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Measurement of transverse polarization of $\Lambda(\bar{\Lambda})$ within jet in pp collisions at 200 and 510 GeV

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For the STAR Collaboration

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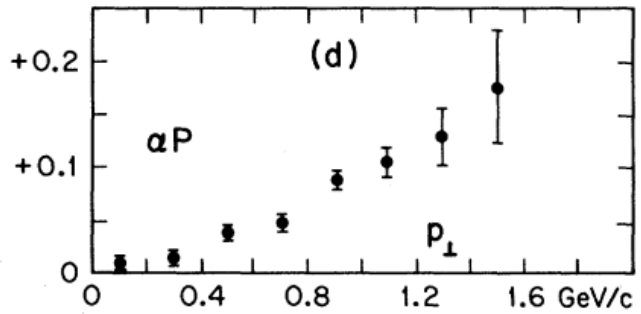
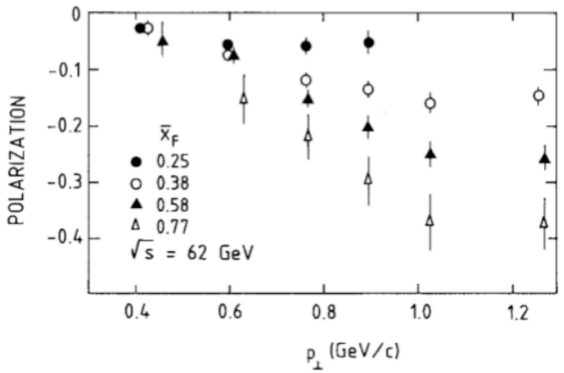
NSFC National Natural Science Foundation of China

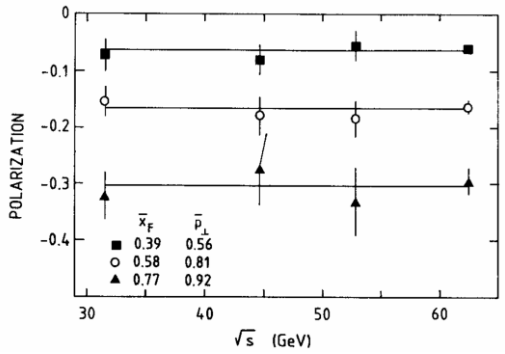
Λ spontaneous polarization puzzle

- Large transverse polarization of Λ hyperon in unpolarized hadron scatterings, along the normal to the production plane, first observed in 1976
- Λ polarization was sensitive to p_T and x_F, almost no energy dependence
- $\bar{\Lambda}$ polarization was consistent with 0

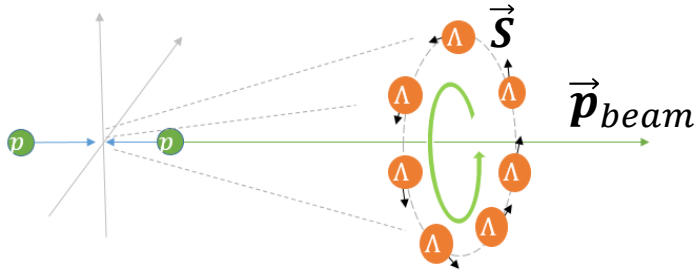
G.Bunce et al. PRL 36, 1113 (1976)







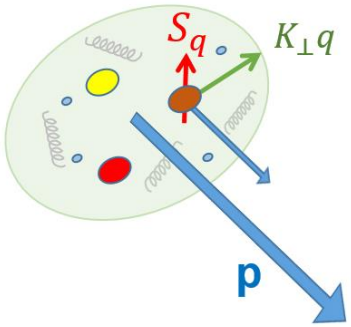
A.D. Panagiotou, Int.J.Mod.Phys.A 5, 1197 (1990)



$$\vec{S} = \frac{\vec{p}_{\text{beam}} \times \vec{p}_{\Lambda}}{|\vec{p}_{\text{beam}} \times \vec{p}_{\Lambda}|}$$

Possible sources

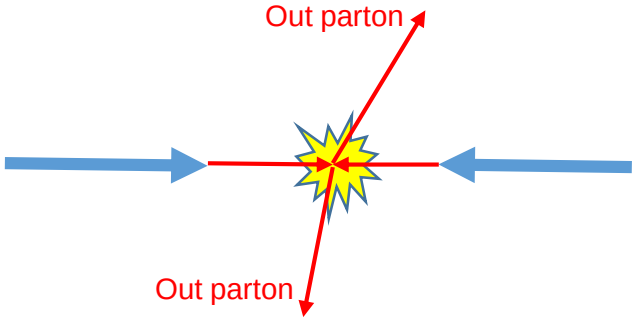
Initial state



Boer and Mulders, PRD 57, 5780 (1998)

- Boer-Mulders function
- Describing a polarized parton in an unpolarized proton

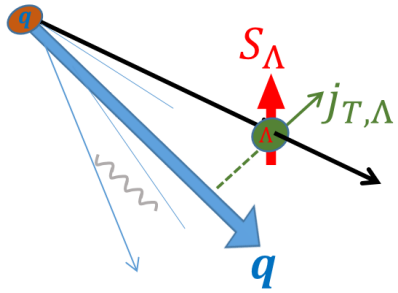
Hard scattering



Kane, Pumplin & Repko, PRL 41, 1689 (1978)

- pQCD calculation predicted ~0 polarization from hard-scattering

Final state



Mulders, Tangerman, Nucl. Phys. B 461, 197 (1996)

- Polarizing fragmentation function (PFF)
- Describing transverse polarized hadrons from unpolarized quark

(Focus of this talk)

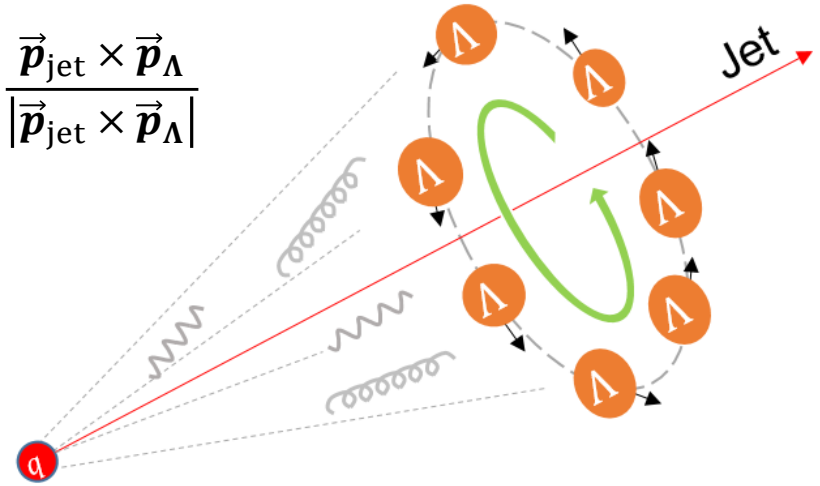
Polarizing fragmentation function

TMD FF
Quark polarization

Hardon polarization

	U	L	T
U	D_1		$H_1^\perp$
L		G_1	$H_{1L}^\perp$
T	$D_{1T}^\perp$	$G_{1T}^\perp$	$H_1, H_{1T}^\perp$

$$\vec{S} = \frac{\vec{p}_{\text{jet}} \times \vec{p}_\Lambda}{|\vec{p}_{\text{jet}} \times \vec{p}_\Lambda|}$$



