33rd International Workshop on Deep Inelastic Scattering and Related Subjects
DIS 2026

Hyperon polarization in deep inelastic scattering

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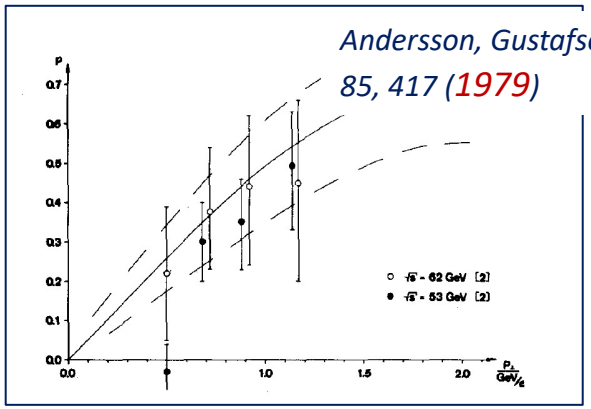
Istituto Nazionale di Fisica Nucleare

Funded by the European Union

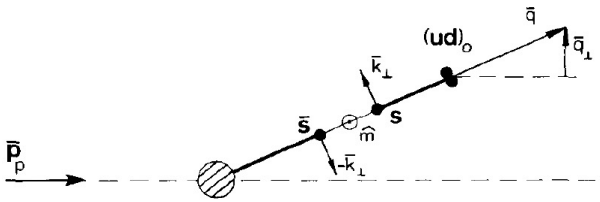
Hyperon spontaneous polarization

Non-zero polarization along the normal to the production plane of the hyperon [unpolarized beams]

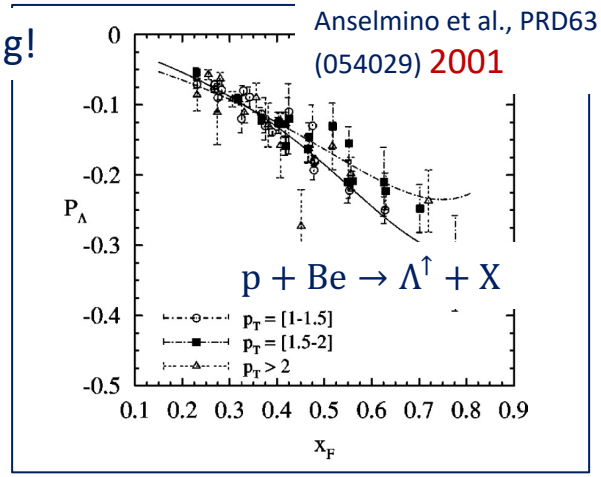
- Known to be sizeable for Λ in hadronic collisions: puzzling!



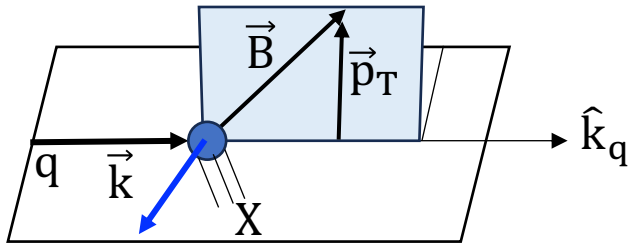
Andersson, Gustafson, Ingelman, PRL 85, 417 (1979)



semi-classical Lund String + $^3P_0$



Anselmino et al., PRD63 (054029) 2001



Polarizing FF $D_{1T}^\perp$

$$\vec{S}_{BT} \propto \frac{D_{1T}^\perp}{D_1}\, \hat{k}_q \times \vec{p}_T$$

Mulders, Tangerman, NPB 484, 538-540 (1997)

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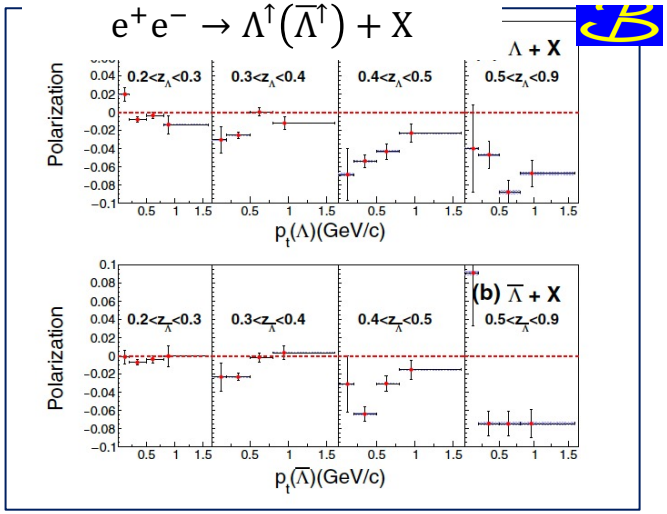
  Results from RHIC → see X. Liu, WG4

PRL 122, 042001 (2019)



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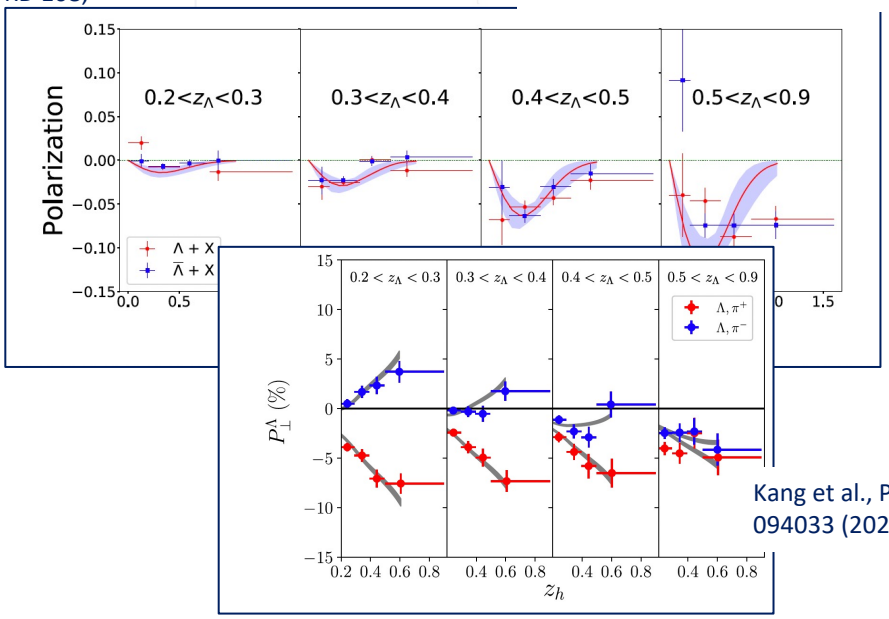
- Motivated new QCD studies based on pFF

  - 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)



D'Alesio, Murgia, Zaccheddu, PRD 102, 054001 (2020)

Kang et al., PRD 105, 094033 (2022)

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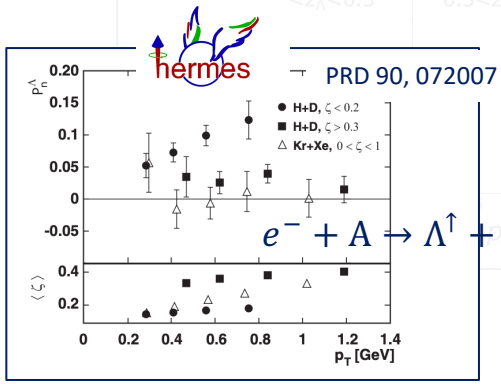

PRD 90, 072007 (2014)

Hyperon spontaneous polarization

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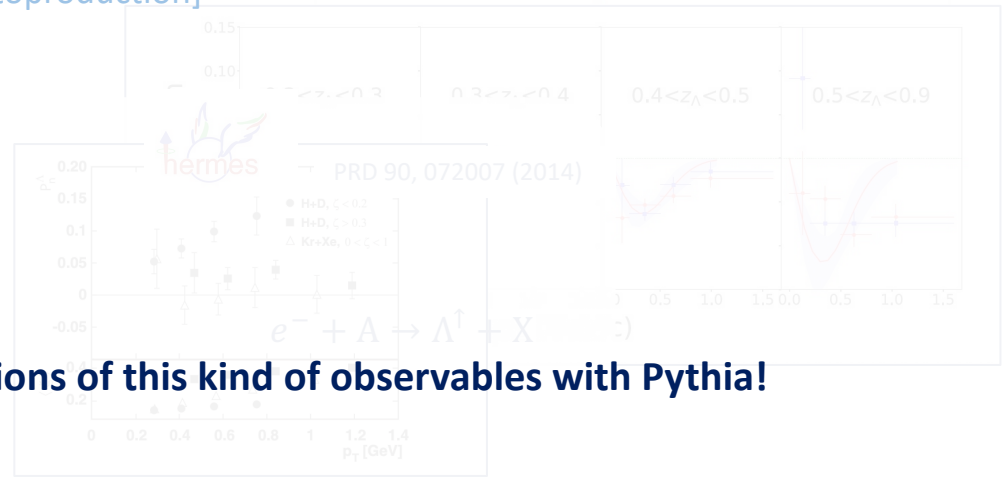

We are working to enable simulations of this kind of observables with Pythia!

