Lambda Polarization at EIC

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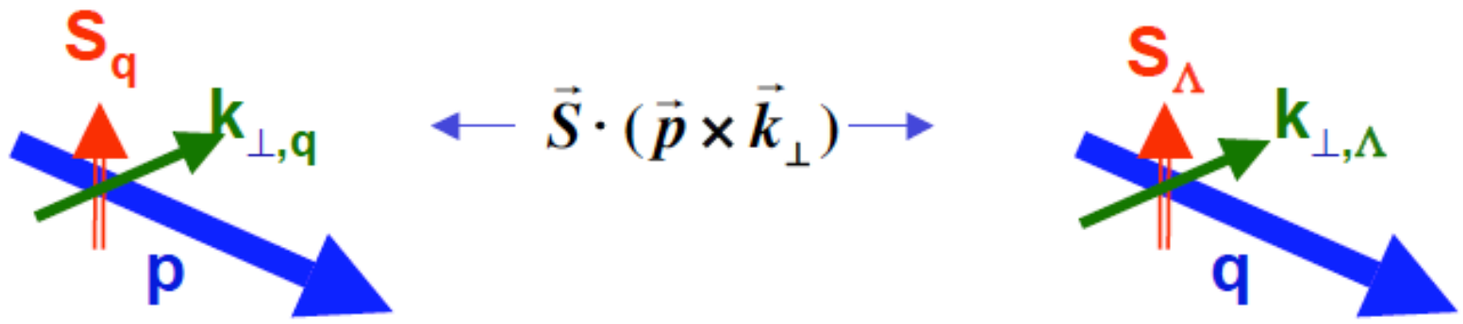
In Collaboration with Zhong-Bo Kang, John Terry, Anselm Vossen, and Qinghua Xu

TMD at Initial and Final States

TMD distributions

TMD fragmentation



Quark pol.

Hadron pol.

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

TMD PDFs

Quark pol.

Hadron pol.

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

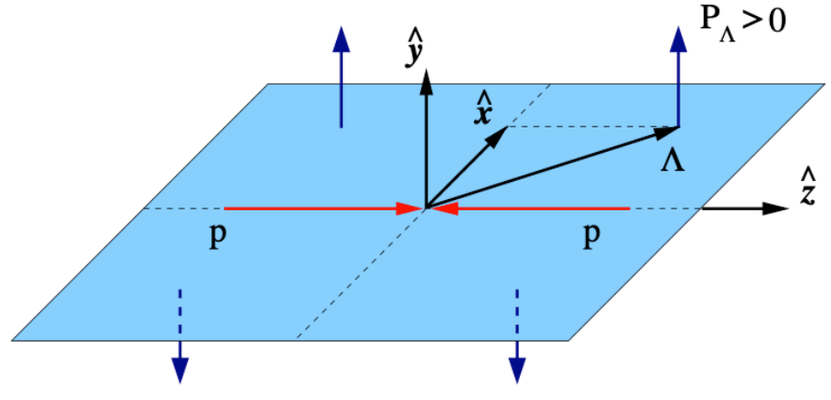
TMD FFs

Can not distinguish them in hadron-hadron reactions

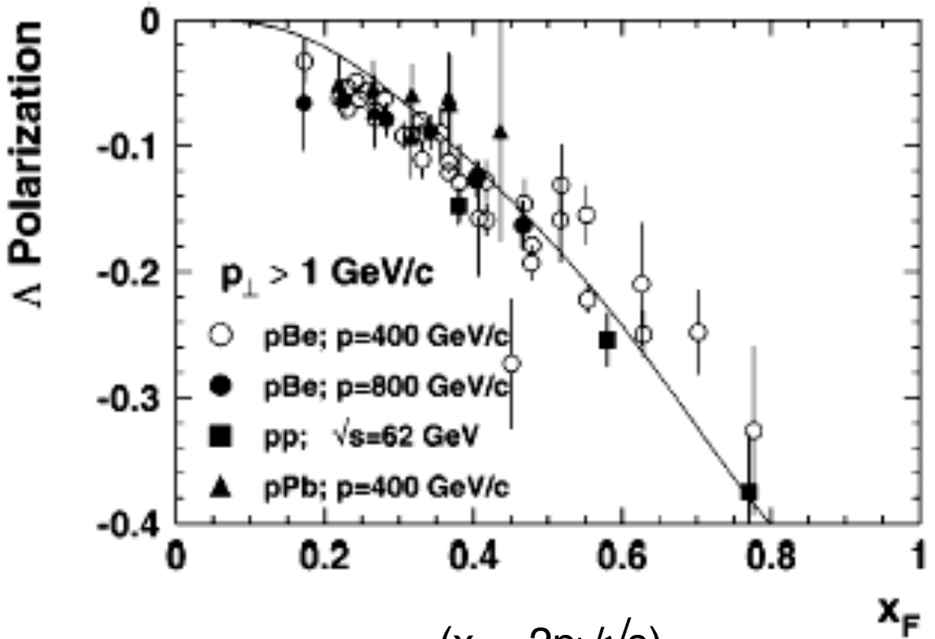
But, lepton-hadron and e^+e^- can separate them.

Lambda：Final state “polarimetry”

- Self-analyzing weak decay: Lambda polarization can be measured from the angular distribution of its daughter particles:
  $\Lambda \to p\pi^-$(Br~64%) $\Lambda \to n\pi^0$ (Br~36%)



- Λ polarization plays an important role in spin physics
  - *Transverse polarization* in ***unpolarized*** pp, pA (G.Bunce et al 1976)
  - Study pol. fragmentation function and spin content of hyperon
  - Complementary to Kaon SIDIS, study spin structure of nucleon