- **Polarizing Fragmentation Function (PFF)**
  - ✓ Describing fragmentation of unpolarized quarks into polarized hadrons

- Experimental test
  - ✓ Measuring Λ polarization within a jet in different processes, such as: e^+e^-, pp, ep

Boer et al, PLB 671, 91-98 (2008)
Kang, Lee, Zhao, PLB 809, 135756 (2020)

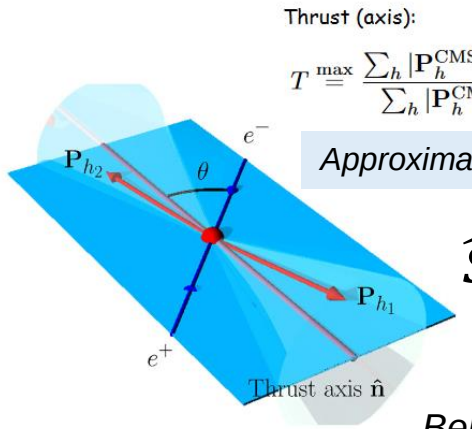
Λ polarization in e^+e^- annihilation

- At LEP ($\sqrt{s} = 90$ GeV)
  - ALEPH $P_T^{\Lambda,\bar{\Lambda}} = 0.016 \pm 0.007$
    ALEPH, PLB 374, 319 (1996)
  - OPAL $P_T^{\Lambda} = 0.019 \pm 0.014$ ($p_T > 0.3$ GeV/c)
    OPAL, EPJC 2, 49 (1998)
- At Belle ($\sqrt{s} = 10.6$ GeV)
  - Significant polarization with z dependence
  - Using π, K mesons tag quark flavor
- Extraction of polarizing Fragmentation Function (PFF)

  Callos, Kang, Terry, PRD 102, 096007 (2020)

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

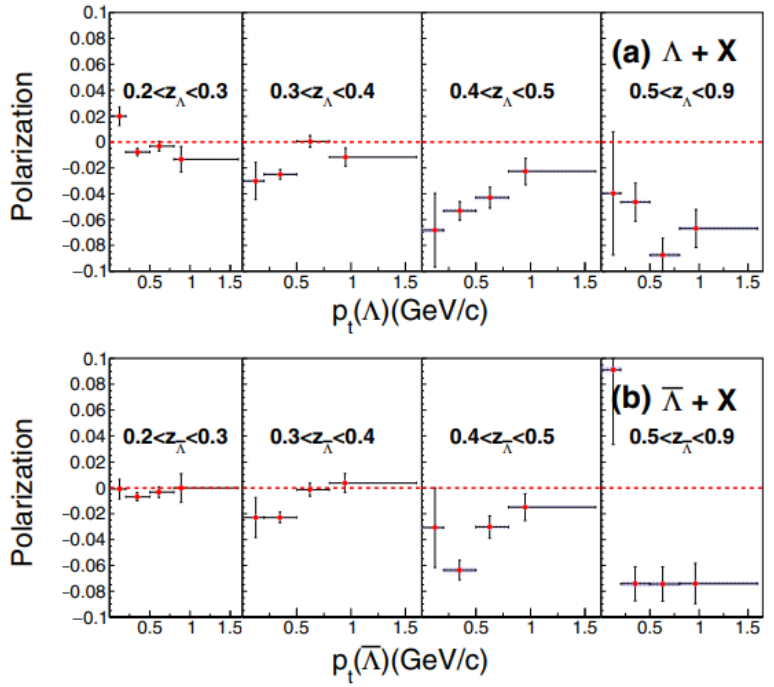
  Chen, Liang, Pan, Song, Wei, PLB 816, 136217 (2021)
- Gluon PFF are not constrained by e^+e^- data



Approximate jet axis

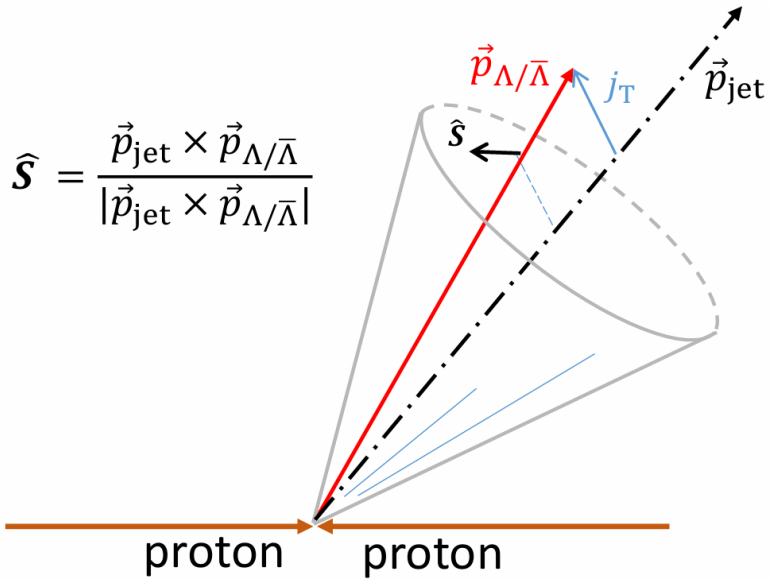
$$\hat{\boldsymbol{S}} = \hat{\boldsymbol{n}}_{\mathrm{thrust}} \times \hat{\boldsymbol{p}}_{\Lambda}$$

Belle, PRL 122, 042001 (2019)



What can we do at RHIC?

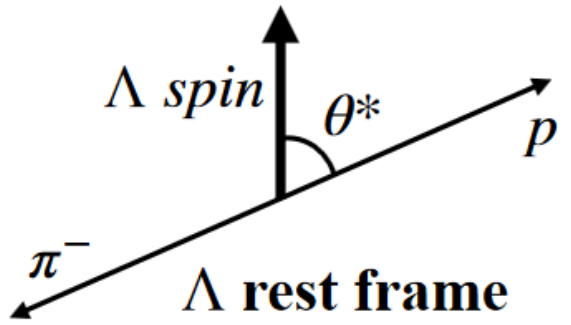
- Polarizing Fragmentation Function (PFF) can be accessed by transverse polarization of Λ-in-jet in pp collision *Boer et al, PLB 671, 91-98 (2008)*
  - ✓ Cover a wide range of jet p_T: 5~50 GeV/c
  - ✓ Constraints for gluon PFF
  - ✓ Test universality of PFF



- Λ polarization can be measured through angular distribution of its daughter particle

