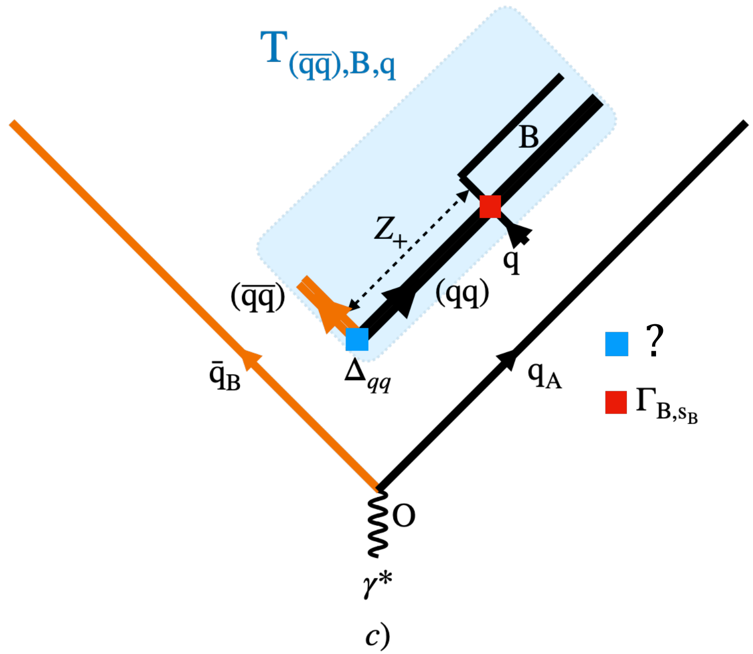
- Distinguish between
  scalar $(qq)_0$
  pseudovector $(qq)_1$

- (qq) tunneling suppressed compared to q tunneling

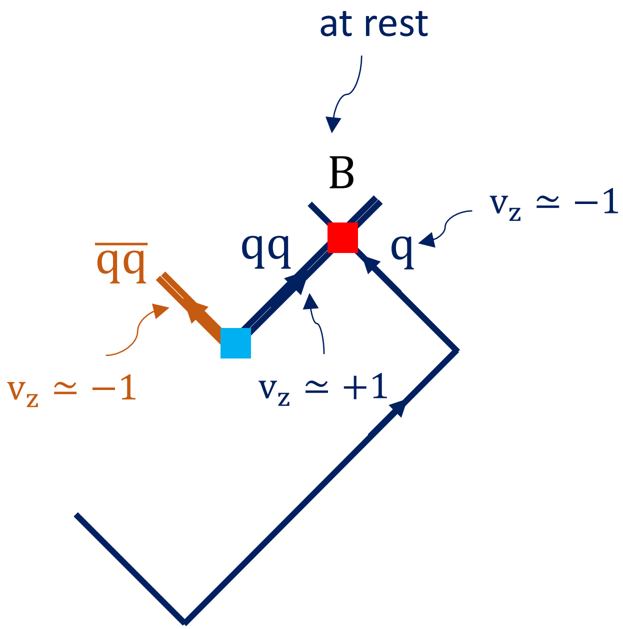
Schwinger formula	$P_{qq} \simeq e^{-\pi\frac{m_{qq}^2}{\kappa}}$
string tension	$\kappa \simeq 0.2\ \mathrm{GeV}^2$
typical qq mass	$m_{qq} \sim 0.5\ \mathrm{GeV}$
Pythia	$P_{qq}/P_q \sim 0.1$

- $(qq)_1$ suppressed w.r.t $(qq)_0$
  Pythia $P_{(qq)_1}/P_{(qq)_0} \sim 0.03$

- Need to introduce new splitting amplitudes for
  $q \to B + (\overline{qq})_1$ $\quad (\overline{qq})_1 \to \overline{B} + q'$
  $q \to B + (\overline{qq})_0$ $\quad (\overline{qq})_0 \to \overline{B} + q'$



Splitting amplitude for $q \to B + (\overline{qq})$



- Propagation of PV diquark $(qq)_1$

$$\chi^\dagger(\mathbf{S}_B)\, T_{(\overline{qq})_1,B,q}\, \chi(\mathbf{S}_q) = \left[F^{LM}_{(\overline{qq})_1,B,q}\right]^{\frac{1}{2}} \times$$

$$\times\, \phi^\dagger_{\overline{qq},a}\, \Delta_{qq,ab}(\mathbf{k}'_T)\;\; \chi^\dagger(S_B)\, \Gamma_{B,b}\, \chi(S_q)$$