The model: string+$^3P_0$

- Quantum mechanical extension of the Lund string Model including spin
  mesons (pseudoscalar, vector)

  AK, X. Artru, Z. Belghobsi, F. Bradamante, A. Martin, PRD 97 (2018) 7, 074010
  AK, X. Artru, A. Martin, PRD 104, 114038 (2021)

- Interfaced to Pythia by StringSpinner
  parton showers OFF

  AK, L. Lönnblad, CPC **292** (2023) 108886
  https://gitlab.com/albikerbizi/stringspinner

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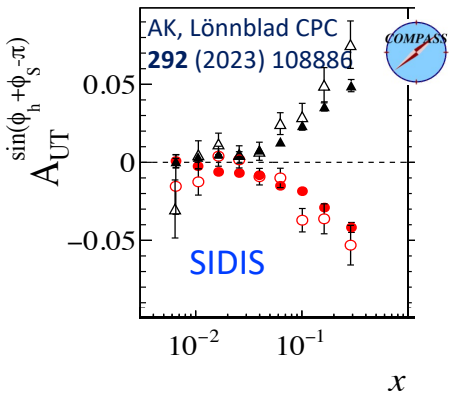
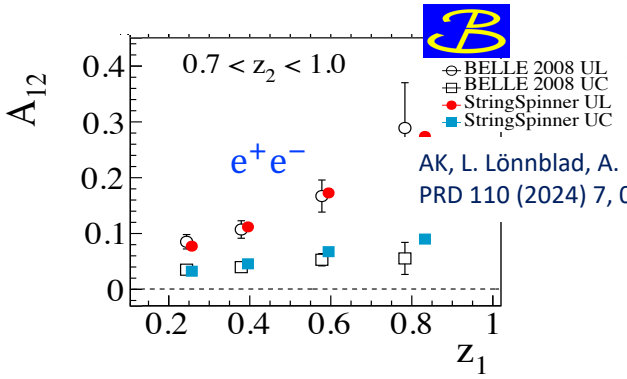
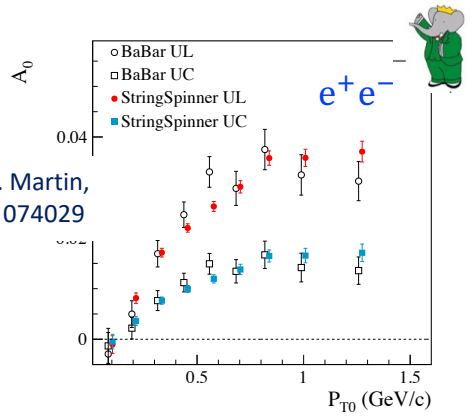
- Reproduces transverse spin effects for final state mesons
  Collins effect as measured in SIDIS and e^+e^-





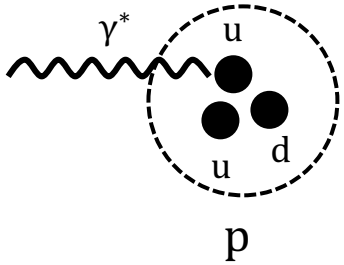


- **Recently extended to include spin-1/2 baryons [production and decays]**

The string+$^3P_0$ model with mesons and baryons

AK, X. Artru, PRD 113 (2026) 3, 034007

String breaking



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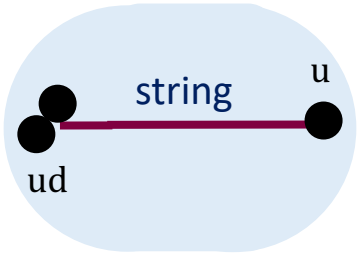

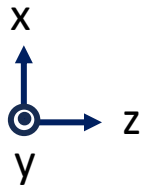

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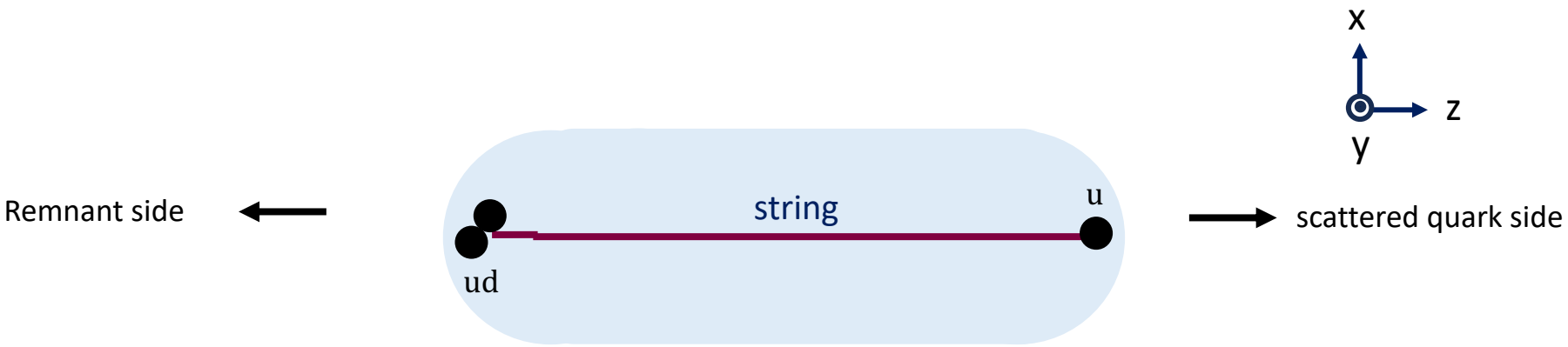
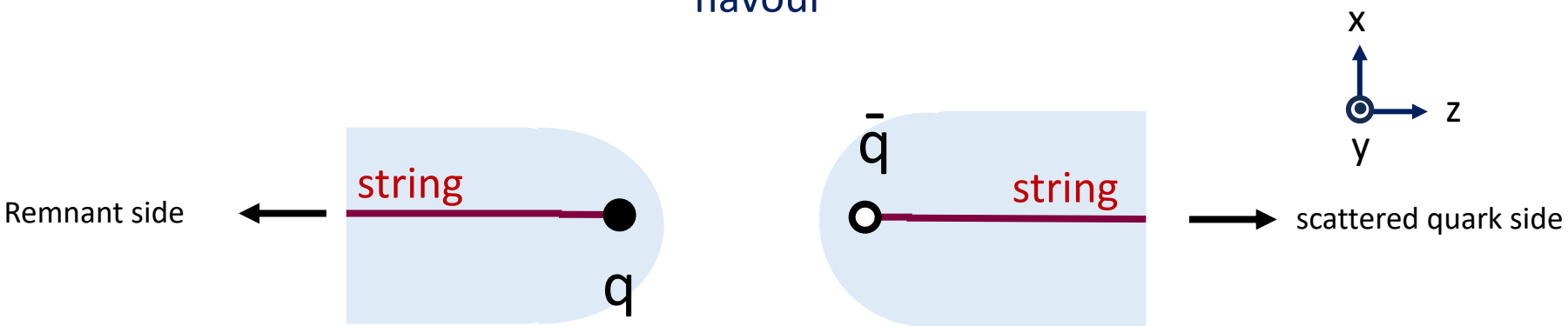