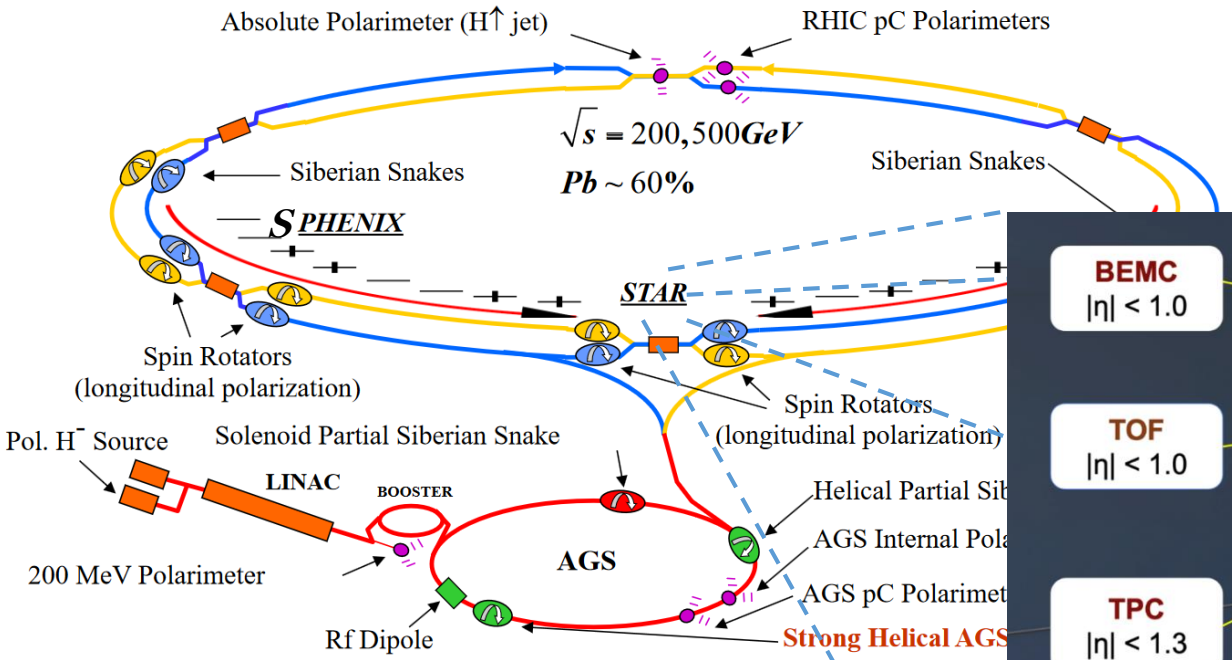
$$\frac{dN}{d\cos\theta^*} \propto \mathrm{A}_{(\cos\theta^*)}(1 + \alpha P \cos\theta^*)$$

$A(\cos\theta^*)$: acceptance correction function
$\alpha_\Lambda = 0.747 \pm 0.009$, $\alpha_{\bar{\Lambda}} = -0.757 \pm 0.004$
P: Λ polarization
θ^*: angle between p and spin direction in the Λ rest frame

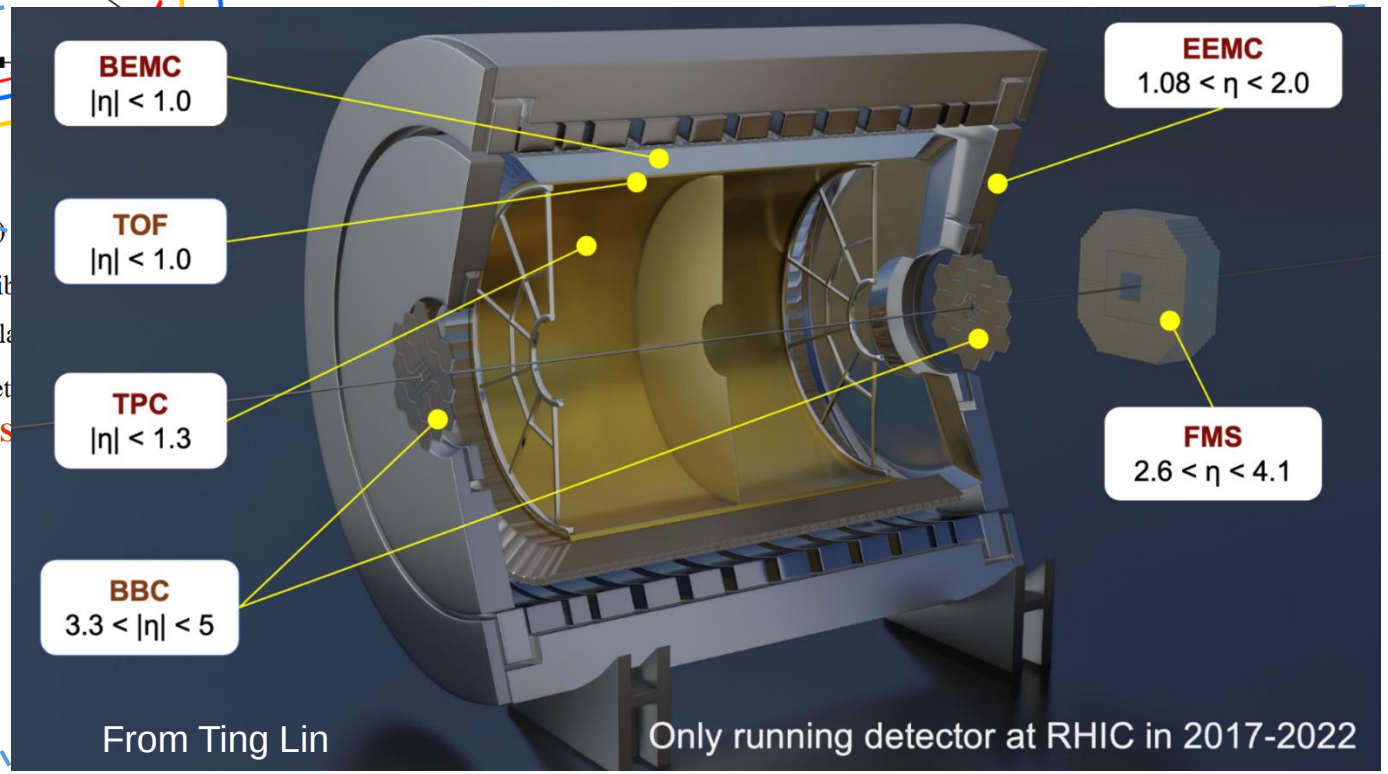


Relativistic Heavy Ion Collider (RHIC)

The world's first and only polarized proton collider



- Datasets: pp collision
  - $\sqrt{s} = 200$ GeV ~133 pb^{-1}
  - $\sqrt{s} = 510$ GeV ~350 pb^{-1}