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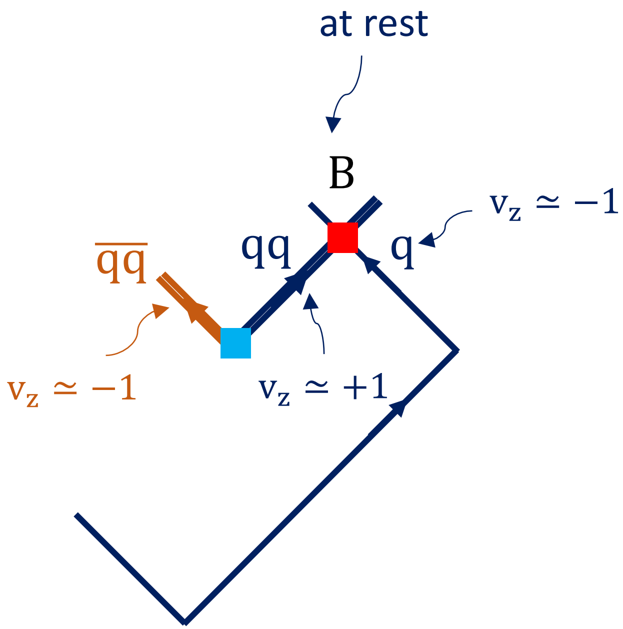

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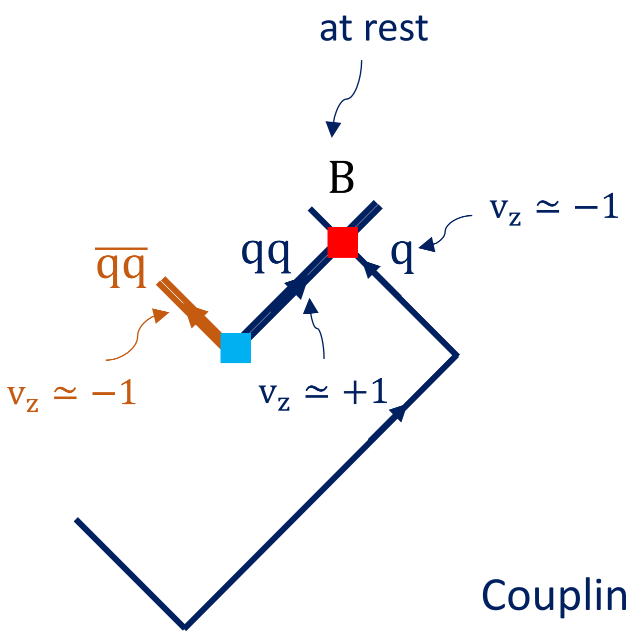
Spin-less Lund splitting function → energy-momentum sharing between $\overline{qq}$ and B

$$F^{LM}_{\overline{qq},B,q} = \left|C_{\overline{qq},B,q}\right|^2\ |D_B(M^2)|^2 \left(\frac{1-Z_+}{Z_+}\right)^{a_{qq}} \left(\frac{Z_+}{\varepsilon_B^2}\right)^{a} \exp\left[-\frac{b_L \varepsilon_B^2}{2Z_+}\right] N^{-\frac{1}{2}}_{a_{qq},a_q}(\varepsilon_B^2)\, e^{-\frac{b_T k'^2_T}{2}}$$

$$N_{a_{qq},a_q}(\varepsilon_B^2) = \int_0^1 dZ\, Z^{-1} \left(\frac{1-Z_+}{Z_+}\right)^{a_{qq}} \left(\frac{Z_+}{\varepsilon_B^2}\right)^{a_q} \exp\left[-\frac{b_L \varepsilon_B^2}{2Z_+}\right]$$

Splitting amplitude for $q \rightarrow B + (\overline{qq})$



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$$\times\, \phi^\dagger_{\overline{qq},a}\, \Delta_{qq,ab}(\mathbf{k}'_T)\;\; \chi^\dagger(S_B)\, \Gamma_{B,b}\, \chi(S_q)$$

$\Gamma_{B,b} \downarrow \sigma_b$, $b = x, y, L$

Coupling for $q \rightarrow B + qq$ from reduction of covariant amplitude

$$\bar{u}(B)\, \gamma_5 \gamma^\mu\, \varepsilon^*_{qq,\mu}\, u(q) \rightarrow \phi^\dagger_{qq,b}\, \chi^\dagger(S_B)\, \sigma_b\;\; \chi(S_q)$$