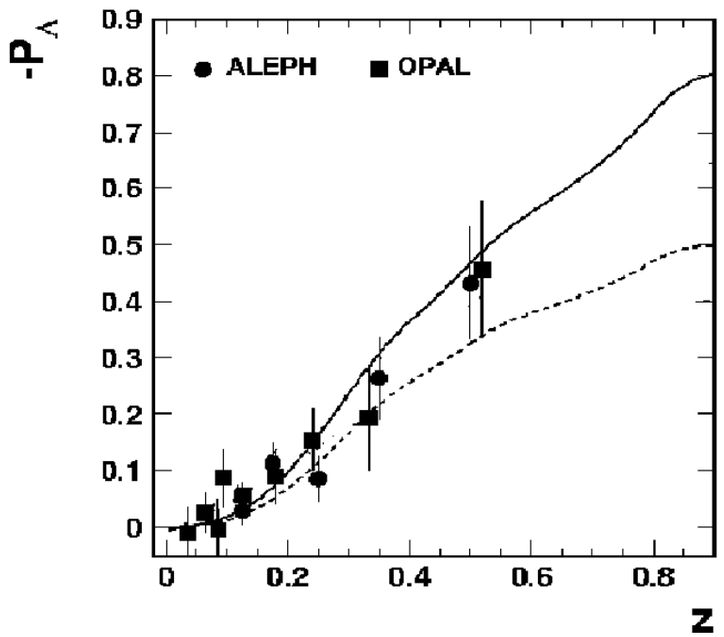


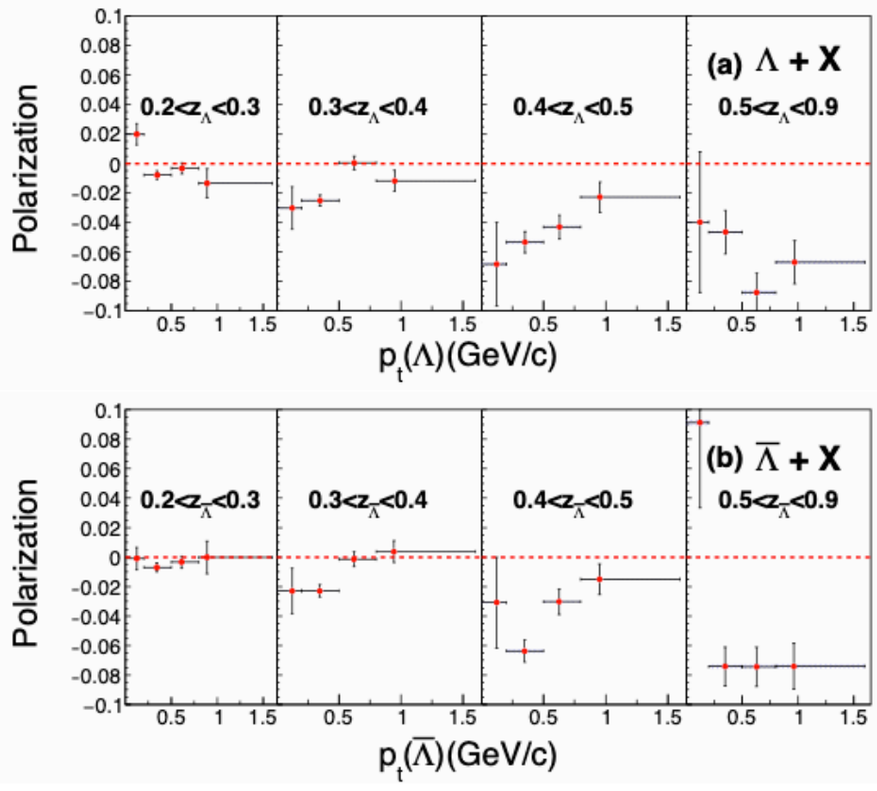
($x_F = 2p_L/\sqrt{s}$)

Previous Measurements

Long history …

- Longitudinal
  - e+e-: ALEPH(PLB'96), OPAL(EPJC'98)
  - Lepton-nucleon E665(EPJC'00), HERMES(PRD'01),NOMAD(NPB'01), COMPASS
  - Nucleon-nucleon: STAR(PRD'09, PRD'18)
- Transverse
  - e+e-: Belle (PRL'19)
  - Fixed target hadron-hadron(nucleus): E704 (PRL'97), DISTO(PRL'99)
  - Lepton-nucleon: COMPASS (arxiv'21)
  - pp: STAR (PRD'18)

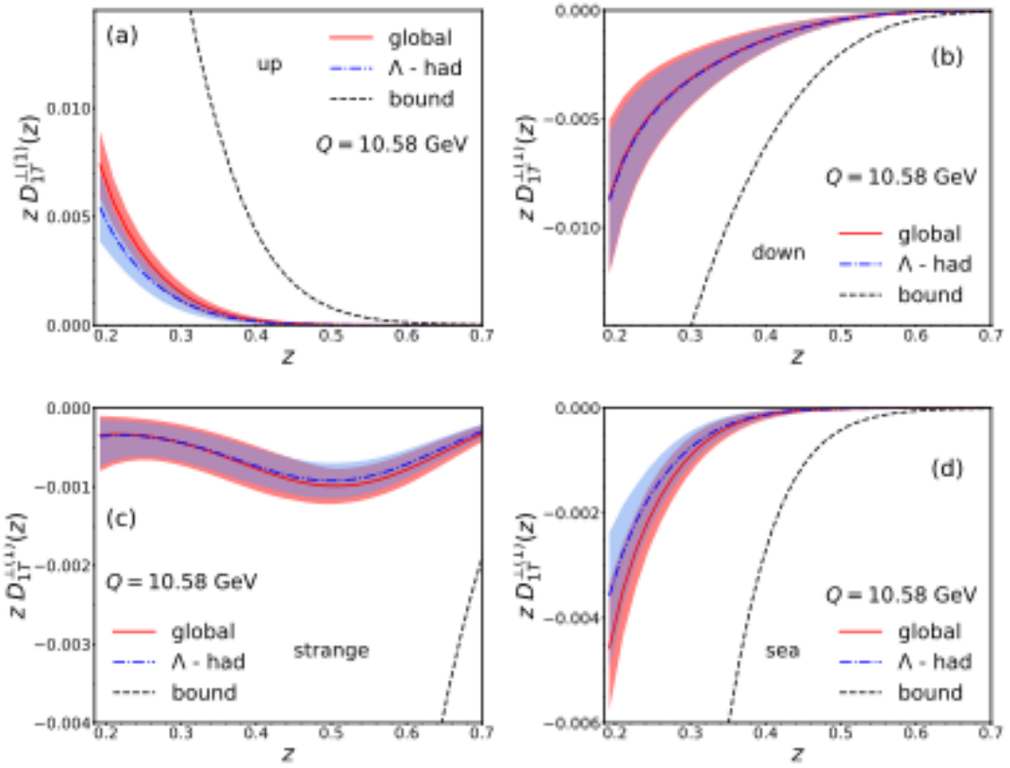




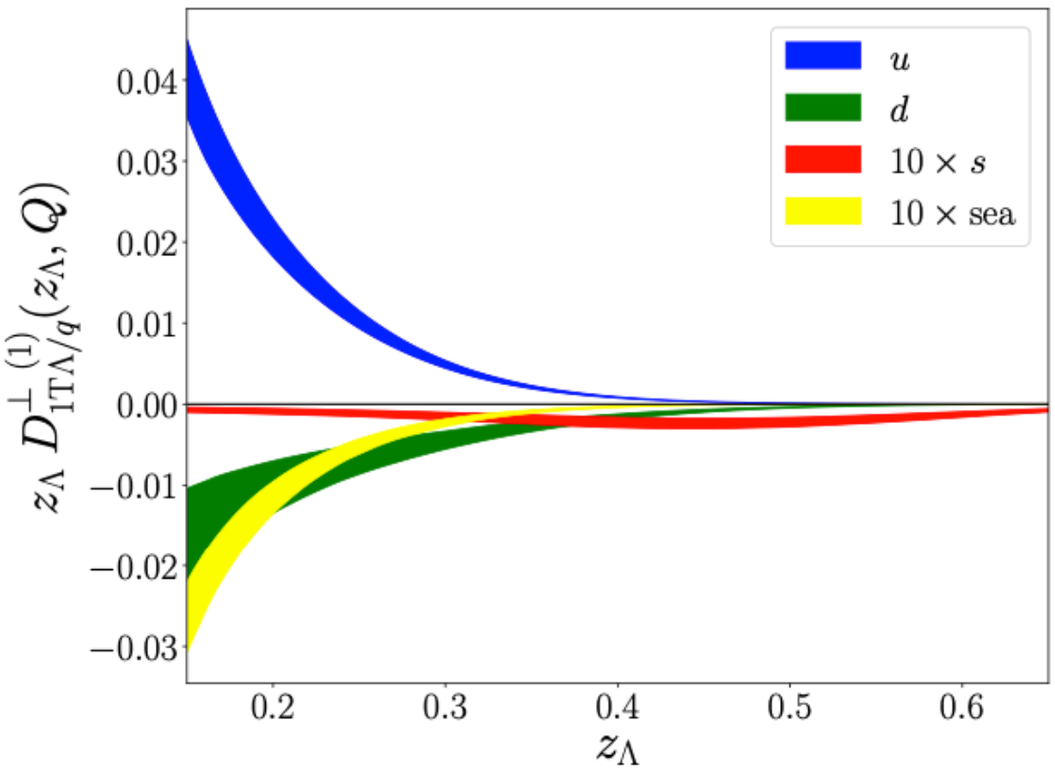
Review for even earlier data, A.D. Panagiotou, Int.J.Mod.Phys.A 5, 1197,(1990)