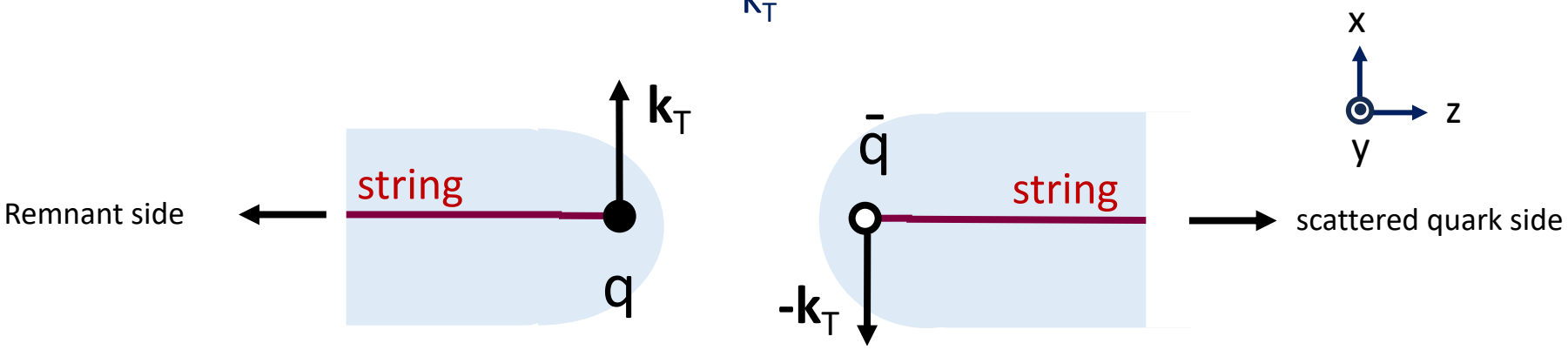
String breaking
flavour



String breaking via $q\bar{q}$ tunneling

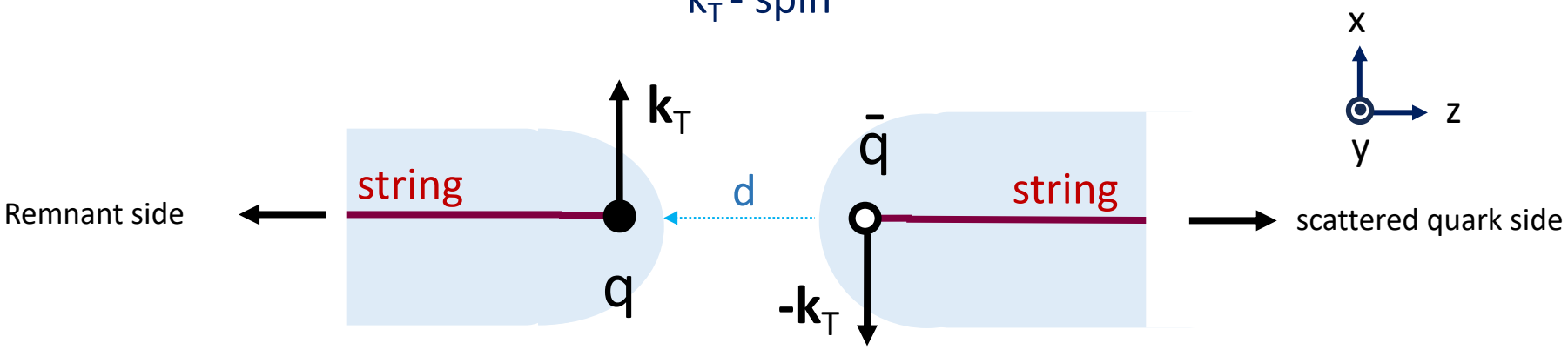
u, d, s quarks produced

String breaking
k_T



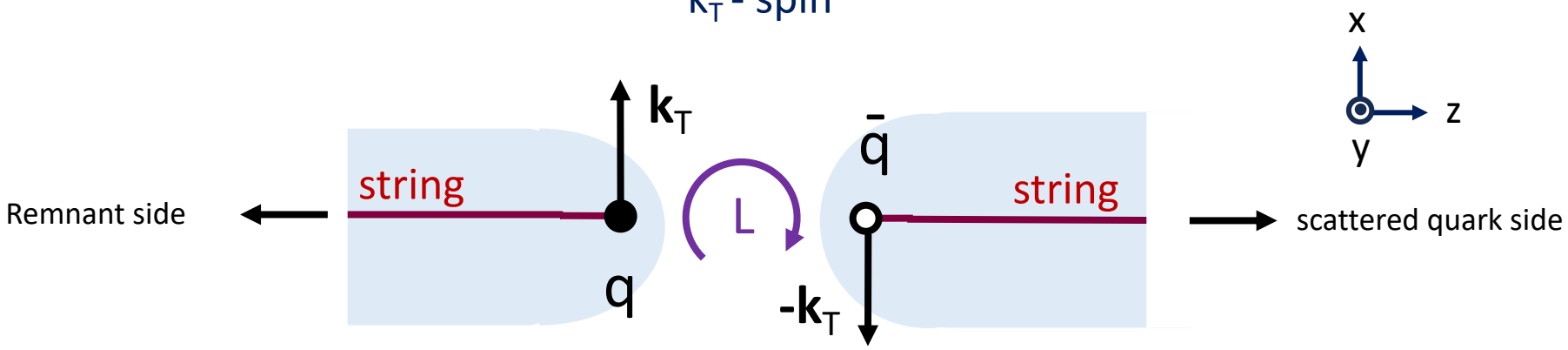
Local conservation of k_T
+ exponential damping [Schwinger mechanism]

String breaking
k_T - spin



The pair is produced at a distance d

String breaking
k_T - spin



The pair is produced at a distance d

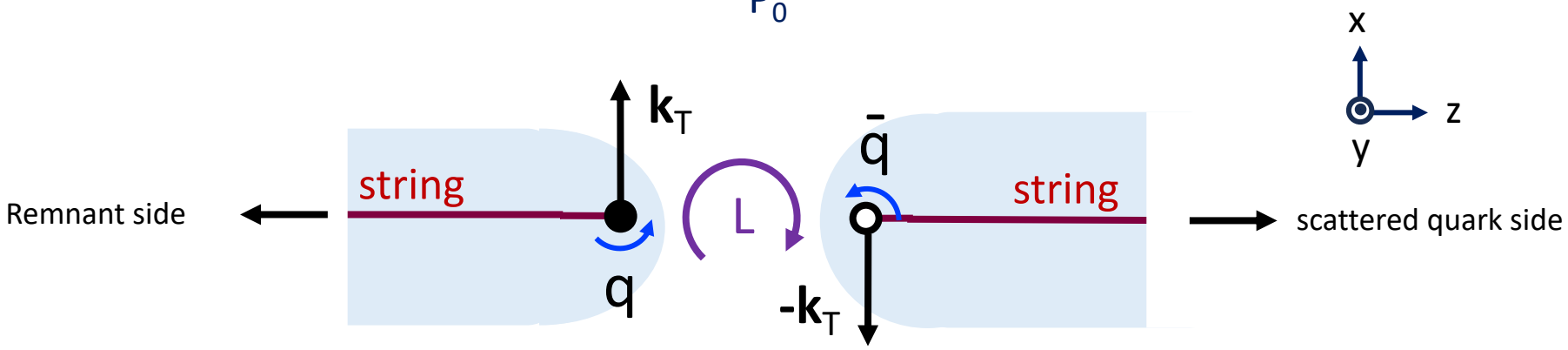
$$\vec{L} = \vec{d} \times \vec{k}_T \neq \vec{0}$$

Local conservation of angular momentum

$$\vec{S} = \vec{S}_q + \vec{S}_{\bar{q}} \neq \vec{0}$$

String breaking

$^3P_0$



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Local conservation of angular momentum

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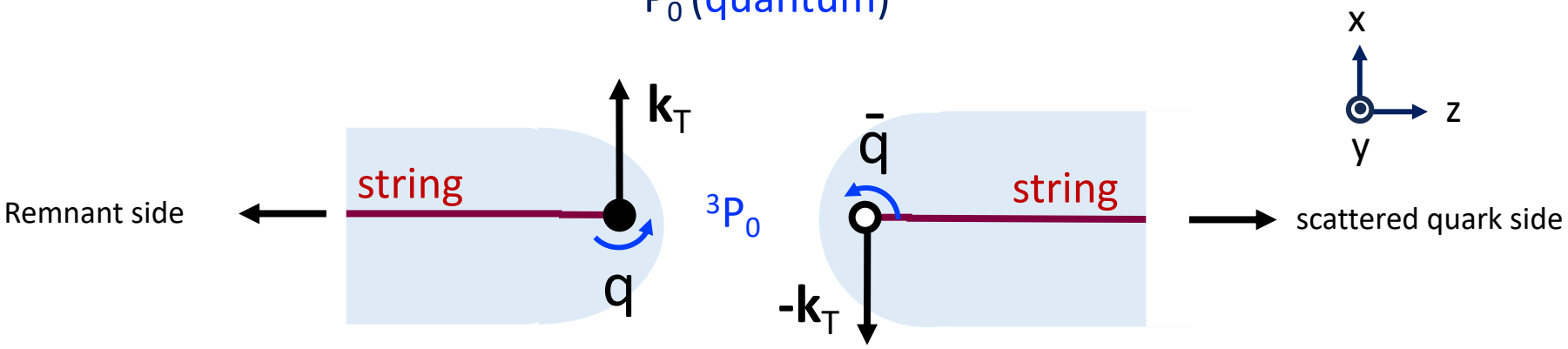
therefore

$$\vec{J} = \vec{L} + \vec{S} = \vec{0}$$

$L=1$, $S=1$

$q\bar{q}$ pair in $^3P_0$ state

String breaking
$^3P_0$ (quantum)



spin-k_T correlation described by
"propagator" (2x2)

$$\Delta_q = \mu + \sigma_z \boldsymbol{\sigma}_T \cdot \mathbf{k}_T$$

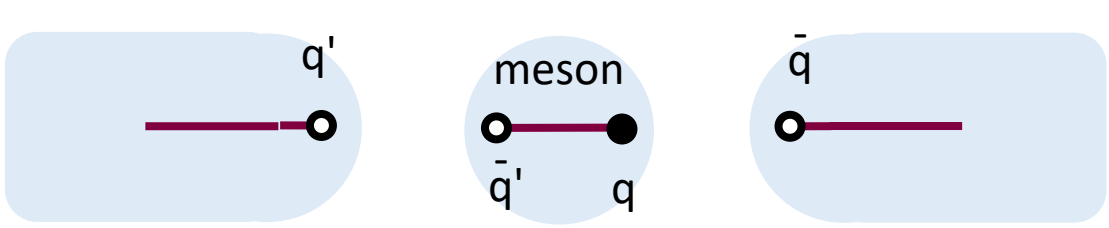
"complex mass" μ

2 free parameters
$\mathrm{Re}(\mu), \mathrm{Im}(\mu)$

AK, X. Artru, Z. Belghobsi, F. Bradamante, A. Martin, PRD 97 (2018) 7, 074010

Meson production

two successive string breakings

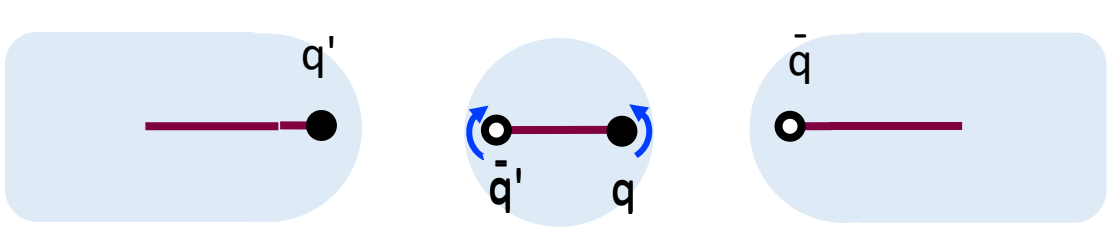


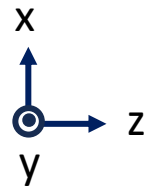
Pseudoscalar meson (PM) or vector meson (VM)

$\mathrm{PM:VM} \simeq 1:1$

Pythia 8

Meson production
PM (quantum)





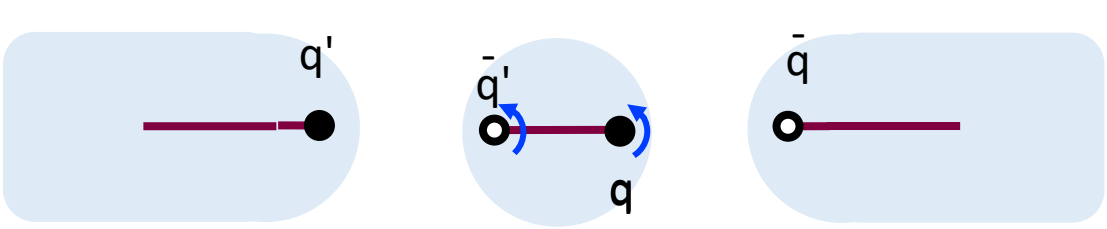
Pseudoscalar meson (PM) or vector meson (VM)