Covariant coupling
Bacchetta, Conti, Radici, PRD78, 074010

reduced coupling

$$\phi_{qq} = (\boldsymbol{\varepsilon}_T, \phi_L)$$

reduced qq pol. vector
with $v_z \simeq +1$

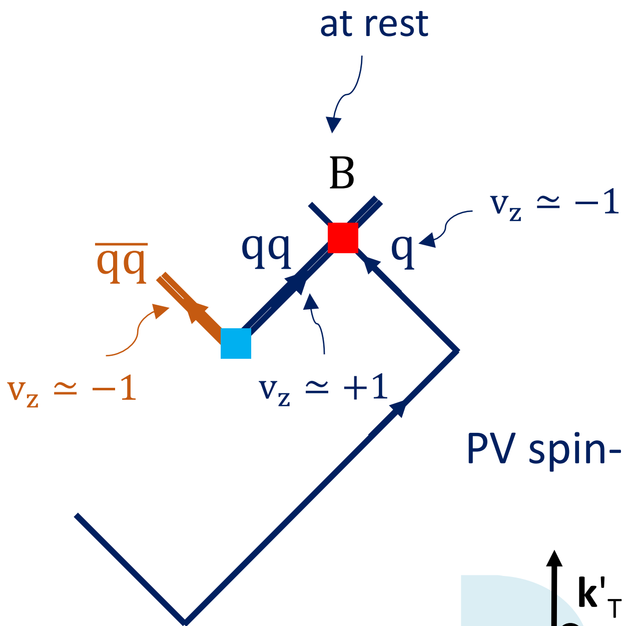
$$\phi_L = 2\varepsilon^z_{qq}$$

B at rest with boosts

$$B_T^{-1}(p_T/\varepsilon_B^2)B_L^{-1}(p_z/M_B)$$

required by LR symmetry

Splitting amplitude for $q \to B + (\overline{qq})$



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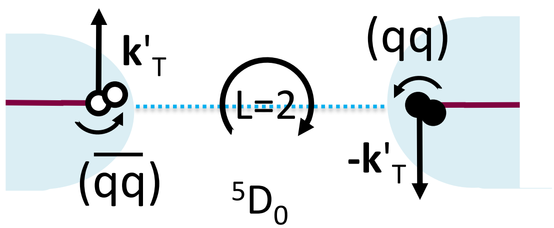
PV spin-1 diquark propagator



Vacuum quantum numbers

$J^{PC} = 0^{++} \to \vec{L} = -(\vec{S}_{qq} + \vec{S}_{\overline{qq}})$

$P = (-)^L, \qquad C = (-)^{L+S}$

Hence

$L = S = 0 \to {}^1S_0$ state

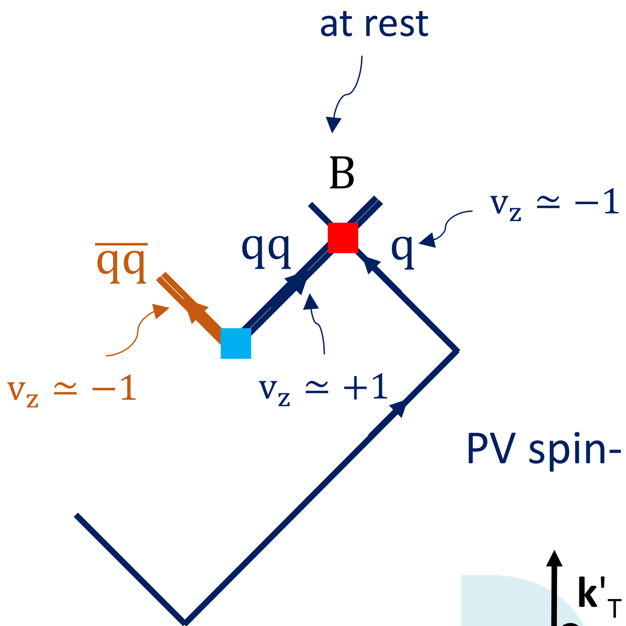
$L = S = 2 \to {}^5D_0$ state

Schwinger mechanism $\langle L \rangle \sim 1.3$

$m_{qq} \simeq 0.5\text{GeV}$

$\to$ mainly $^5D_0$ state

Splitting amplitude for $q \to B + (\overline{qq})$



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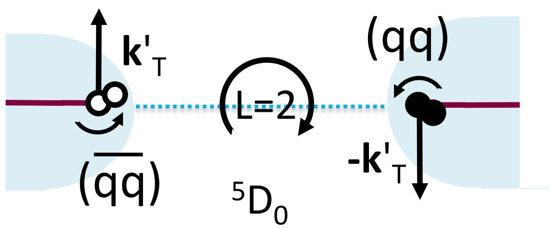

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$m_{qq} \simeq 0.5\text{GeV}$