Polarizing FFs extracted from Belle data

D'Alesio, Murgia, Zaccheddu PRD **102**, 054001

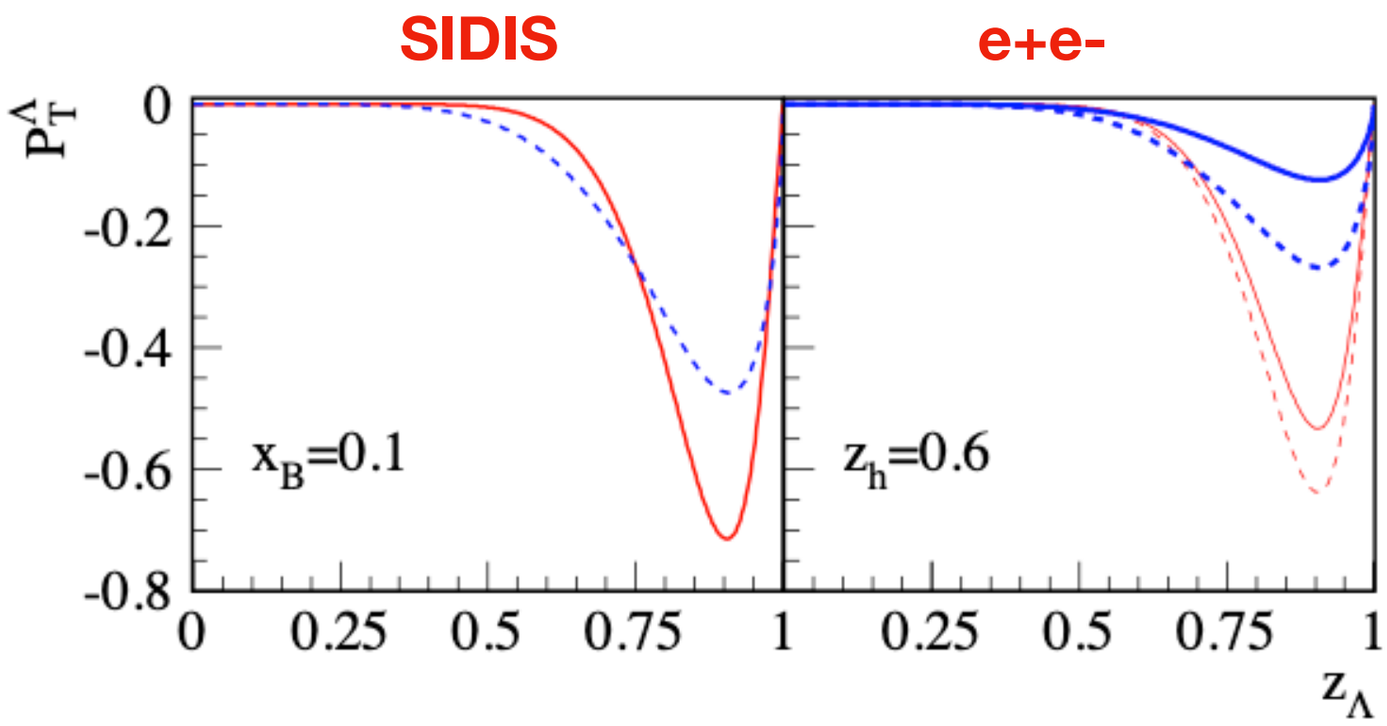


Callos, Kang, Terry PRD **102**, 096007



- Polarizing FFs by fitting Belle Lambda data
- Extraction also by Chen et. al. PLB 816, 136217

Universality tests for polarizing FFs



Boer, Kang, Vogelsang, Yuan, PRL'10

- Unlike the counterpart Sivers function changing sign between SIDIS and DY, polarizing FFs is predicted to be universal.
  - Metz, PLB 549 (2002) 139; Gamberg, Mukherjee, Mulders, PRD 77 (2008) 114026 Meissner, Metz, 0812.3783/hep-ph; Yuan, Zhou, 0903.4680/hep-ph
- e+e- data are existing, need test from SIDIS

Longitudinal Spin Transfer to Λ in ep

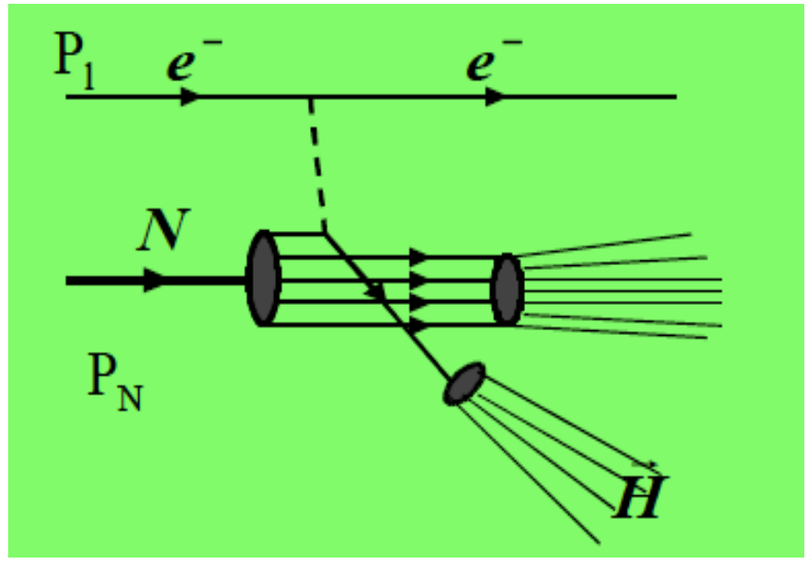
- Polarization of scattered quark:

pol. of lepton beam pol. of hadron beam

$$P_f = \frac{P_l D(y) q_f(x) + P_N \Delta q_f(x)}{q_f(x) + P_l D(y) P_n \Delta q_f(x)}$$

unpol. pdf pol. pdf

Depolarization factor: $D(y) = \frac{y(2-y)}{1-2y+y^2}$



- Polarization of of Λ in the current region:
  - $p_N = 0,\ P_l \neq 0:\quad P_\Lambda = P_l D(y) \frac{\Sigma_f e_f^2 q(x,Q^2) \Delta D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)}$ → clean measurement of pol. FFs
  - $p_N \neq 0,\ P_l = 0:\quad P_\Lambda = P_N \frac{\Sigma_f e_f^2 \Delta q(x,Q^2) \Delta D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)}$ → pol. FFs and pol. PDFs

Transverse Spin Transfer to Λ in ep

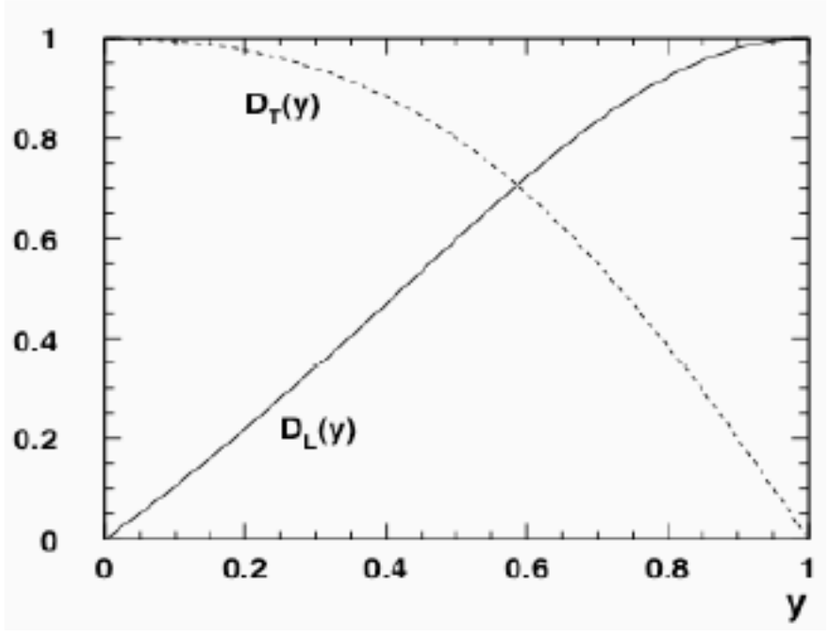
- Polarization of scattered quark:

transiversity

$$P_f = D_T(y)\frac{\delta q(x,Q^2)}{q_f(x,Q^2)}$$

unpol. pdf

Depolarization factor: $D_T(y) = \frac{2(1-y)}{1-2y+y^2}$



P_f is independent of lepton polarization, and small y is required!