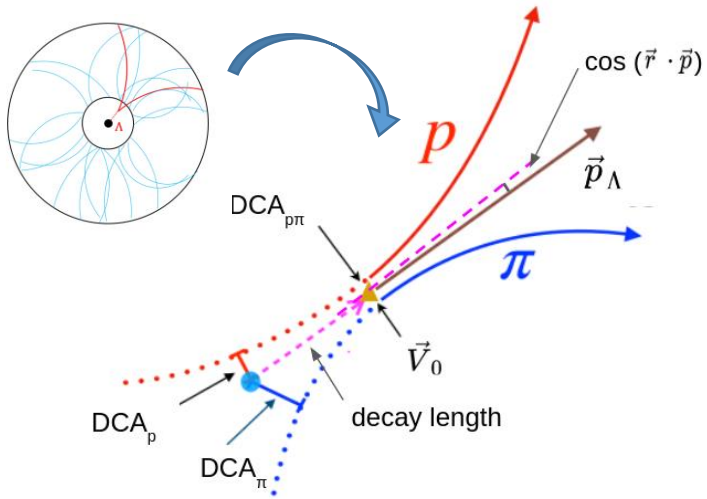


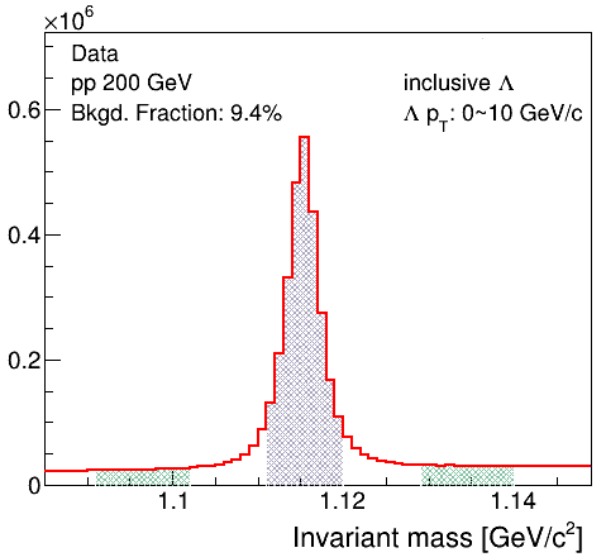
- Hard scattering events were selected by the EMC-based jet triggers

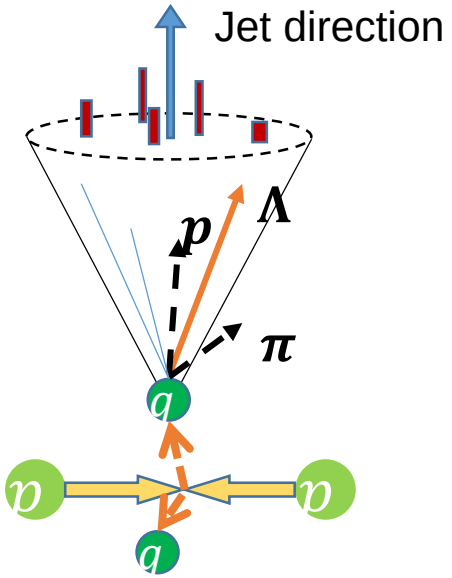
Λ and jet reconstruction

- Λ reconstruction:
  - ✓ $\Lambda \to p + \pi^-$; $\quad \overline{\Lambda} \to \bar{p} + \pi^+$
  - ✓ Track reconstruction and particle identification by TPC
  - ✓ Topological criteria

- Jet reconstruction
  - ✓ Anti-k_T with $\mathrm{R} = 0.6$
  - ✓ Reconstructed $\Lambda, \overline{\Lambda}$ as inputs
  - ✓ Including tracks and tower energies



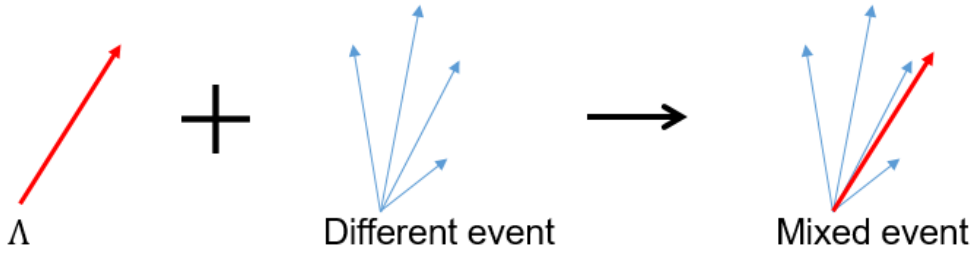




Acceptance correction

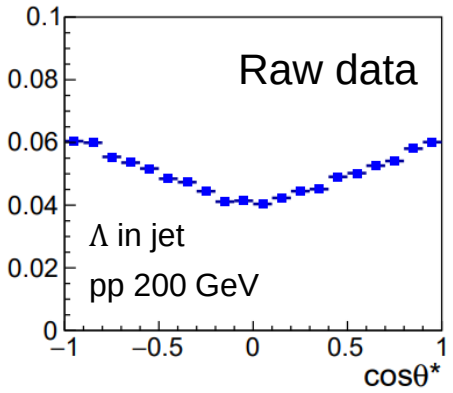
Mixed events

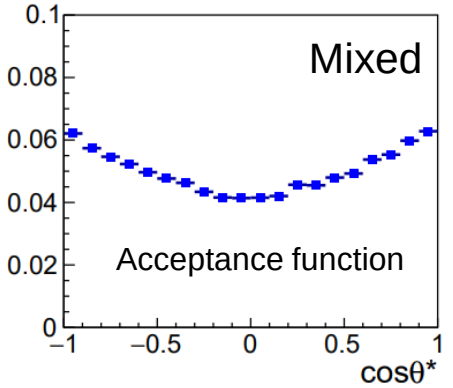
- Mixed Λ with jet from different event
- Difference of V_z: $|\Delta V_z| \leq 5$ cm
- The same trigger



Acceptance correction

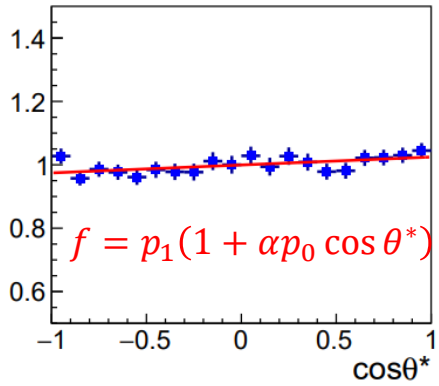
- Reweighting 3D distribution of $\Delta\eta, \Delta\phi$ between Λ and jet, and η_{jet}
- Correction $\dfrac{N(cos\theta^*)_{Data}}{N(cos\theta^*)_{Mixed}}$