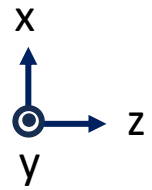
spin given by coupling (2x2)

$$\Gamma_{h=PM} = \sigma_z$$

no new free parameters

Meson production
VM (quantum)





Pseudoscalar meson (PM) or vector meson (VM)

spin given by coupling (2x2)

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

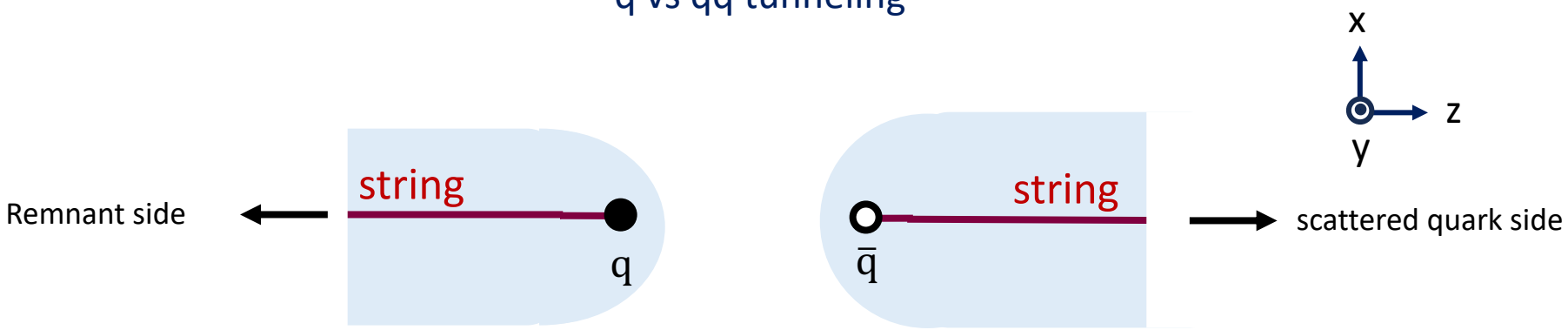
2 free parameters:

Fraction of L Polarized VMs $f_L = \left|\frac{G_L}{G_T}\right|^2 / [2 + \left|\frac{G_L}{G_T}\right|^2]$

L/T interference $\theta_{LT} = \arg G_L/G_T$

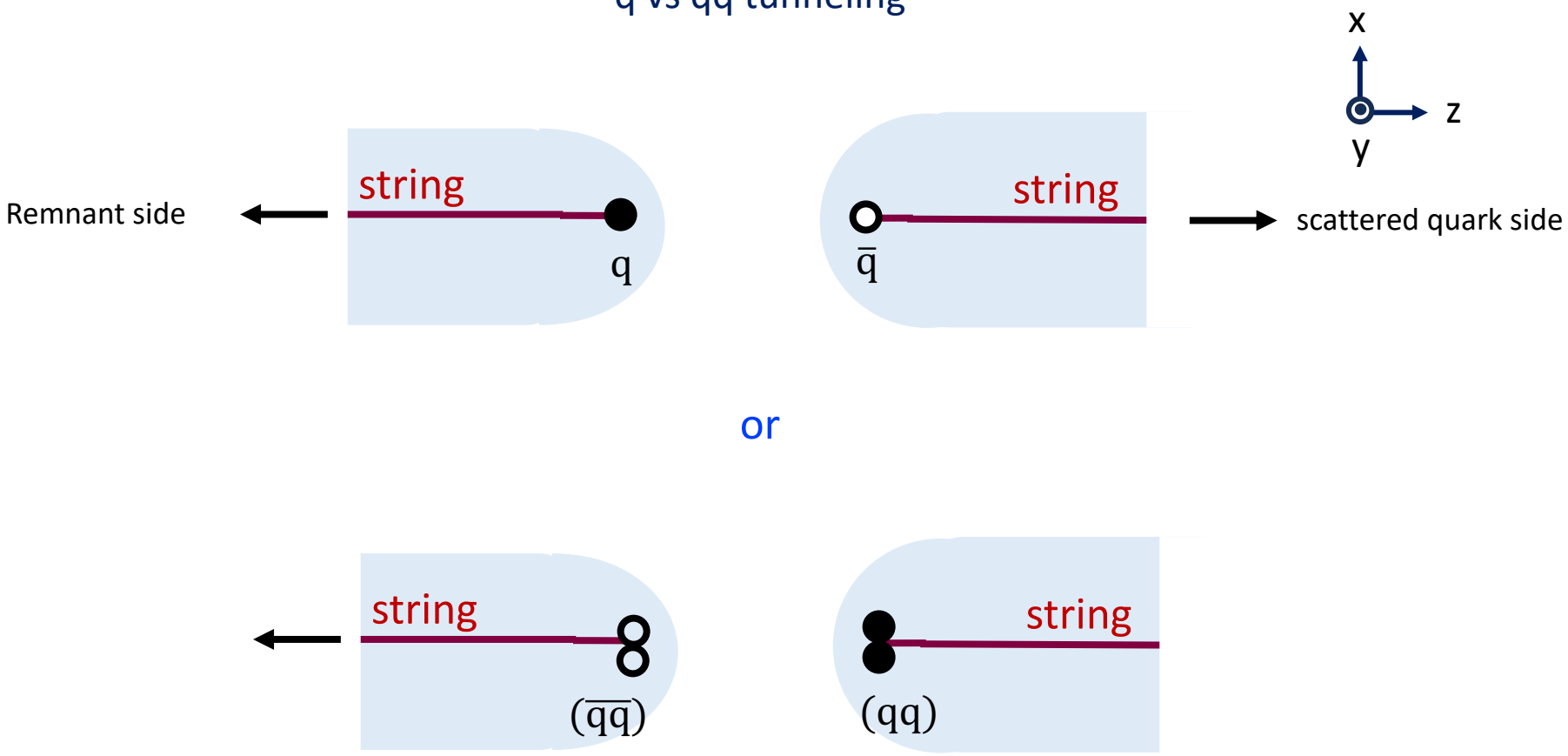
AK, X. Artru, A. Martin, PRD 104 (2021) 11, 114038

String breaking
q vs qq tunneling



or

String breaking
q vs qq tunneling



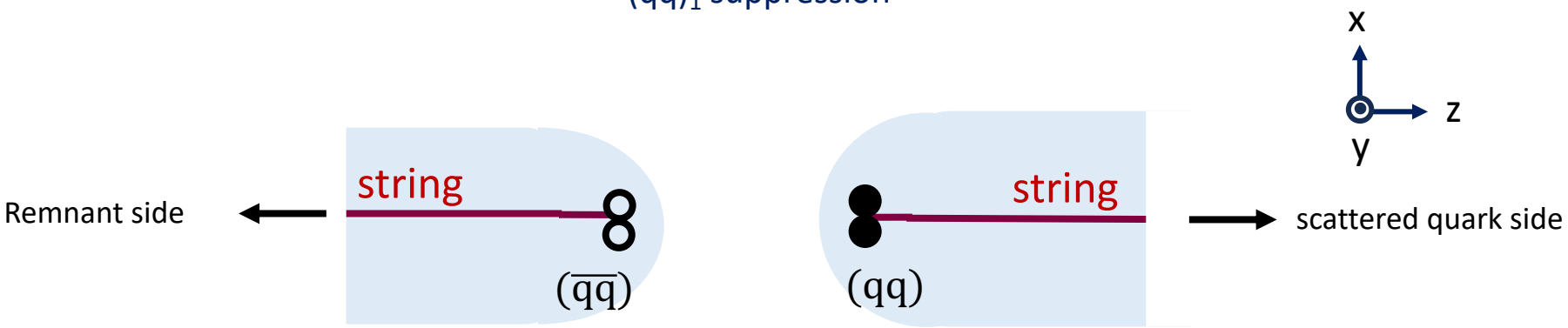
diquark tunneling suppressed w.r.t quark tunneling