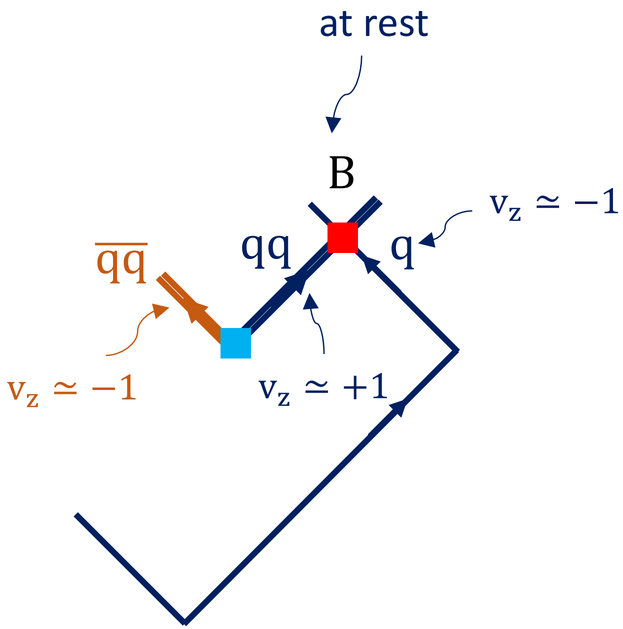
→ mainly ${}^5D_0$ state

$$\Delta_{qq}(\vec{k}'_T) = \begin{pmatrix} k'^2_x + m^2_{qq}/3 & k'_x k'_y & \kappa_{qq} k'_x \\ k'_x k'_y & k'^2_y + m^2_{qq}/3 & \kappa_{qq} k'_y \\ \kappa_{qq} k'_x & \kappa_{qq} k'_y & \kappa^2_{qq} + m^2_{qq}/3 \end{pmatrix}$$

κ_{qq} new complex parameter inspired by diquark momentum during tunneling

$$k_z \simeq i\sqrt{m^2_{qq} + k'^2_T}$$

Splitting amplitude for $q \to B + (\overline{qq})$



❑ Propagation of PV diquark $(qq)_1$

$$\chi^\dagger(\mathbf{S}_B)\, T_{(\overline{qq})_1,B,q}\, \chi(\mathbf{S}_q) = [F^{LM}_{(\overline{qq})_1,B,q}]^{\frac{1}{2}} \times$$

$$\times\, \phi^\dagger_{\overline{qq},a}\, \Delta_{qq,ab}(\mathbf{k}'_T)\; \chi^\dagger(S_B)\, \Gamma_{B,b}\, \chi(S_q)$$

❑ Propagation of scalar diquark $(qq)_0$

$$\chi^\dagger(\mathbf{S}_B)\, T_{(\overline{qq})_0,B,q}\, \chi(\mathbf{S}_q) = [F^{LM}_{(\overline{qq})_0,B,q}]^{\frac{1}{2}} \times$$

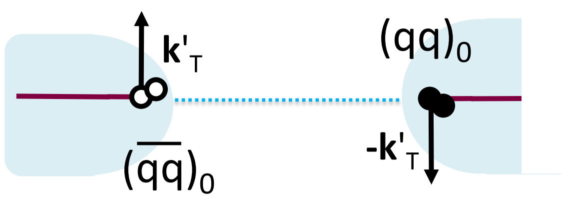
$$\times \phi^\dagger_{(qq)_0}\, \chi^\dagger(S_B)\, \Gamma_{B,0}\, \chi(S_q)$$

c-number

$$1_{2\times 2}$$

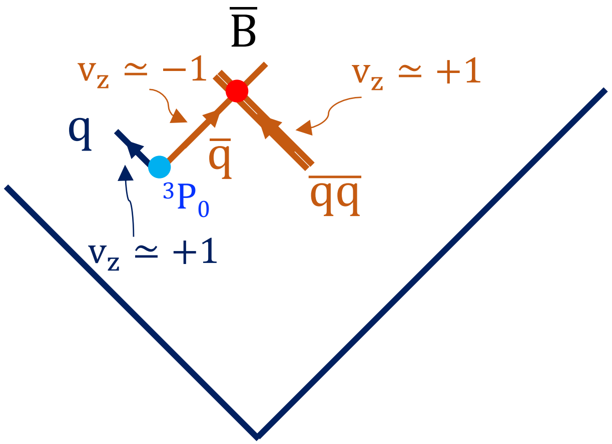
Reduction of the covariant amplitude

$\bar{u}(B)\; 1_{4\times 4}\; u(q)$



no spin-$\mathbf{k}'_T$ correlation at string breaking

Splitting amplitude for $(\overline{qq}) \to \overline{B} + q'$



- Splitting of PV anti-diquark $(\overline{qq})_1$

$$\chi^\dagger(\mathbf{S}_{q'})\, T_{q',\overline{B},(\overline{qq})_1} \sigma_z \chi(-\mathbf{S}_{\overline{B}}) = \left[F^{LM}_{q',\overline{B},(\overline{qq})_1}\right]^{\frac{1}{2}} \times$$