Polarization extraction

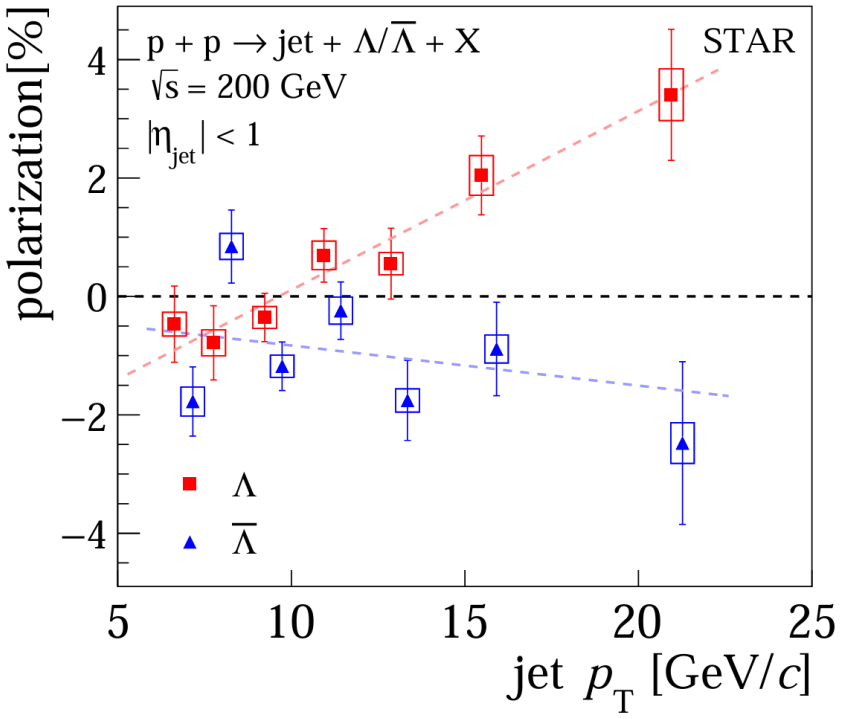
$$\frac{dN}{d\cos\theta^*} \propto (1 + \alpha P \cos\theta^*)$$



Results as function of jet p_T

- First measurement of Λ polarization in jet in pp collisions
  - Clear jet p_T dependence of Λ polarization, with indication of the sign change from low to high jet p_T
  - $\overline{\Lambda}$ polarization mostly remains negative
  - Mean polarizations
    - $P_{\Lambda} = 0.24 \pm 0.19(stat.) \pm 0.09(sys.)[\%]$
    - $P_{\overline{\Lambda}} = -0.77 \pm 0.20(stat.) \pm 0.09(sys.)[\%]$
  - Jet p_T dependence could be related to relative contributions from different parton flavor
  - Provide first constraints on gluon PFF

STAR,arXiv:2509.17487 (submitted to PRL)

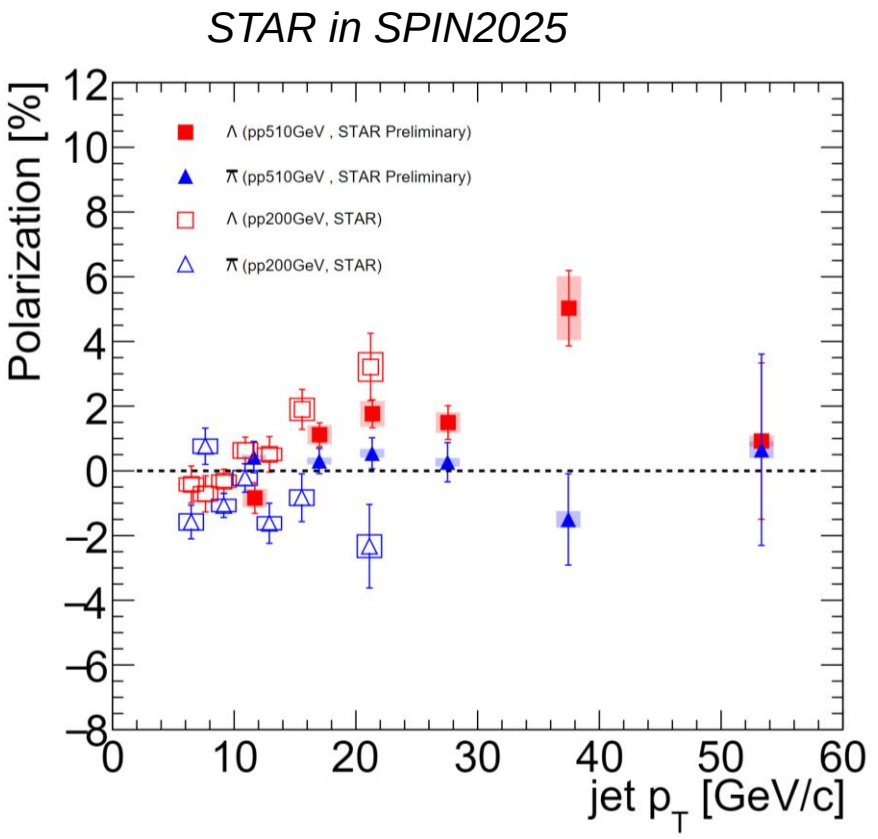


Fitted slopes

Λ: 0.303 ± 0.067 $\overline{\Lambda}$: -0.067 ± 0.075

Results as function of jet p_T

- The preliminary results at $\sqrt{s}$=510 GeV cover jet p_T up to 50 GeV
- Λ polarization consistent with the trend at $\sqrt{s}$ = 200 GeV
- The relative contribution from different partons is different between $\sqrt{s}$= 200 GeV and $\sqrt{s}$=510 GeV even at same jet p_T