- Polarization of Λ in the current region:

$$P_\Lambda = P_N \frac{\Sigma_f e_f^2 \delta q(x,Q^2)\Delta_T D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)}$$

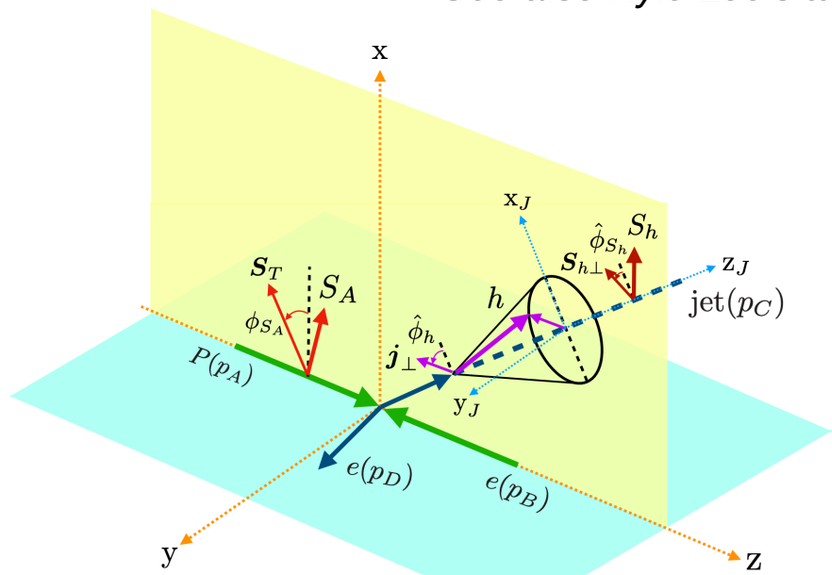
Artru, Mekhfi 1991

Information on δq(x) or $\Delta_T D(z)$ can be accessed via transverse polarization of Lambda in ep and pp

Lambda in Jet

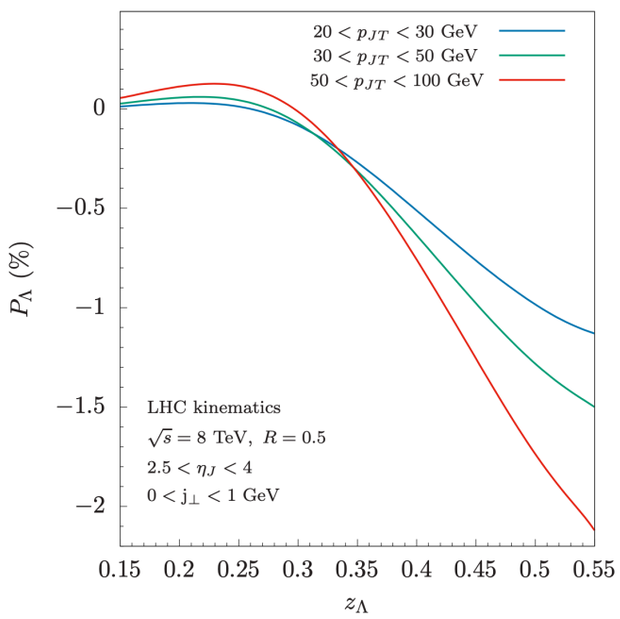
See also Kyle Lee's talk

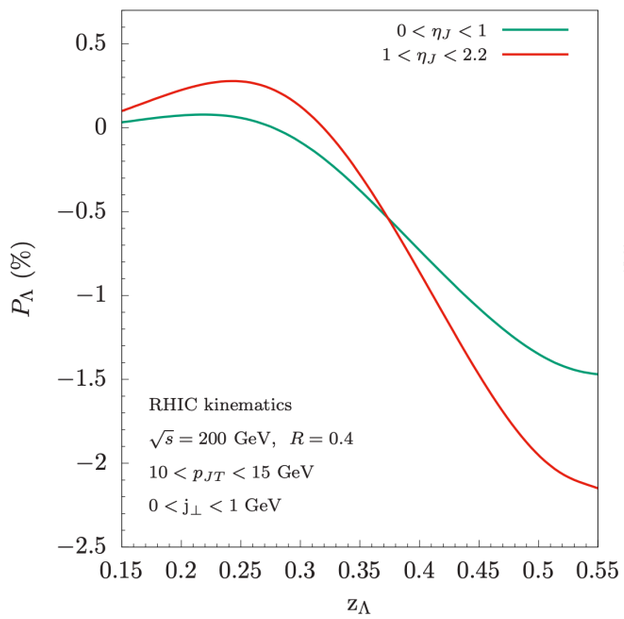
$$e(\ell) + p(P, \boldsymbol{S}_\perp) \to e(\ell') + (\mathrm{jet}(\boldsymbol{q}_\perp)\, \Lambda(z_{J\Lambda}, \boldsymbol{j}_\perp, \boldsymbol{S}_\perp)) + X$$

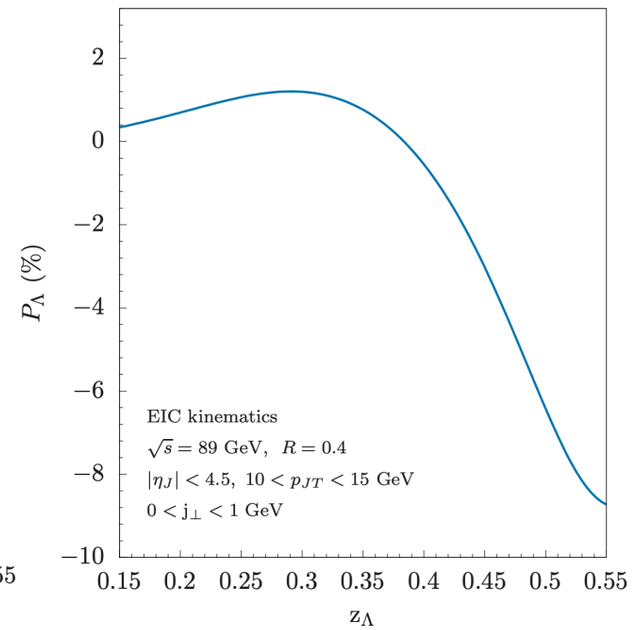


- Measuring hadron distribution in jet allows de-correlating TMD FF from other TMDs
  - Kang, Liu, Ringer, Xing, *JHEP* 11 068 (2017)
  - Kang, Lee, Terry, Xing, *PLB* 798, 134978 (2019)
  - Kang, Lee, Zhao, *PLB* 809 (2020) 135756
  - Kang, Lee, Shao, Zhao, *arXiv*: 2106.15624