$$\times\, \chi^\dagger(S_{q'})\, \Delta_{q'}(\mathbf{k'}_T)\, \sigma_z \Gamma_{B,b} \sigma_z\, \sigma_z \chi(-\mathbf{S}_{\overline{B}})\, \phi_{\overline{qq},b}$$

$^3P_0$ propagator

$\Delta_{q'} = \mu + \sigma_z \boldsymbol{\sigma}_T \cdot \mathbf{k'}_T$

σ_b

- Analogous for scalar anti-diquark $(\overline{qq})_0$, with $\Gamma_{B,b} = 1_{2\times 2}$

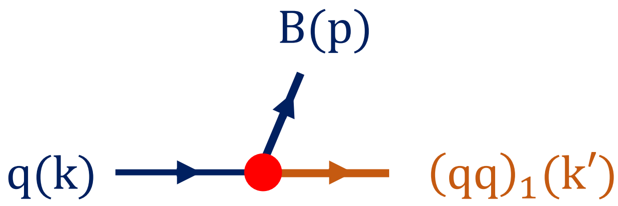
In the following slides

- ❑ recall of string+$^3P_0$
- ❑ new amplitudes for baryon production
- ❑ predictions of the new model

AK, X. Artru, in preparation

Probability distribution of the produced baryon:
Collins effect

- Distribution of B produced in $q \rightarrow B + (\overline{qq})_1$



$$\frac{dP_{q\rightarrow B+(\overline{qq})_1}}{dZ_+ Z_+^{-1} d^2\mathbf{p}_T} = \mathrm{Tr}_B T_{(\overline{qq})_1,B,q}\, \rho(\mathbf{S}_q) T^{\dagger}_{(\overline{qq})_1,B,q}$$

$$= [\ldots]\, e^{-\frac{b_T k'^2_T}{2}} \times \left[\left(|\kappa_{qq}|^2 + {k'_T}^2\right)^2 + \frac{m^2_{qq}}{3}\lambda\left(k'^2_T\right)\right] \times \left[1 + \hat{a}_{C,B}\, \vec{S}_{q,T} \cdot \left(\hat{z} \times \hat{k}'_T\right)\right]$$

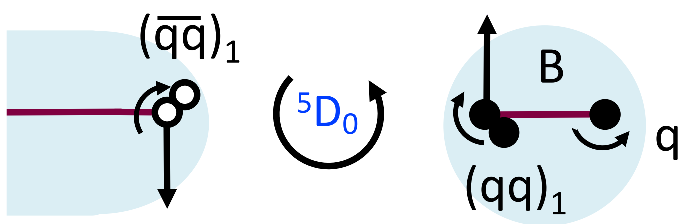
$$\hat{a}_{C,B} = \frac{2\mathrm{Im}\left(\kappa_{qq}\right)\left(|\kappa_{qq}|^2 + {k'_T}^2\right) k'_T}{\left(|\kappa_{qq}|^2 + {k'_T}^2\right)^2 + \frac{m^2_{qq}}{3}\lambda({k'_T}^2)}$$

$$\lambda\left({k'_T}^2\right) = (m^2_{qq} + 2{k'_T}^2 + 2\mathrm{Re}(\kappa^2_{qq})$$

Collins effect!
in agreement with classical string+$^5D_0$ mechanism for $\mathrm{Im}\left(\kappa_{qq}\right) < 0$

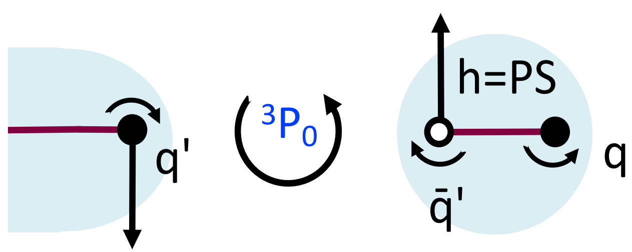
Probability distribution of the produced baryon:
Collins effect

classical string+$^5D_0$



scalar diquark tunneling

classical string+$^3P_0$



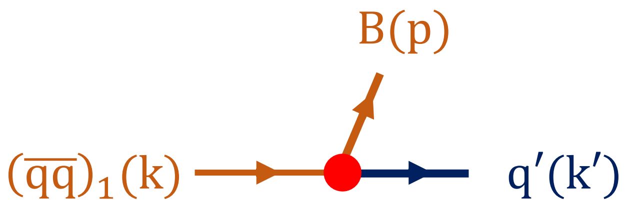
- No Collins effect for $\overline{\mathrm{B}}$ produced in $(\overline{qq})_0 \rightarrow \overline{\mathrm{B}} + q'$ [expected]