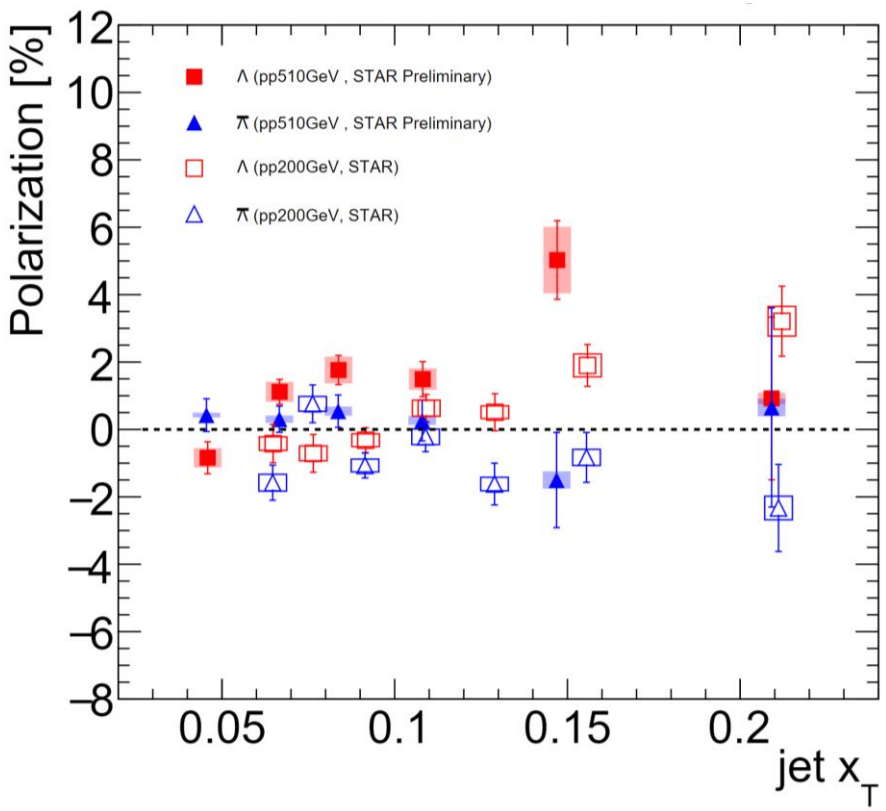


Results as function of x_T

$$x_T = \frac{2p_T^{\text{jet}}}{\sqrt{s}}$$

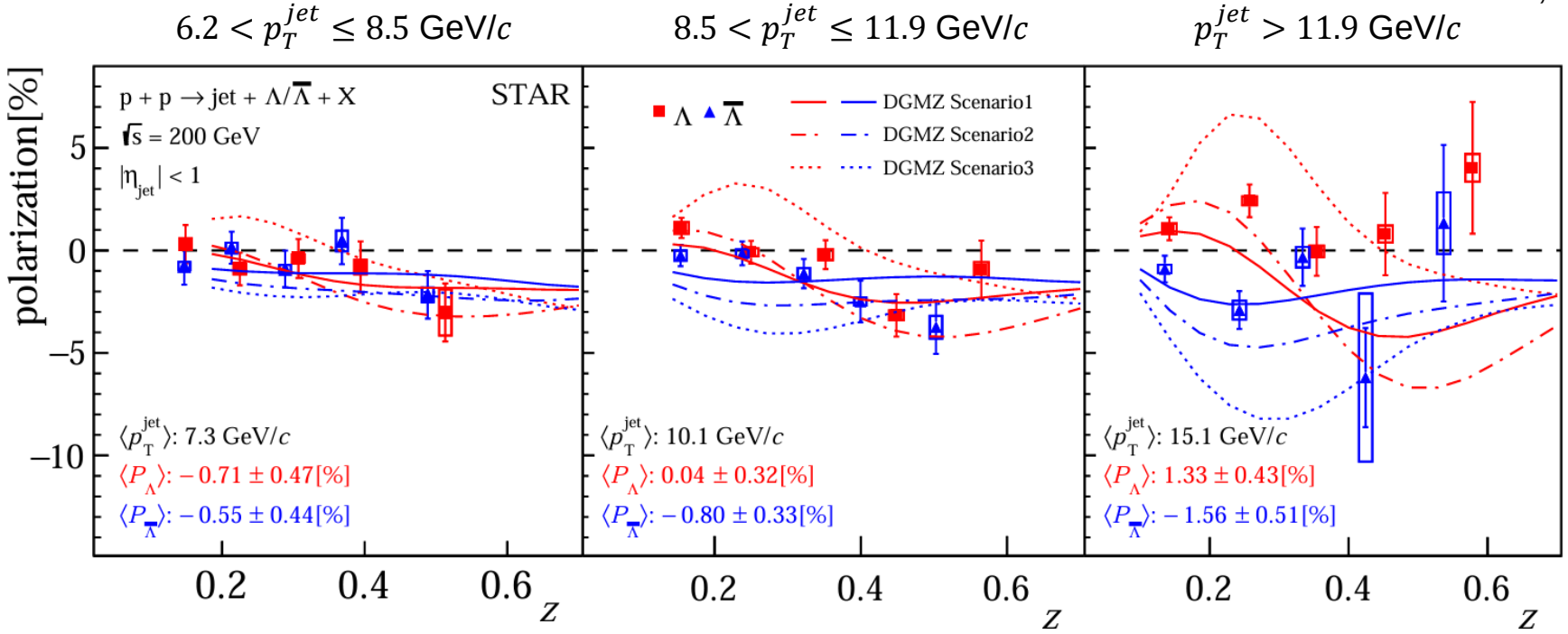
- x_T approximate to the momentum fractions of scattering partons at $\sqrt{s}$ = 200 and 510 GeV
- The comparison between $\sqrt{s}$ = 200 GeV and 510GeV at same x_T, then reflects the scale dependence; with a factor of 2.55 difference

STAR in SPIN2025



Results as function of z

STAR,arXiv:2509.17487 (submitted to PRL)



DGMZ model:

D'Alesio, Gamberg, Murgia, Zaccheddu, Phys. Lett. B 851 (2024) 138552

Scenario 1: Different PFF for u, d, s and their antiquarks

Scenario 2: Same as in Sc. 1 including charm in unpolarized x-section

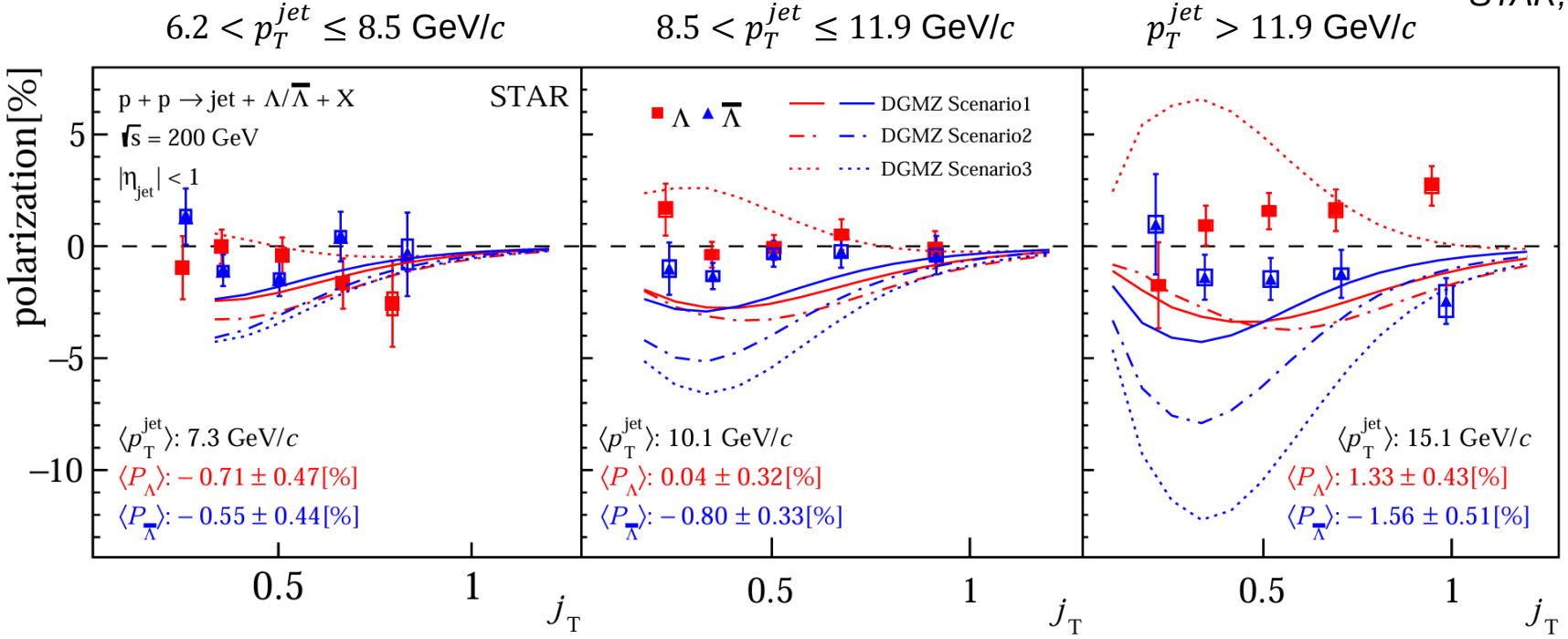
Scenario 3: Including $SU(2)$ isospin symmetry based on Sc. 2

z: jet longitudinal momentum fraction carried by Λ

- Provide the first experimental constraints for PFF from pp collisions
- Possible z dependences are observed at different jet p_T ranges