$$\frac{P_{qq}}{P_q} \approx 0.1$$

Pythia 8

String breaking

$(qq)_1$ suppression



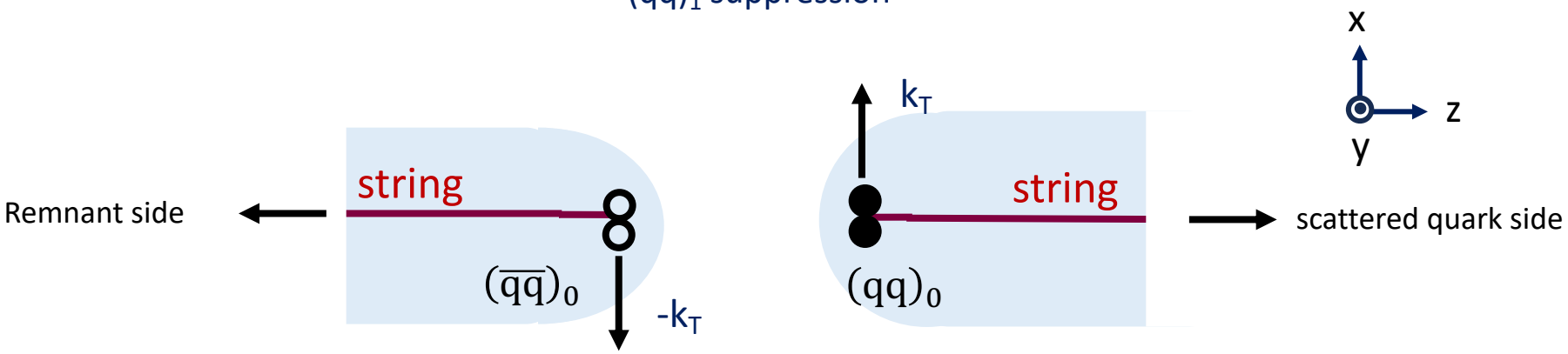
Suppression of spin-1 diquarks

$$\frac{P_{(qq)_1}}{P_{(qq)_0}} \approx 0.03$$

Pythia 8

String breaking

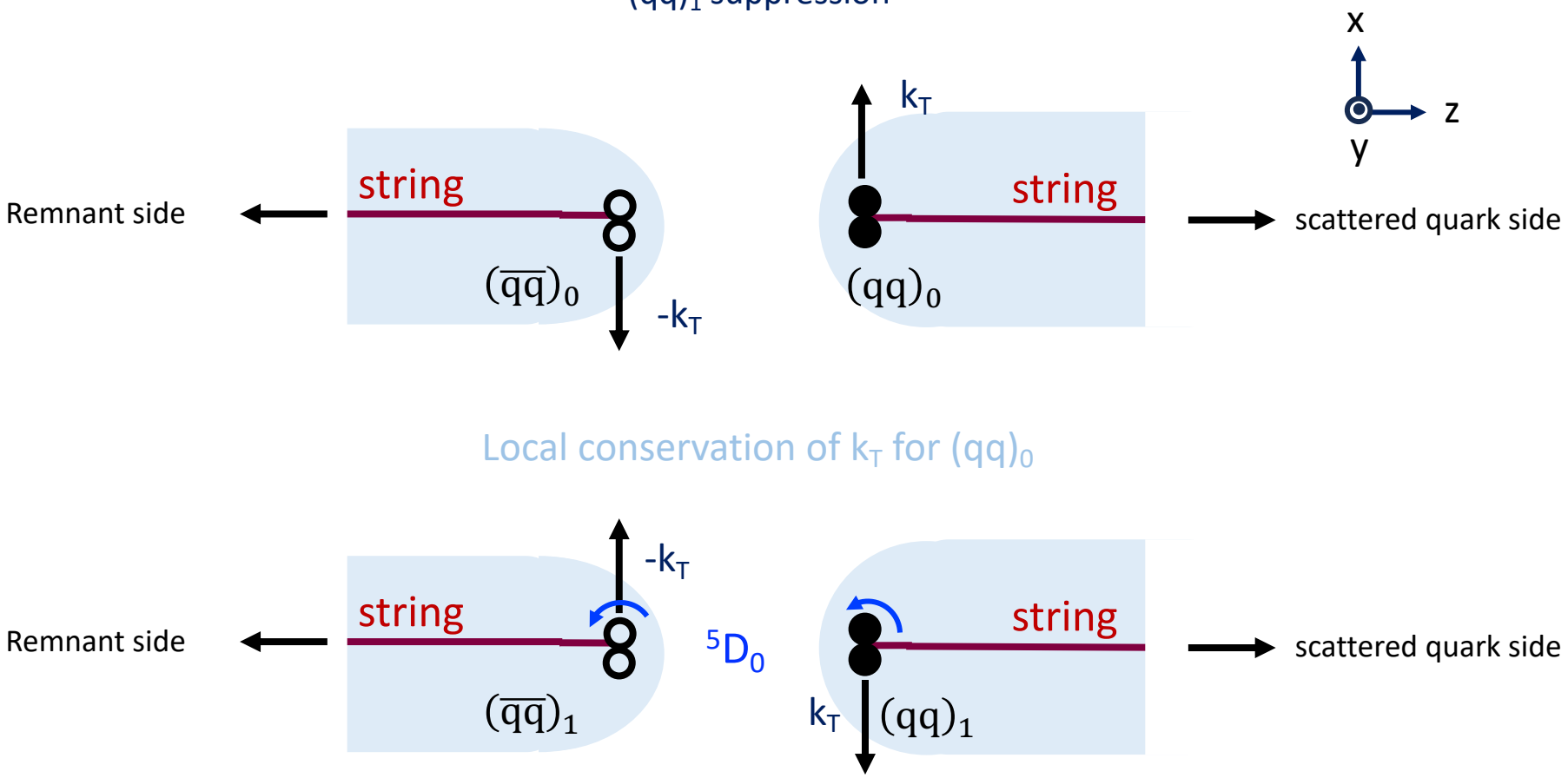
$(qq)_1$ suppression



Local conservation of k_T for $(qq)_0$

String breaking

$(qq)_1$ suppression



Local conservation of angular momentum for $(qq)_1$

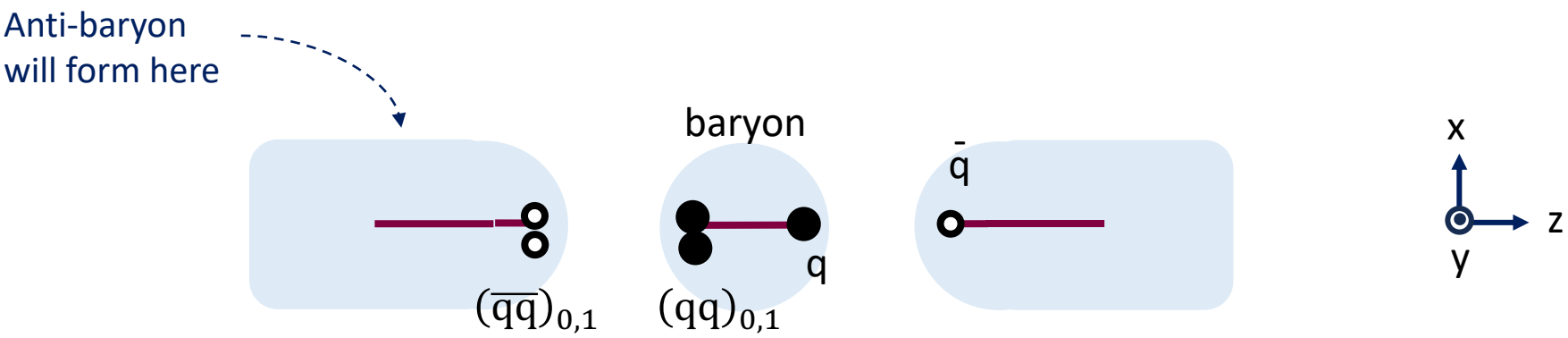
$^5D_0$ mechanism

3x3 propagator depending on complex mass μ_{qq}

see AK, X. Artru, PRD 113 (2026) 3, 034007

Baryon production

two successive string breakings



Coupling with $(qq)_0$

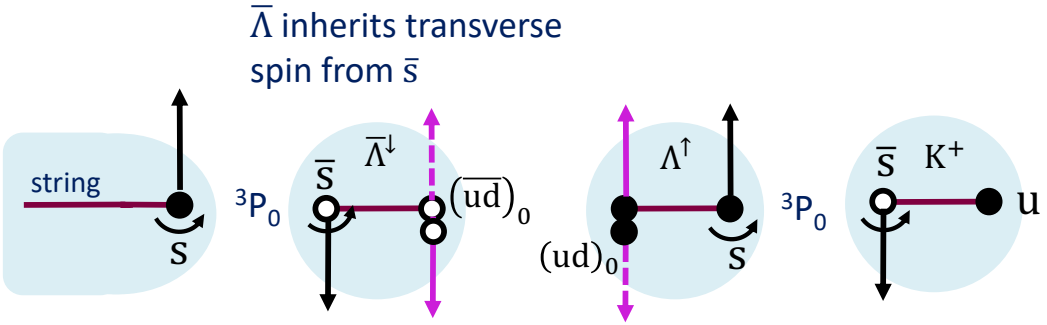
$$\Gamma_B = 1$$

Coupling with [polarization vector of] $(qq)_1$

$$\Gamma_B = \boldsymbol{\sigma} \cdot \mathbf{V}_{qq}$$

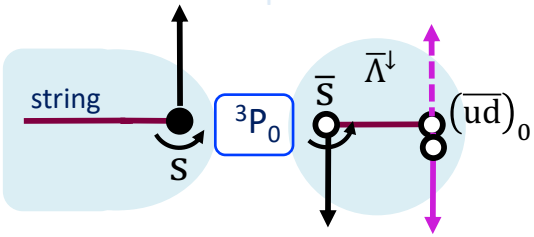
No new free parameters

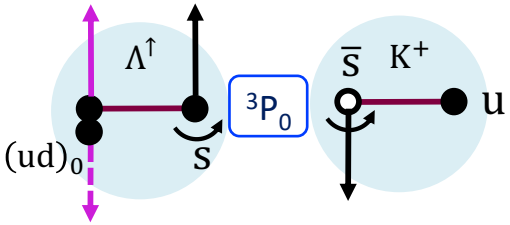
Hyperon production



Hyperon production

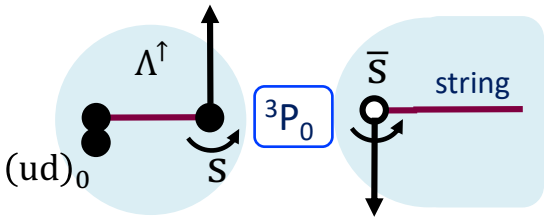
$\bar{\Lambda}$ inherits transverse spin from $\bar{s}$





~large x_F
CFR

Λ inherits transverse spin from s



~negative x_F
TFR

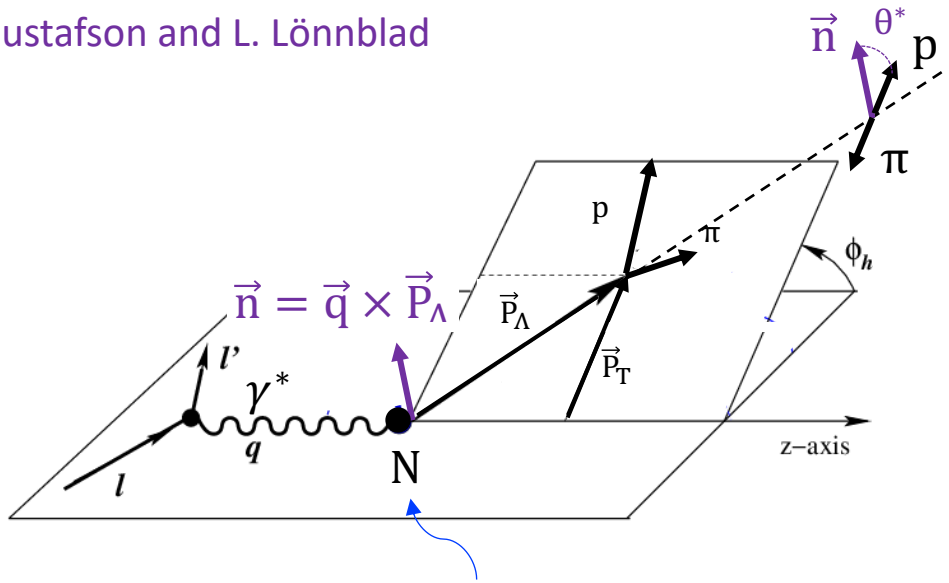
Λ inherits transverse spin from s

$^3P_0$ breakings → spin parameters fixed from Collins effect!