Collins effect!
in agreement with classical string+$^5D_0$ mechanism for $\mathrm{Im}(\kappa_{qq}) < 0$

Probability distribution of the produced antibaryon: Collins effect

- Distribution of $\overline{\mathrm{B}}$ produced in $(\overline{\mathrm{qq}})_1 \rightarrow \overline{\mathrm{B}} + \mathrm{q}'$

$$\frac{dP_{(\overline{qq})_1 \rightarrow \overline{B}+q'}}{dZ_+ Z_+^{-1} d^2\mathbf{p}_T} = \mathrm{Tr}_{q'} T^{a}_{q',B,(\overline{qq})_1} \, T^{b\dagger}_{q',B,(\overline{qq})_1} \rho_{ab}(\overline{qq})$$



$$= [\ldots]\, e^{-\frac{b_T k'^2_T}{2}} \times \left[|\mu|^2 + k'^2_T\right]$$
$$\times \left[1 + \hat{a}_{C,\overline{B}}\, \vec{S}_{qq,T} \cdot \left(\hat{z} \times \hat{\mathbf{k}}'_T\right)\right]$$

$$\vec{S}_{qq,c} = i\varepsilon_{abc}\rho_{ab}(\overline{qq})$$

$$\hat{a}_{C,\overline{B}} = -\frac{2\mathrm{Im}(\mu) k'_T}{|\mu|^2 + k'^2_T}$$

Collins effect due to the $^3P_0$ mechanism (as for PS mesons)

- No Collins effect for $\overline{\mathrm{B}}$ produced in $(\overline{\mathrm{qq}})_0 \rightarrow \overline{\mathrm{B}} + \mathrm{q}'$ as expected

Probability distribution of the produced antibaryon: Collins effect

- Distribution of $\bar{\mathrm{B}}$ produced in $(\overline{\mathrm{qq}})_1 \to \bar{\mathrm{B}} + \mathrm{q}'$

$$\frac{dP_{(\overline{qq})_1\to\bar{B}+q'}}{dZ_+ Z_+^{-1} d^2\mathbf{p}_T} = \mathrm{Tr}_{q'} T^{a}_{q',B,(\overline{qq})_1}\, T^{b\dagger}_{q',B,(\overline{qq})_1} \rho_{ab}(\overline{qq})$$

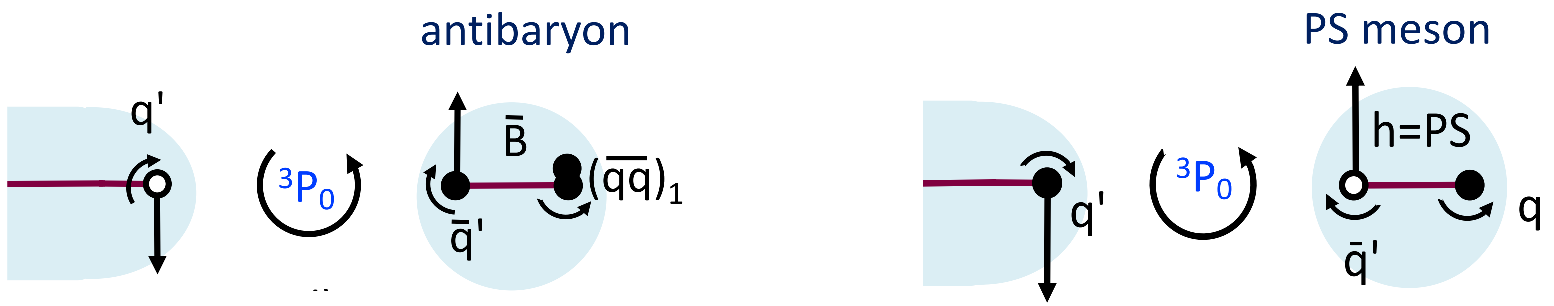
$$= [\dots]\, e^{-\frac{b_T k'^2_T}{2}} \times \left[|\mu|^2 + k'^2_T\right]$$
$$\times \left[1 + \hat{a}_{C,\bar{B}}\, \vec{S}_{qq,T} \cdot \left(\hat{z} \times \hat{\mathbf{k}}'_T\right)\right]$$