Results as function of j_T

STAR,arXiv:2509.17487 (submitted to PRL)



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Scenario 3: Including $SU(2)$ isospin symmetry based on Sc. 2

j_T: transverse momentum of Λ relative to jet

- Provide the first experimental constraints for PFF from pp collisions
- Possible z dependences are observed at different jet p_T ranges
- No significant dependence on j_T at all jet p_T ranges
- Opposite sign of Λ and $\overline{\Lambda}$ polarization at high jet p_T

$$j_T = \frac{p_\Lambda \times p_{jet}}{|p_{jet}|}$$

Summary

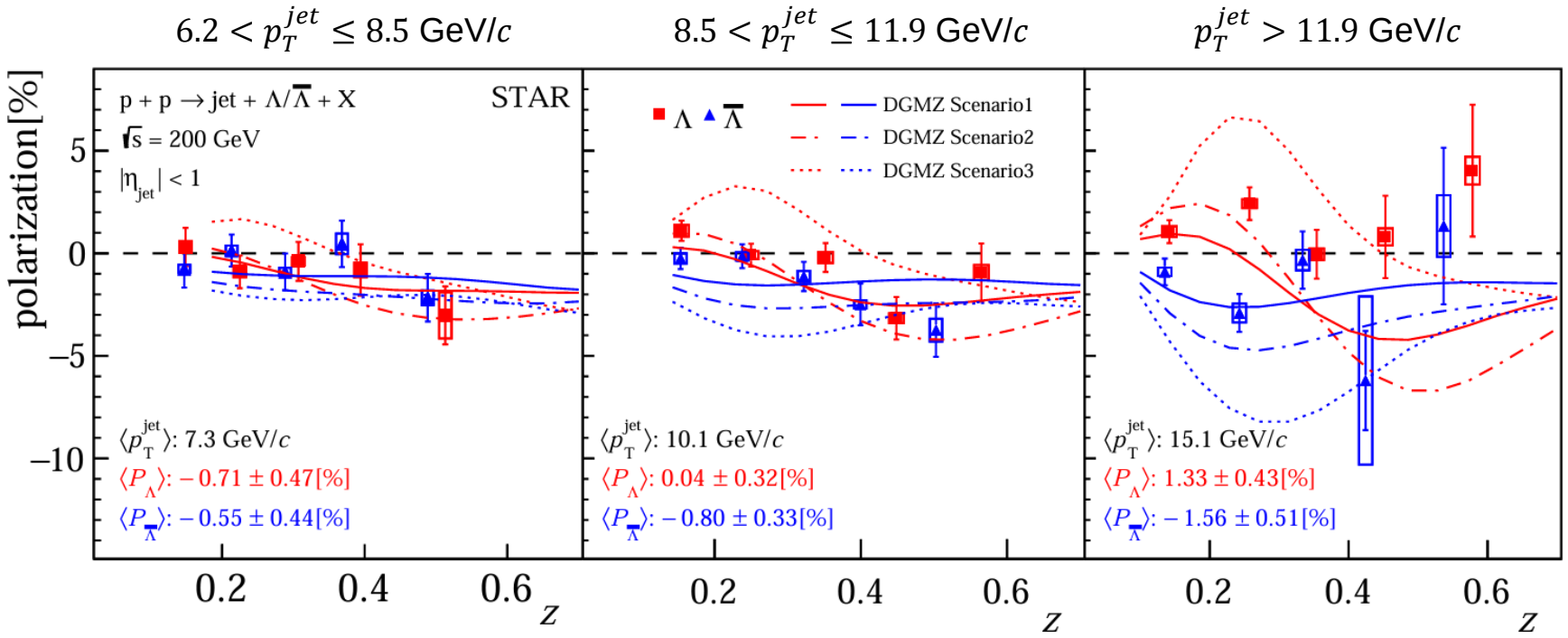
- First measurement of transverse polarization of Λ-in-jet in pp collisions at STAR.
- Clear jet p_T dependence of Λ polarization at $\sqrt{s}$ = 510 and $\sqrt{s}$ = 200 GeV
- New results provide first constraints for gluon PFF and inputs to TMD evolution effect
- Test universality for PFF at different processes

Outlook:

- 200 GeV pAu data being analyzed to study the nuclear medium effect
- Larger sample at 500 GeV and 200 GeV pp collisions recorded in 2022 and 2024 will provide more constraints

Backup

Results as function of z



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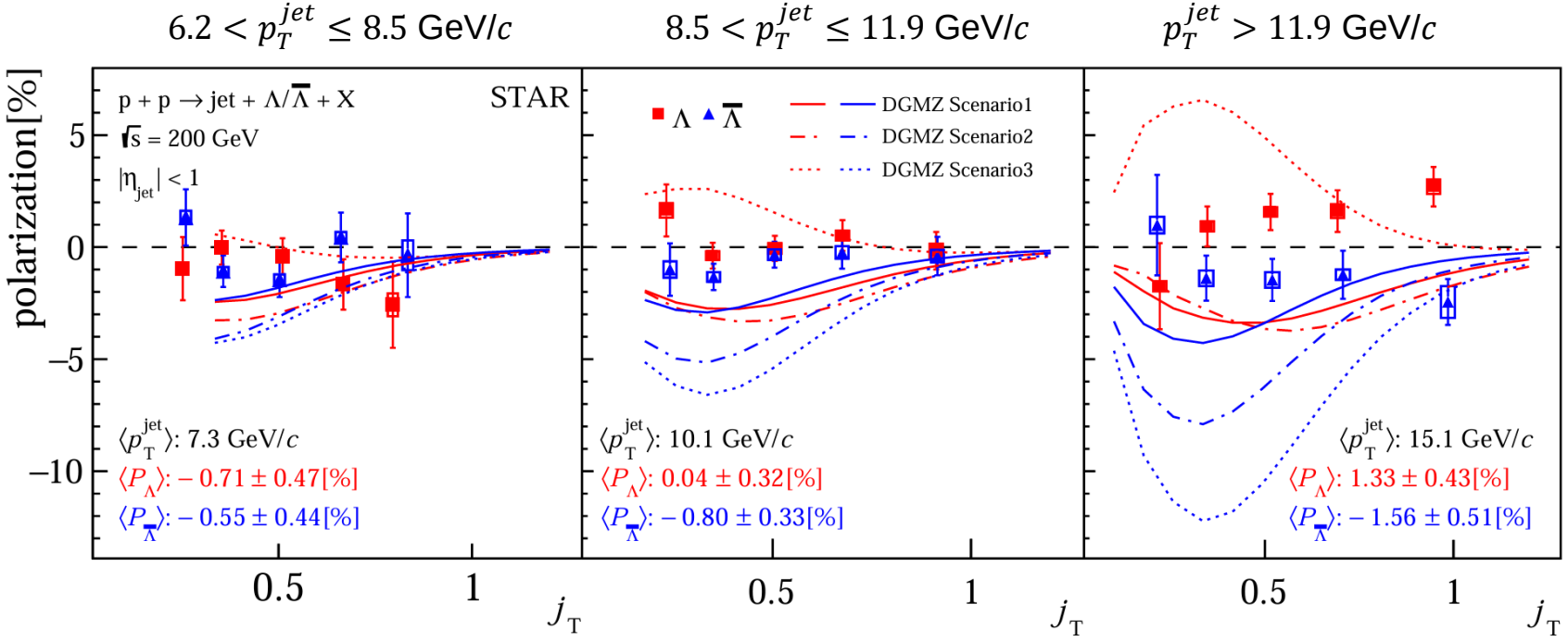
Scenario 2: Same as in Sc. 1 including charm in unpolarized x-section