PLB 809 (2020) 135756

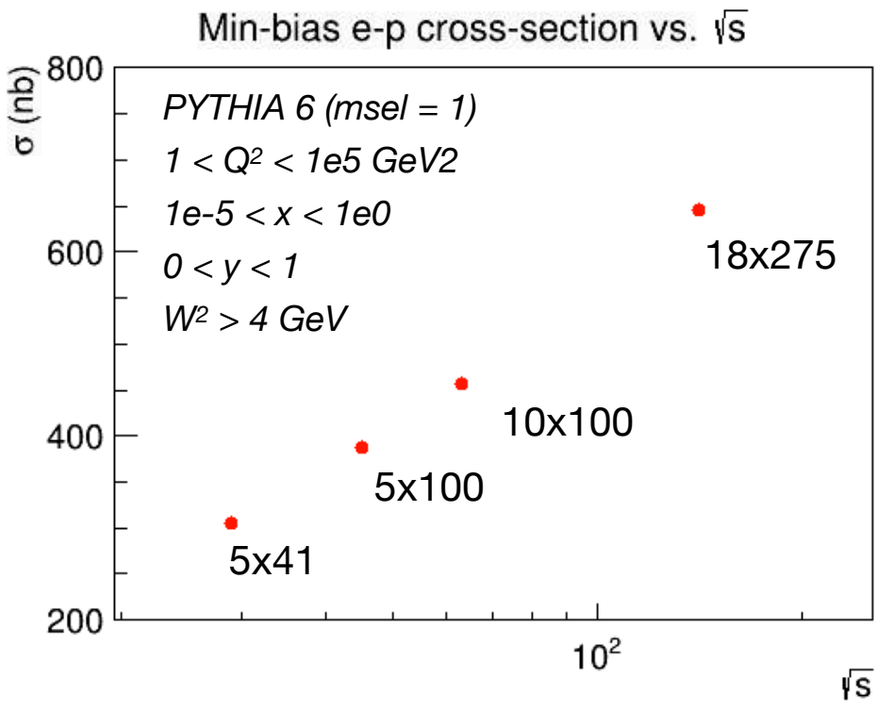


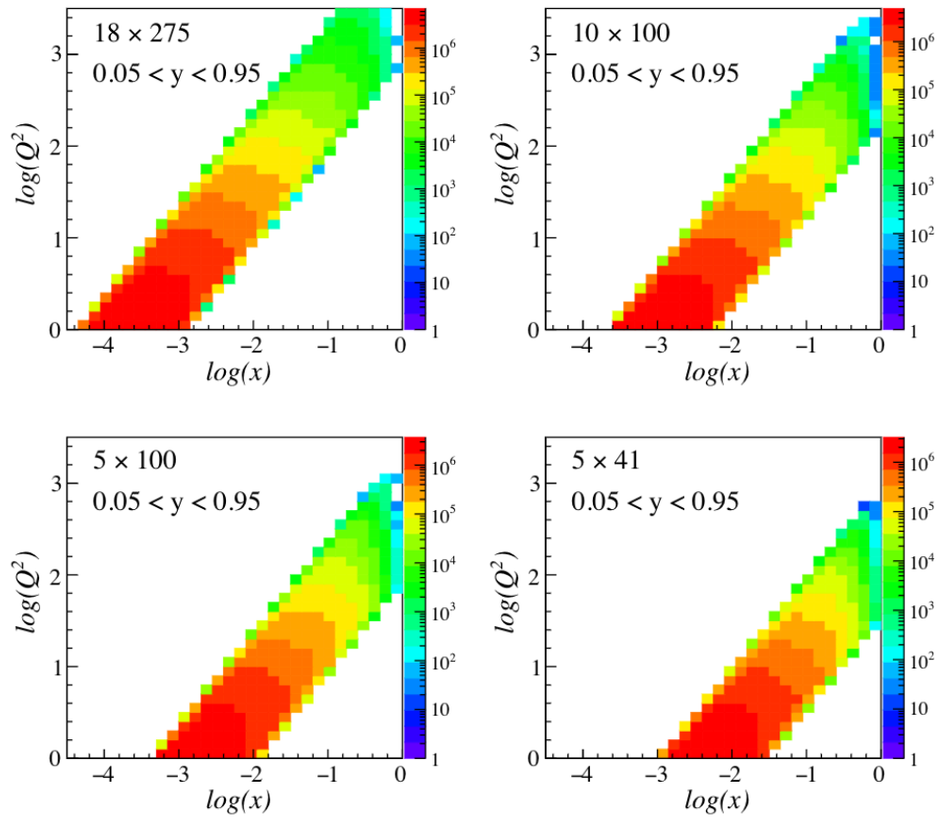




Simulation

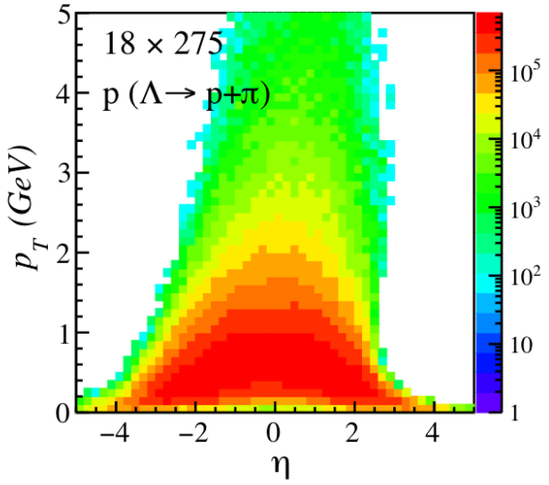
- MC generator: PYTHIA_eRHIC — a modified version of PYTHIA6.4.28
- Collision energies: 18x275, 10x100, 5x100, 5x41
- Kinematics cuts: $Q^2 > 1$GeV, $0.05<y<0.95$
- Jet reconstruction: fastjet with anti-kT (R = 1.0)

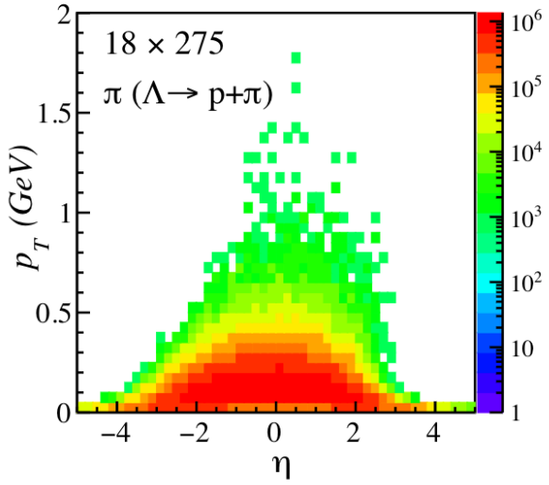


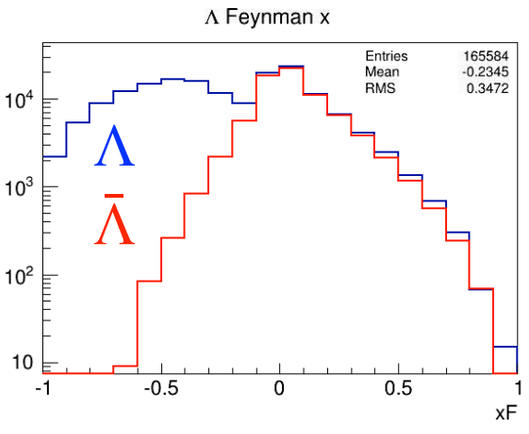


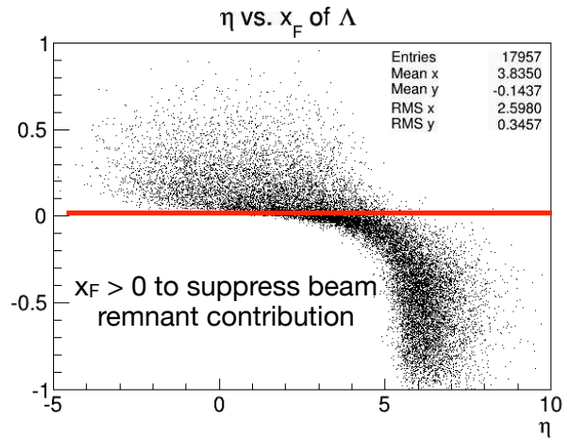
Lambda Reconstruction

- Reconstruct Lambda from $\Lambda \rightarrow p\pi$
  - p_T < 0.1 GeV
  - $|\eta|$<3.5
- Feynman-x > 0 to suppress beam remnant contribution
- $p_\perp^\Lambda / z < Q/4$ to ensure the applicability of TMD factorization
- PID and vertex cut not applied, instead, use a 50% overall eff. factor