All this implemented in StringSpinner… (not public yet)

Spontaneous polarization of Λ and $\overline{\Lambda}$

with G. Gustafson and L. Lönnblad

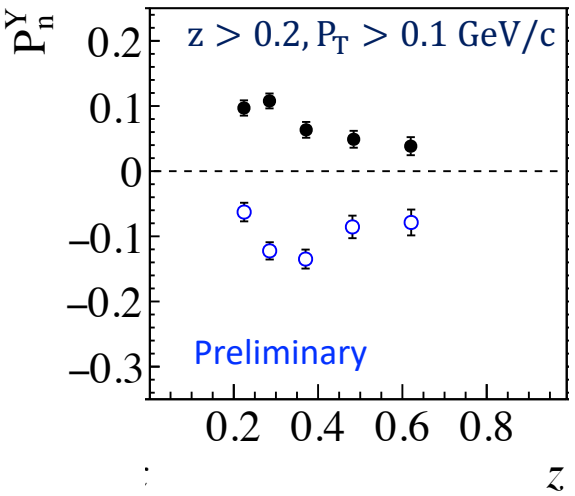


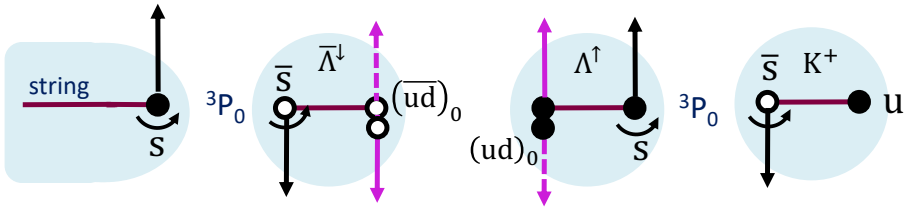
Extracted from the angular distribution of the decay proton in the Λ rest frame

$$\frac{dN_p}{d\cos\theta^*} \propto 1 + \alpha_\Lambda \, P_n^\Lambda \cos\theta^*$$

Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«current fragmentation»

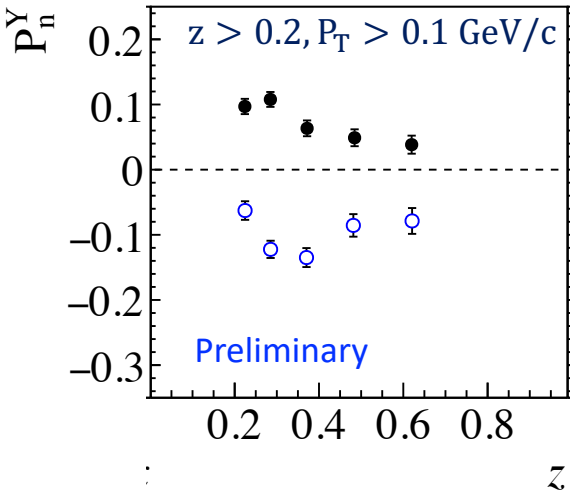


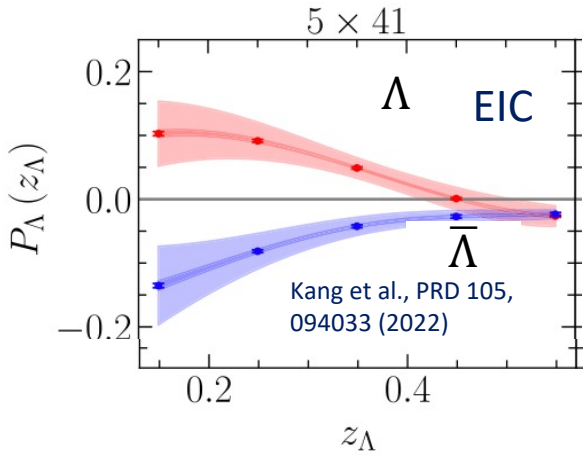


Polarization decreases with z

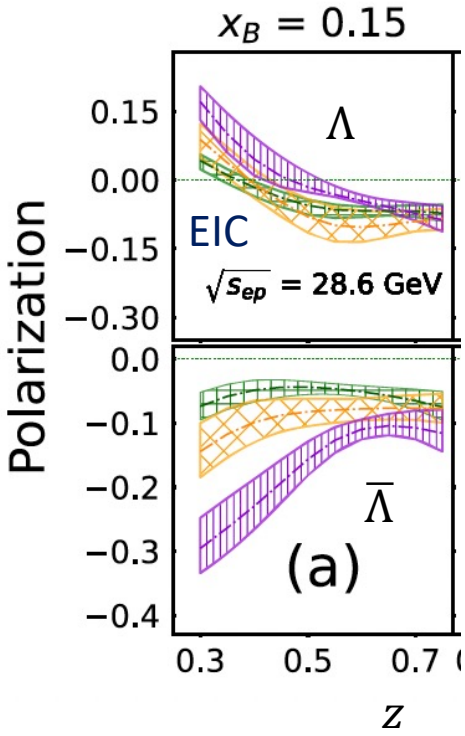
Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«current fragmentation»





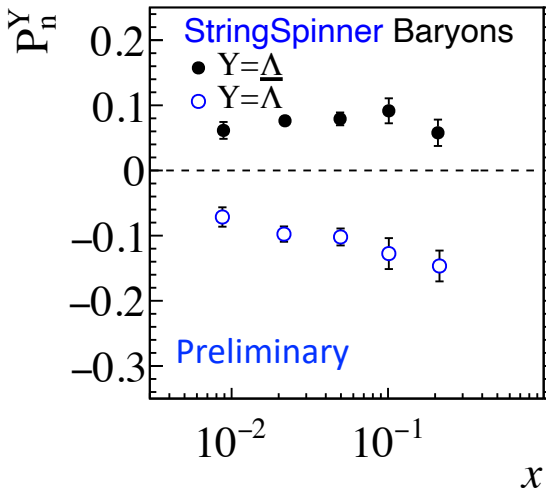
D'Alesio et al., PRD 108, 094004 (2023)

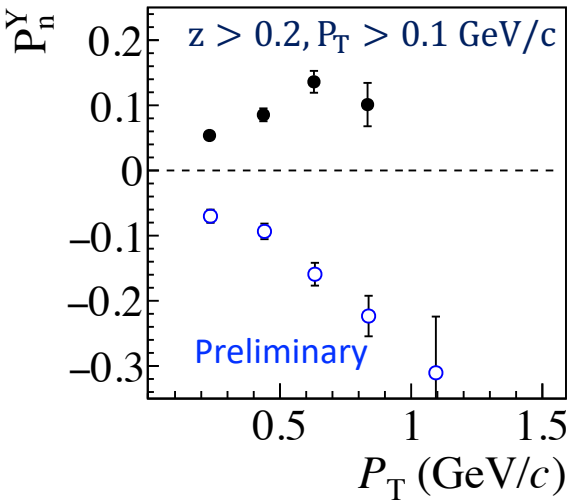


Similar values to recent extractions from e^+e^- data

Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«current fragmentation»