Scenario 3: Including $SU(2)$ isospin symmetry based on Sce. 2

- Possible z dependences are observed at different jet p_T ranges
- Comparable distribution between data and model at low and medium jet p_T
- Large discrepancies between model calculation and data at large jet p_T

Results as function of j_T



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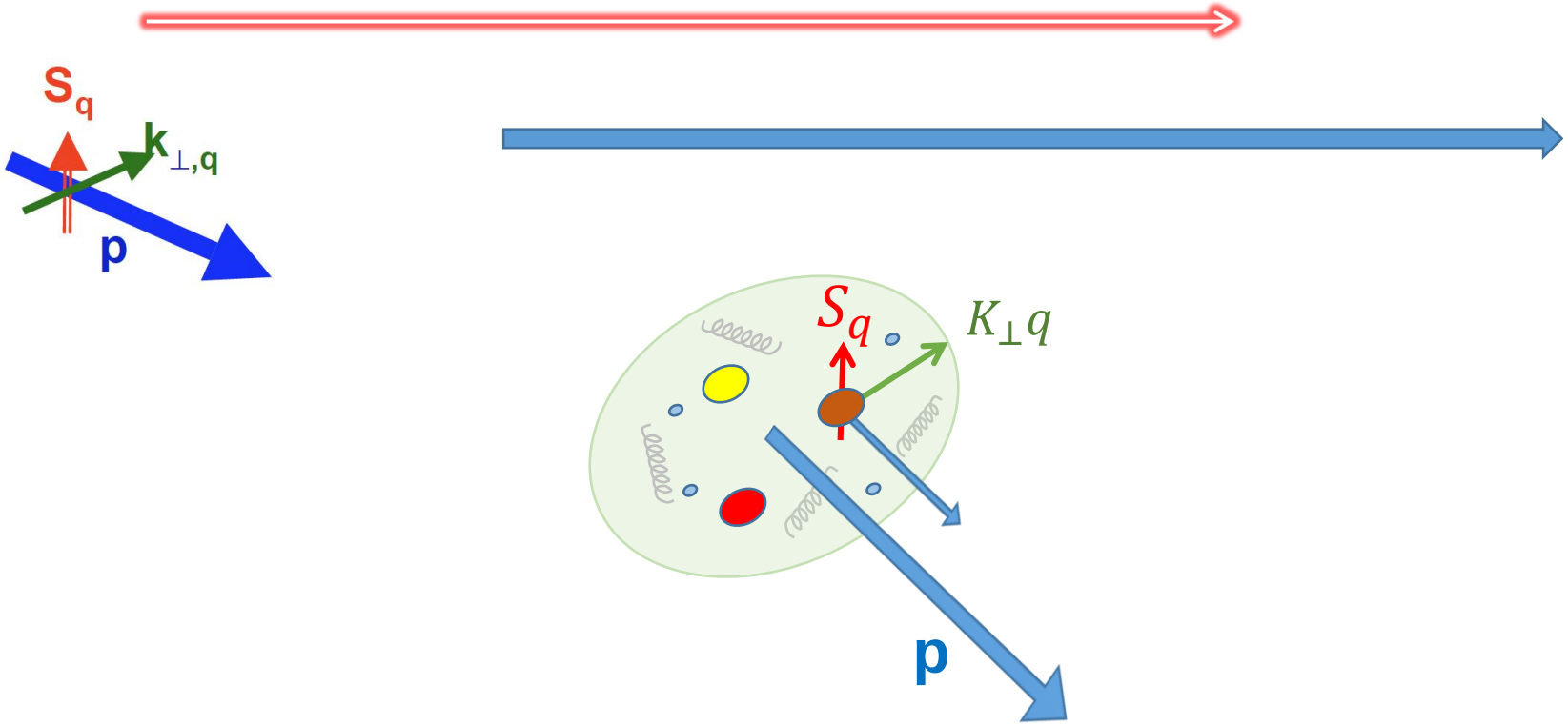
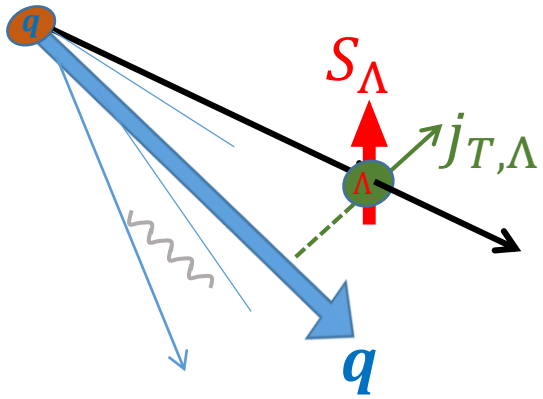
Scenario 1: Different pFFs for u, d, s and their antiquarks

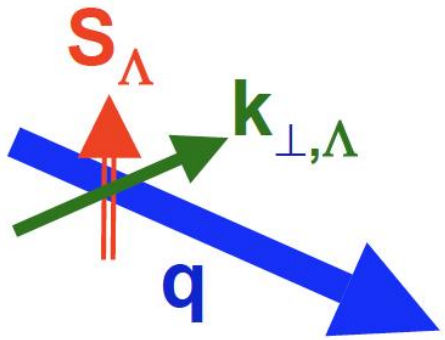
Scenario 2: Same as in Sc. 1 including charm in unpolarized x-section

Scenario 3: Including $SU(2)$ isospin symmetry based on Sce. 2

- No significant dependence on j_T at all jet p_T ranges
- Opposite sign of Λ and $\overline{\Lambda}$ polarization at high jet p_T
- Large discrepancies between theoretical lines and data at large jet p_T


S_q
k_⊥,q
p
S_q
K_⊥q
p


q
S_Λ
$j_{T,\Lambda}$
Λ
q


S_Λ
$k_{\perp,\Lambda}$
q