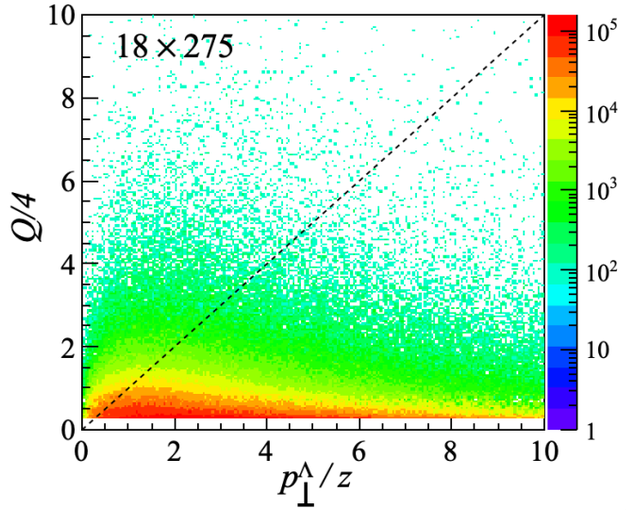


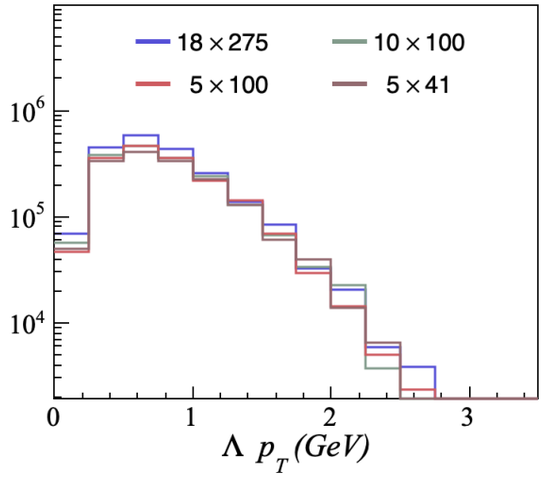


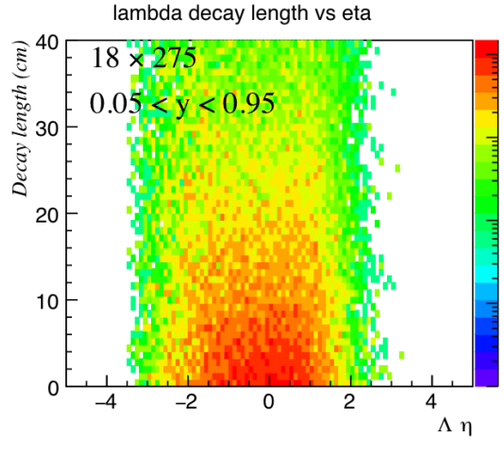




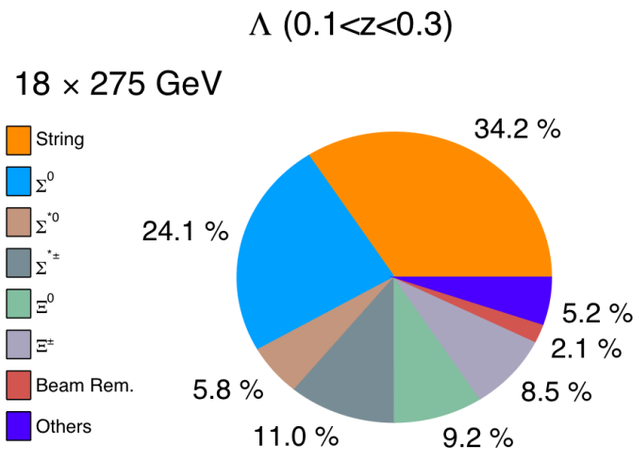
Feynman-x, $x_F = 2p_L^\Lambda / W$



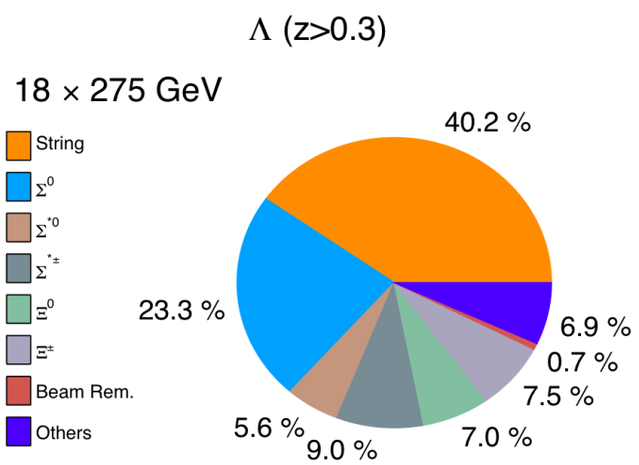


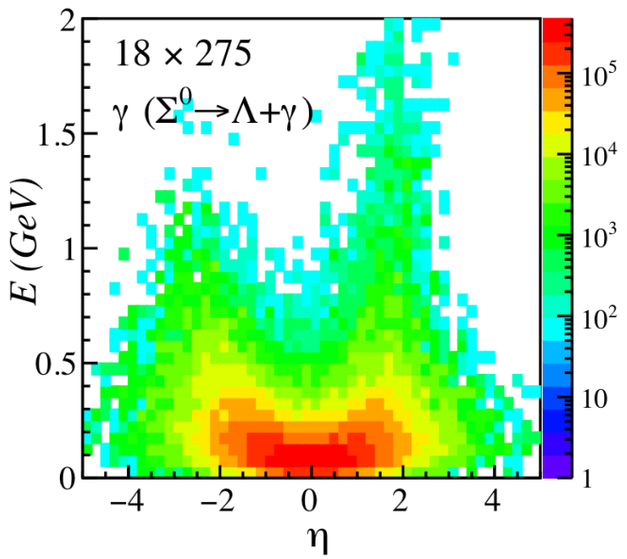


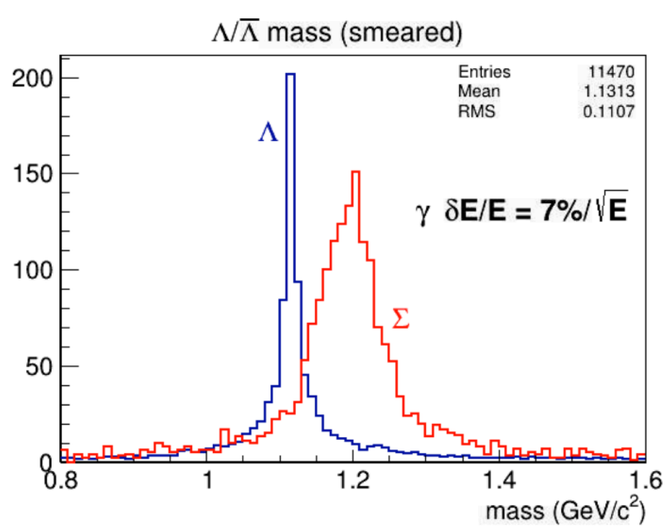
Feed-down contributions



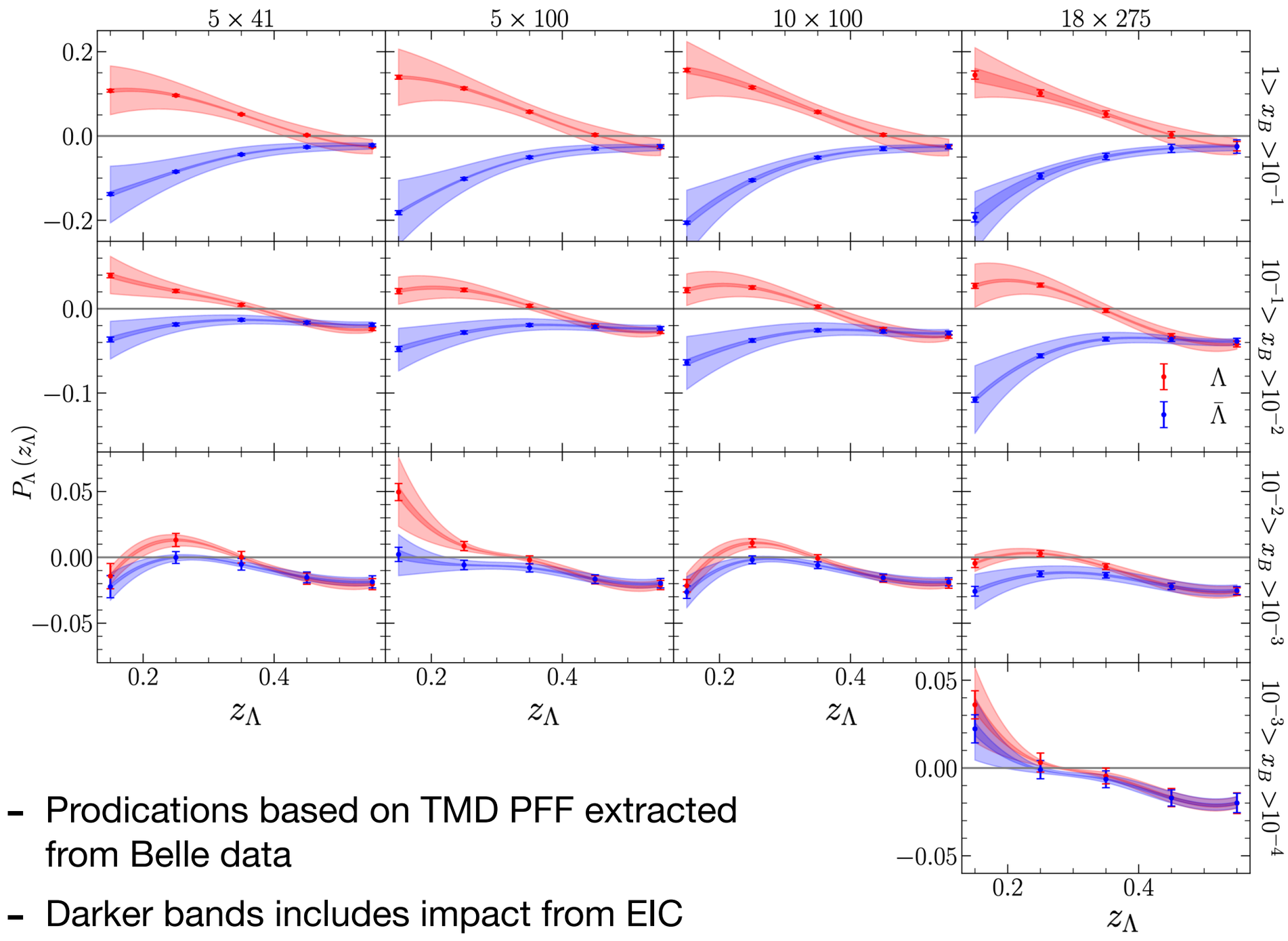