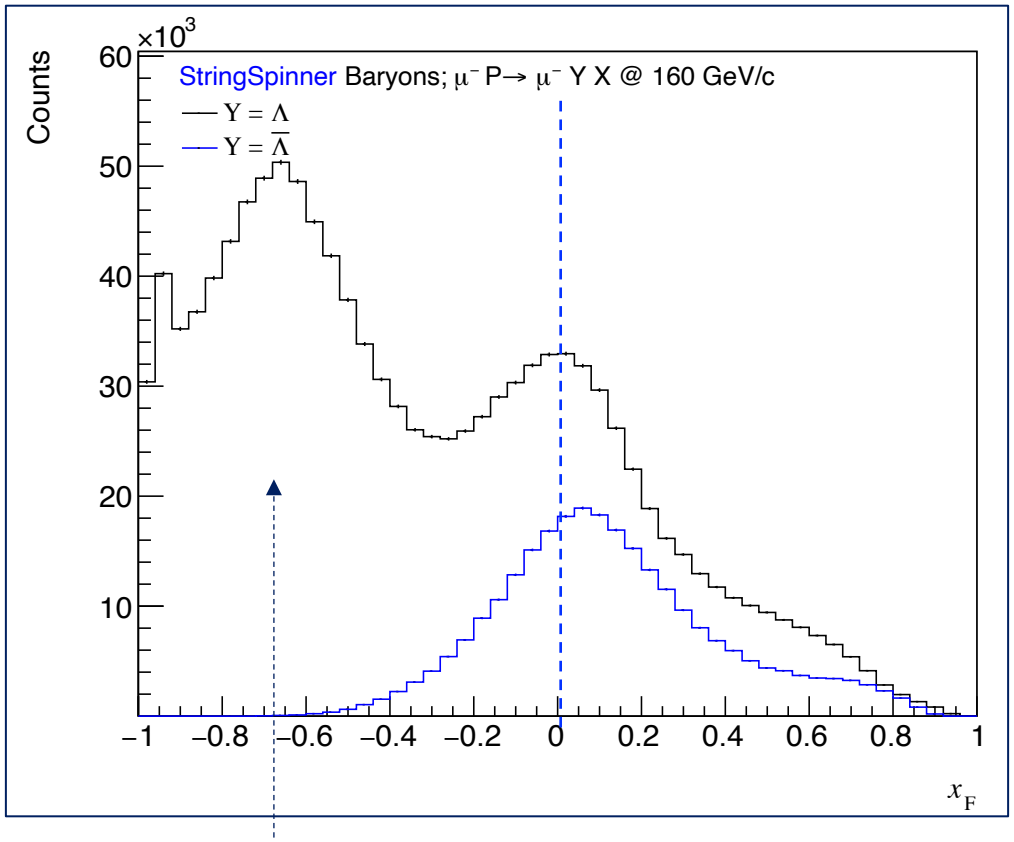


≈ costant vs x

Increasing with P_T

Spontaneous polarization of $\Lambda, \overline{\Lambda}$

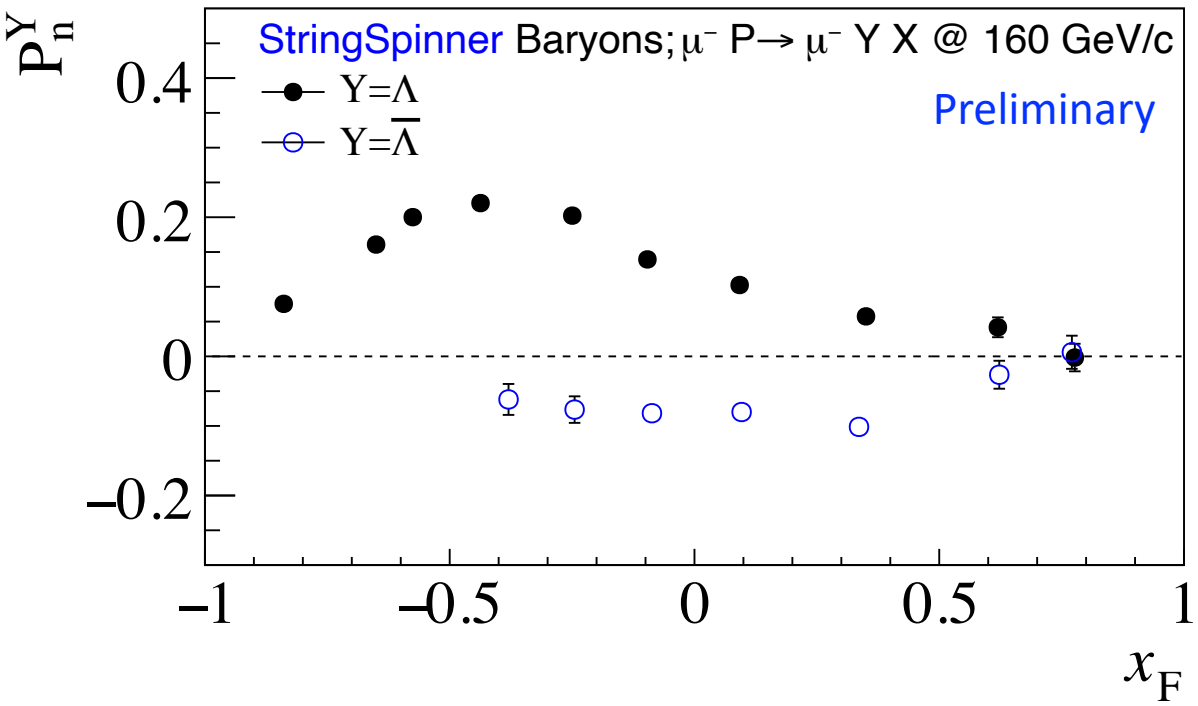
«target fragmentation»



Large fraction of Λs produced in the «target fragmentation» region unlike $\overline{\Lambda}$ …

Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«target fragmentation»



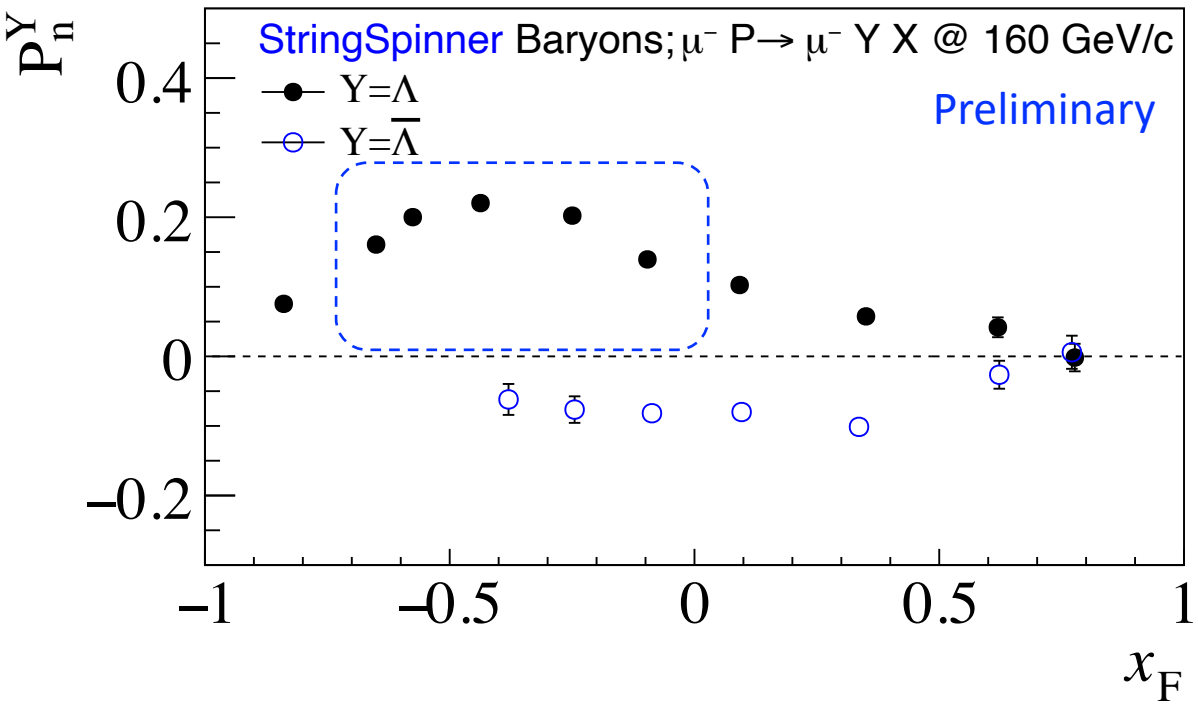
Large polarization predicted for Λ in target fragmentation

prediction of the $^3P_0$ mechanism!

see also Andersson, Gustafson, Ingelman, PRL 85, 417 (1979)

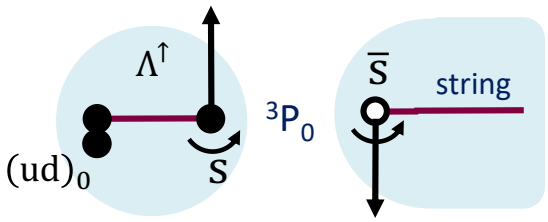
Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«target fragmentation»



Large polarization predicted for Λ in target fragmentation

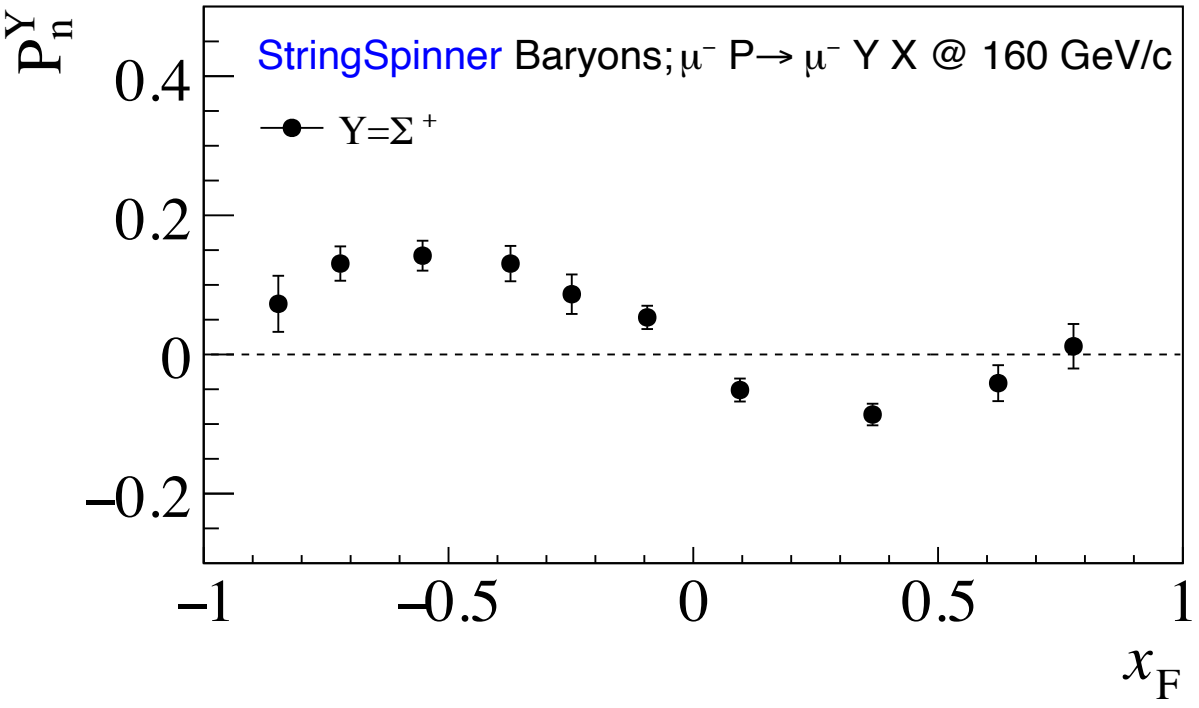
prediction of the $^3P_0$ mechanism!