$$\vec{S}_{qq,c} = i\varepsilon_{abc}\rho_{ab}(\overline{qq})$$

$$\hat{a}_{C,\bar{B}} = -\frac{2\mathrm{Im}(\mu) k'_T}{|\mu|^2 + k'^2_T}$$

Collins effect due to the $^3P_0$ mechanism (as for PS mesons)

classical string+$^3P_0$



Baryon/antibaryon transverse polarization

- B produced in $q \rightarrow B + (\overline{qq})_1$

$$\mathbf{S}_{B,\mathrm{T}} \propto \Big\{ -2\mathrm{Im}(\kappa_{\mathrm{qq}}) \left(|\kappa_{\mathrm{qq}}|^2 + \mathbf{k}'^2_{\mathrm{T}}\right) \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}}$$
$$- \mathbf{S}_{q,\mathrm{T}} \left[(|\kappa_{qq}|^2 + \mathbf{k}'^2_{\mathrm{T}})^2 + \frac{m^2_{qq}}{3} \left(\frac{m^2_{qq}}{3} + 2\mathbf{k}'^2_{\mathrm{T}} + 2\mathrm{Re}(\kappa^2_{\mathrm{qq}}) \right) \right]$$
$$+ 2\,(\mathbf{k}'_{\mathrm{T}} \cdot \mathbf{S}_{q,\mathrm{T}})\mathbf{k}'_{\mathrm{T}} \left(\mathbf{k}'^2_{\mathrm{T}} + |\kappa_{qq}|^2 + \frac{2m^2_{qq}}{3} \right)$$
$$+ 2\mathrm{Re}(\kappa_{\mathrm{qq}})\, \mathrm{S}_{\mathrm{qz}}\, \mathbf{k}'_{\mathrm{T}} \left(\mathbf{k}'^2_{\mathrm{T}} + |\kappa_{\mathrm{qq}}|^2 + \frac{2\mathrm{m}^2_{\mathrm{qq}}}{3} \right) \Big\}$$

- B produced in $q \rightarrow B + (\overline{qq})_0$

$$\mathbf{S}_{B,\mathrm{T}} = \mathbf{S}_{q,\mathrm{T}}$$

- $\overline{B}$ produced in $(\overline{qq})_1 \rightarrow \overline{B} + q'$

$$\mathbf{S}_{\bar{B},\mathrm{T}} \propto \left[(|\mu|^2 + \mathbf{k}'^2_{\mathrm{T}})\, \mathbf{S}_{\overline{qq},\mathrm{T}} - 2\mathrm{Im}(\mu)\, \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}} + 2\mathrm{Im}(\mu)\, 2\mathrm{Re}[\rho_{\mathrm{T}}(\overline{\mathrm{qq}})]\, \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}} \right],$$

- $\overline{B}$ produced in $(\overline{qq})_0 \rightarrow \overline{B} + q'$

$$\mathbf{S}_{\bar{B},\mathrm{T}} = \frac{2\mathrm{Im}(\mu)}{|\mu|^2 + \mathbf{k}'^2_{\mathrm{T}}} \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}}$$

Contributions to the spontaneous polarization of hyperons!

expected to reproduce the sign of $\Lambda, \overline{\Lambda}$ observed in e^+e^-

$\mathbf{p}_{\mathrm{T}} = -\mathbf{k}'_{\mathrm{T}}$ for the first produced hadron

$\hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}} \rightarrow -\hat{\mathbf{z}} \times \mathbf{p}_{\mathrm{T}}$

Baryon/antibaryon transverse polarization

- B produced in $q \to B + (\overline{qq})_1$

$$\mathbf{S}_{B,\mathrm{T}} \propto \Big\{ -2\mathrm{Im}(\kappa_{\mathrm{qq}}) \left(|\kappa_{\mathrm{qq}}|^2 + \mathbf{k}'^2_{\mathrm{T}}\right) \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}}$$
$$+ \mathbf{S}_{q,\mathrm{T}} \left[(|\kappa_{qq}|^2 + \mathbf{k}'^2_{\mathrm{T}})^2 + \frac{m^2_{qq}}{3} \left(\frac{m^2_{qq}}{3} + 2\mathbf{k}'^2_{\mathrm{T}} + 2\mathrm{Re}(\kappa^2_{\mathrm{qq}}) \right) \right]$$
$$+ 2\,(\mathbf{k}'_{\mathrm{T}} \cdot \mathbf{S}_{q,\mathrm{T}})\mathbf{k}'_{\mathrm{T}} \left(\mathbf{k}'^2_{\mathrm{T}} + |\kappa_{qq}|^2 + \frac{2m^2_{qq}}{3} \right)$$
$$+ 2\mathrm{Re}(\kappa_{\mathrm{qq}})\, \mathrm{S}_{\mathrm{qz}}\, \mathbf{k}'_{\mathrm{T}} \left(\mathbf{k}'^2_{\mathrm{T}} + |\kappa_{\mathrm{qq}}|^2 + \frac{2\mathrm{m}^2_{\mathrm{qq}}}{3} \right) \Big\}$$