- 1/3~1/2 of Lambda promptly from string fragmentation
- Leading feed-down contribution from Sigma0, can be reconstructed with proposed EMC resolution
- Integrated in the projections







Spontaneous Lambda Polarization

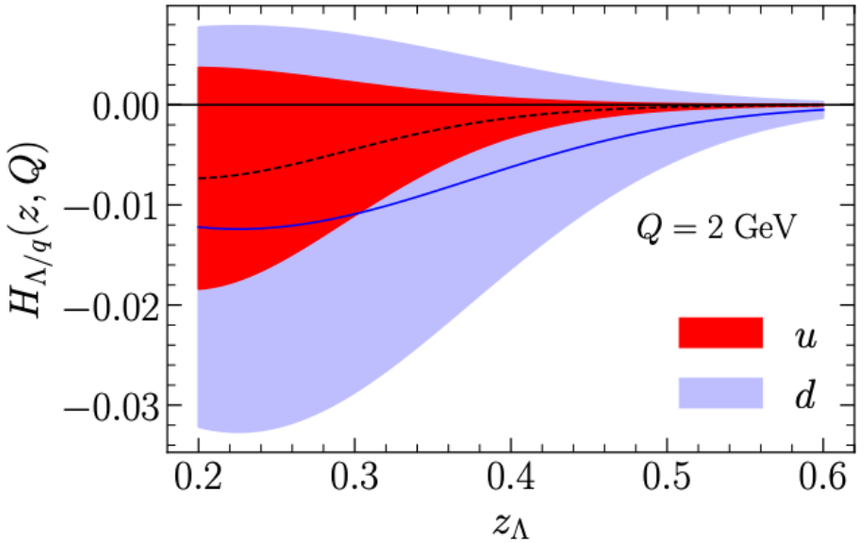


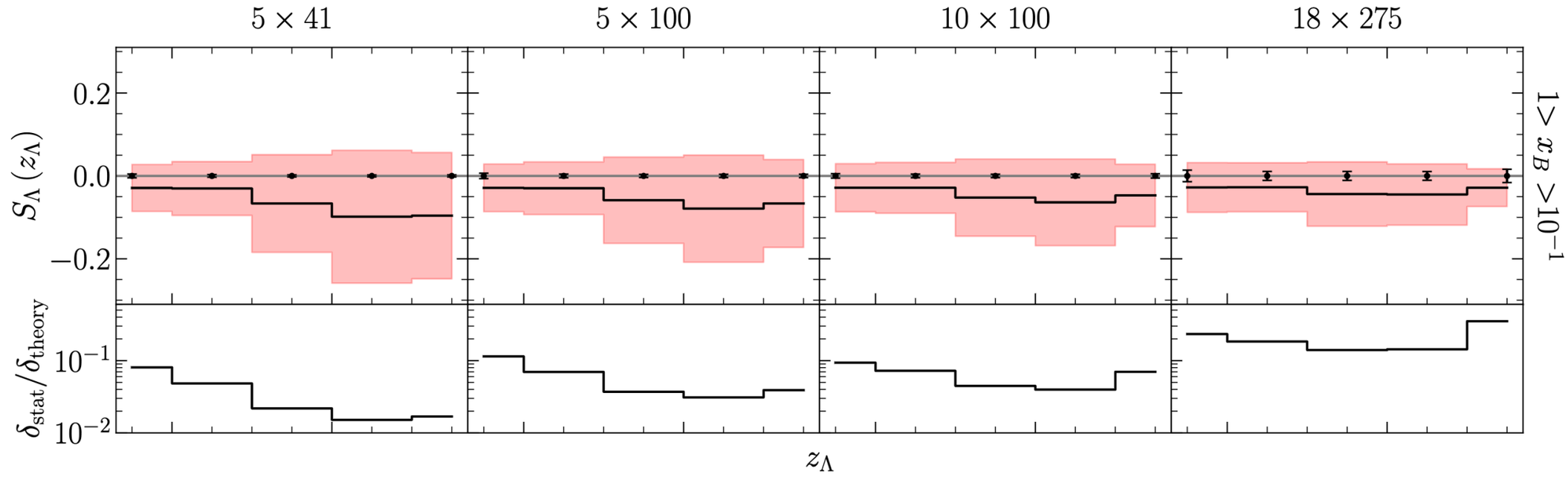
- Prodications based on TMD PFF extracted from Belle data
- Darker bands includes impact from EIC pseudo data (10 /fb)