Large Fracture Function $\widehat{M}_T^h$?

Anselmino, Barone, Kotzinian,
PLB 699 (2011) 108-118

Spontaneous polarization of Σ^+



Other hyperons are also polarized…

Conclusions

- The string+$^3P_0$ model now includes meson and baryon production with spin
- Implemented in Pythia for DIS by StringSpinner
  e^+e^- *to be done soon*
- From prelim. MC results the $^3P_0$ mechanism predicts large spontaneous polarization for Λs in TFR [up to 20%]
  not measured yet…
- Final goal: building a MC that implements systematically spin effects!
  needed for future experiments (EIC, JLAB@22GeV,...)
  but also for the interpretation of current data

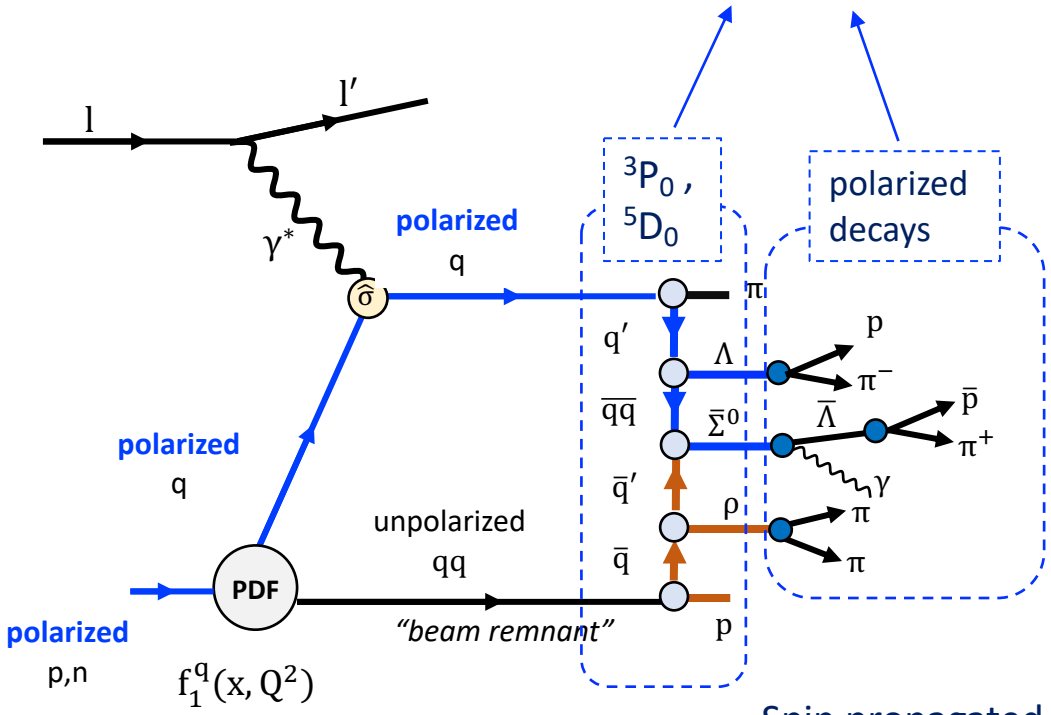
Backup

Implementation of the extended string+$^3P_0$ model in Pythia for DIS

- Extension of the existing StringSpinner package [will be published soon]

parton showers off..

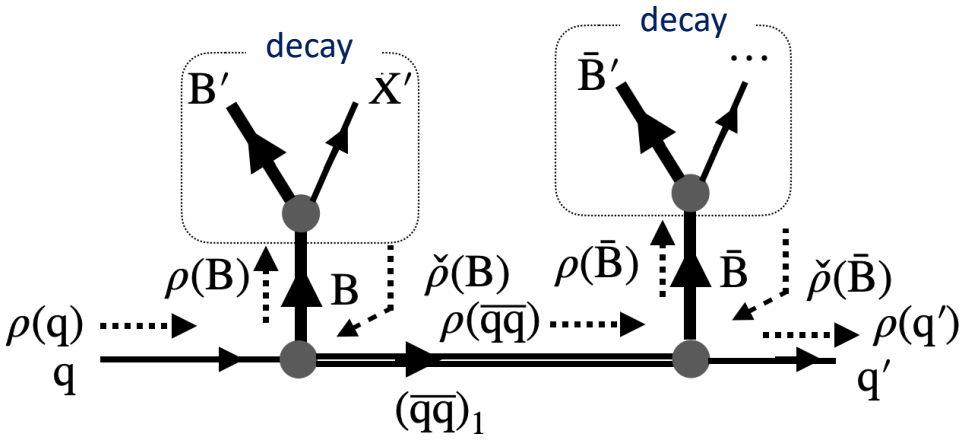
Using the corresponding quantum mechanical amplitudes



Transversity $h_1^q(x)$
or arbitrary polarization of quarks

Spin propagated from struck quark and remnant
→ *Collins-Knowles recipe (backup)*

Spin propagation along the fragmentation chain



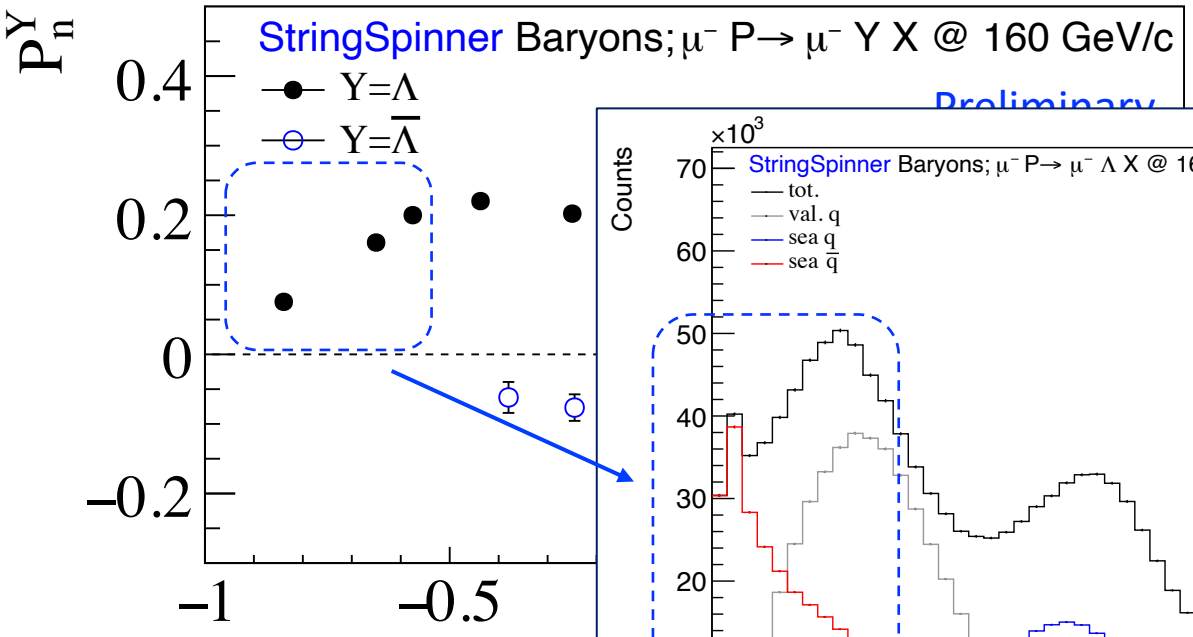
Recursive algorithm starting e.g. with a quark q

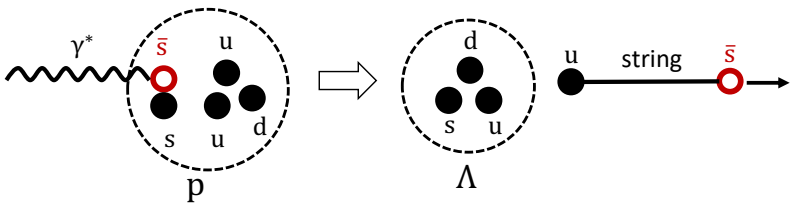
i. chose if to break the string via $q\bar{q}$ or $qq - \overline{qq}$ using P_{qq}/P_q
ii. if qq, decide if $(qq)_1$ or $(qq)_0$ according to $P_{(qq)_1}/P_{(qq)_0}$
iii. draw B according to the splitting function for $q \to B + (\overline{qq})$
iv. Evaluate $\rho(B)$ and decay B → come back with acceptance matrix $\check{\rho}(B)$
v. Evaluate $\rho(\overline{qq})$ using $\rho(q)$ and $\check{\rho}(B)$
vi. Draw $\bar{B}$ according to the splitting function for $\overline{qq} \to \bar{B} + q'$
vii. Decay $\bar{B}$ etc.

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

Spontaneous polarization of $\Lambda, \overline{\Lambda}$

«target fragmentation»





According to Pythia..

Decrease for $x_F \rightarrow -1$ due to struck $\bar{q}$

leads to production of B modeled without $^3P_0$ mechanism