- B produced inq $\to B + (\overline{qq})_0$

$$\mathbf{S}_{B,\mathrm{T}} = \mathbf{S}_{q,\mathrm{T}}$$

- $\overline{B}$ produced in $(\overline{qq})_1 \to \overline{B} + q'$

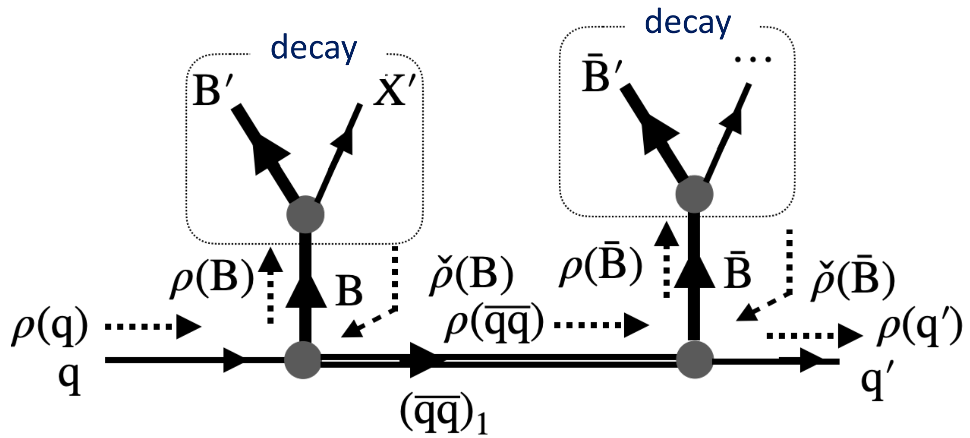
$$\mathbf{S}_{\bar{B},\mathrm{T}} \propto \left[(|\mu|^2 + \mathbf{k}'^2_{\mathrm{T}})\, \mathbf{S}_{\overline{qq},\mathrm{T}} - 2\mathrm{Im}(\mu)\, \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}} + 2\mathrm{Im}(\mu)\, 2\mathrm{Re}[\rho_{\mathrm{T}}(\overline{\mathrm{qq}})]\, \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}} \right],$$

- $\overline{B}$ produced in $(\overline{qq})_0 \to \overline{B} + q'$

$$\mathbf{S}_{\bar{B},\mathrm{T}} = \frac{2\mathrm{Im}(\mu)}{|\mu|^2 + \mathbf{k}'^2_{\mathrm{T}}}\, \hat{\mathbf{z}} \times \mathbf{k}'_{\mathrm{T}}$$

Contributions to the transverse spin transfer to hyperons!

Spin propagation along the fragmentation chain



Recursive algorithm starting e.g. with a quark q

i. chose if to break the string via $q\bar{q}$ or $qq - \overline{qq}$ using P_{qq}/P_q

ii. if qq, decide if $(qq)_1$ or $(qq)_0$ according to $P_{(qq)_1}/P_{(qq)_0}$

iii. draw B according to the splitting function for $q \to B + (\overline{qq})$

iv. Evaluate $\rho(B)$ and decay B → come back with acceptance matrix $\check{\rho}(B)$

v. Draw $\overline{B}$ according to the splitting function for $\overline{qq} \to \overline{B} + q'$

vi. Decay $\overline{B}$ etc.

Note: only $B\overline{B}$ configurations, $BM_1..\overline{B}$ for future work
no interference effects

Conclusions

- We have extended the string+$^3P_0$ model to introduce spin 1/2 baryon production → tunneling of diquark-antidiquark pairs

- Relevant amplitudes for baryon/anti-baryon production written down
  - $^5D_0$ mechanism for spin-1 diquarks

- The model gives
  - Collins effect
  - spontaneous polarization (polarizing FF)
  - spin transfer mechanisms (e.g., transversity FF)

- Implementation in Pythia for DIS and e^+e^- ongoing

- Possible new applications of the model
  - e.g. spin effects in target fragmentation (fracture functions?)