from J. Terry

Transverse Spin transfer

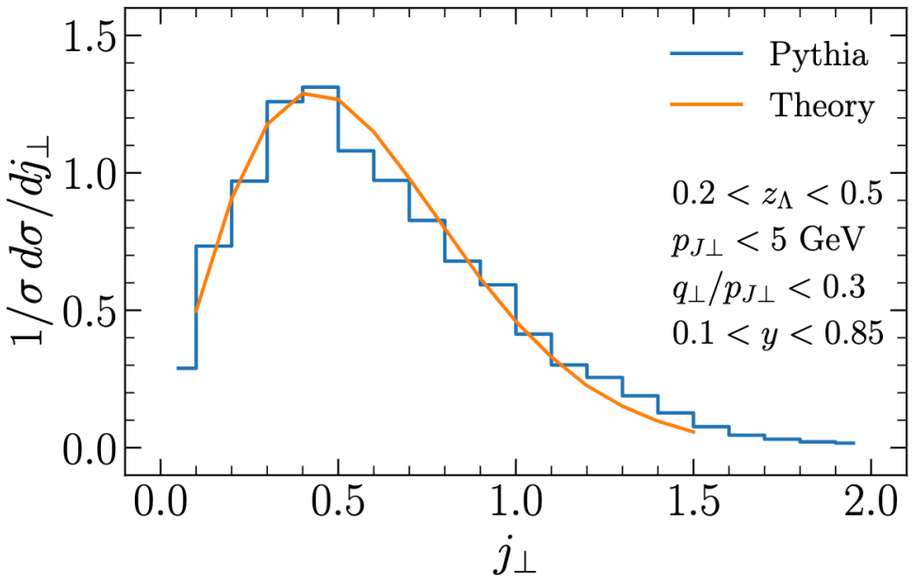
- Collinear transversity FFs extracted from COMPASS spin transfer data
- EIC can provide first constraints for transversity TMD FFs

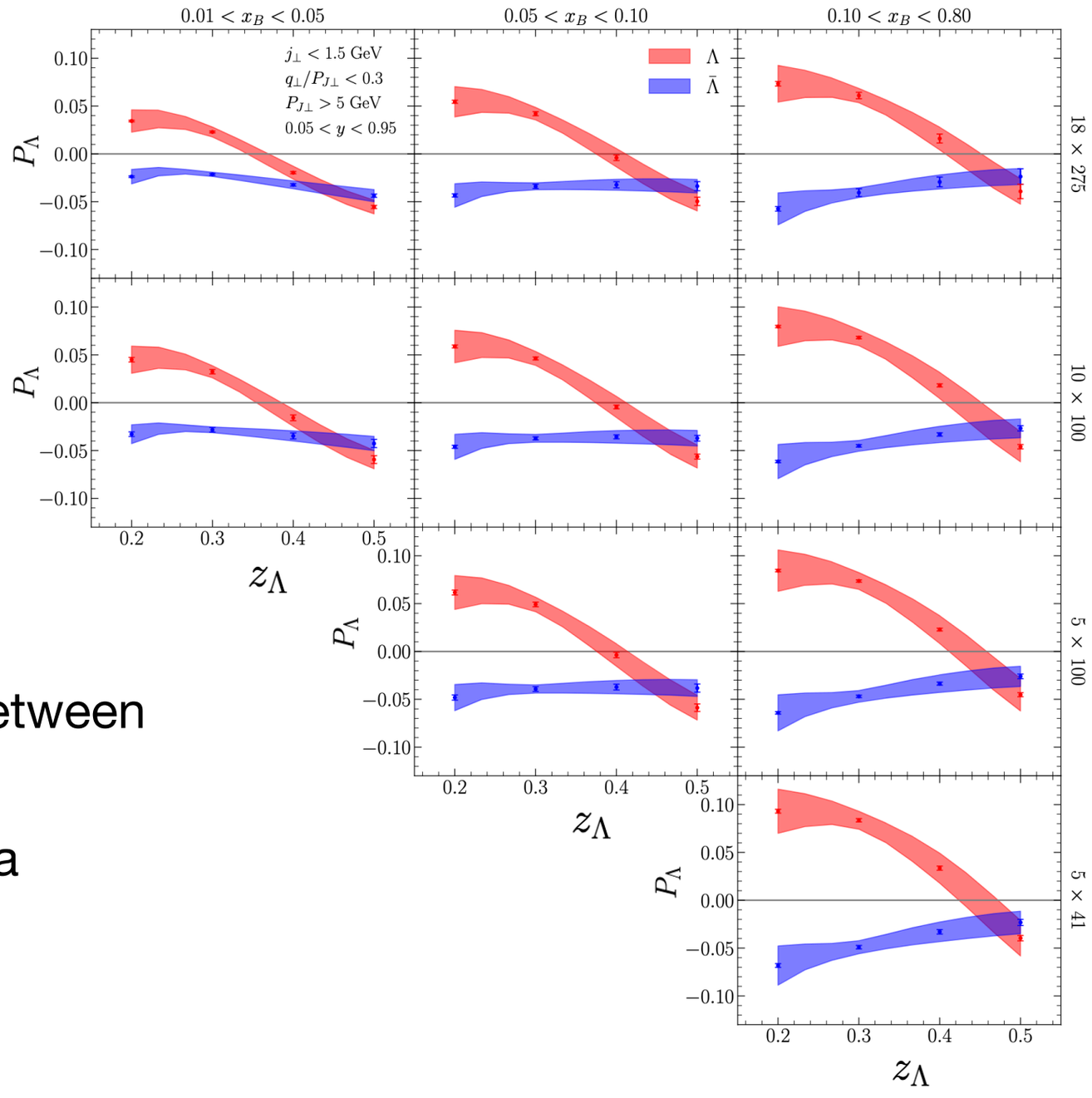




from J. Terry

Spontaneous Polarization of Lambda in jet

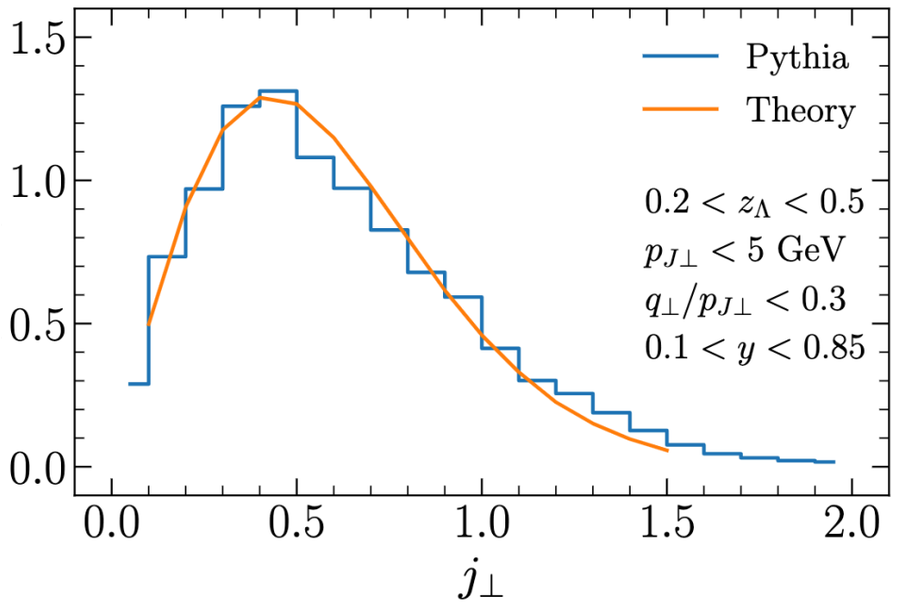


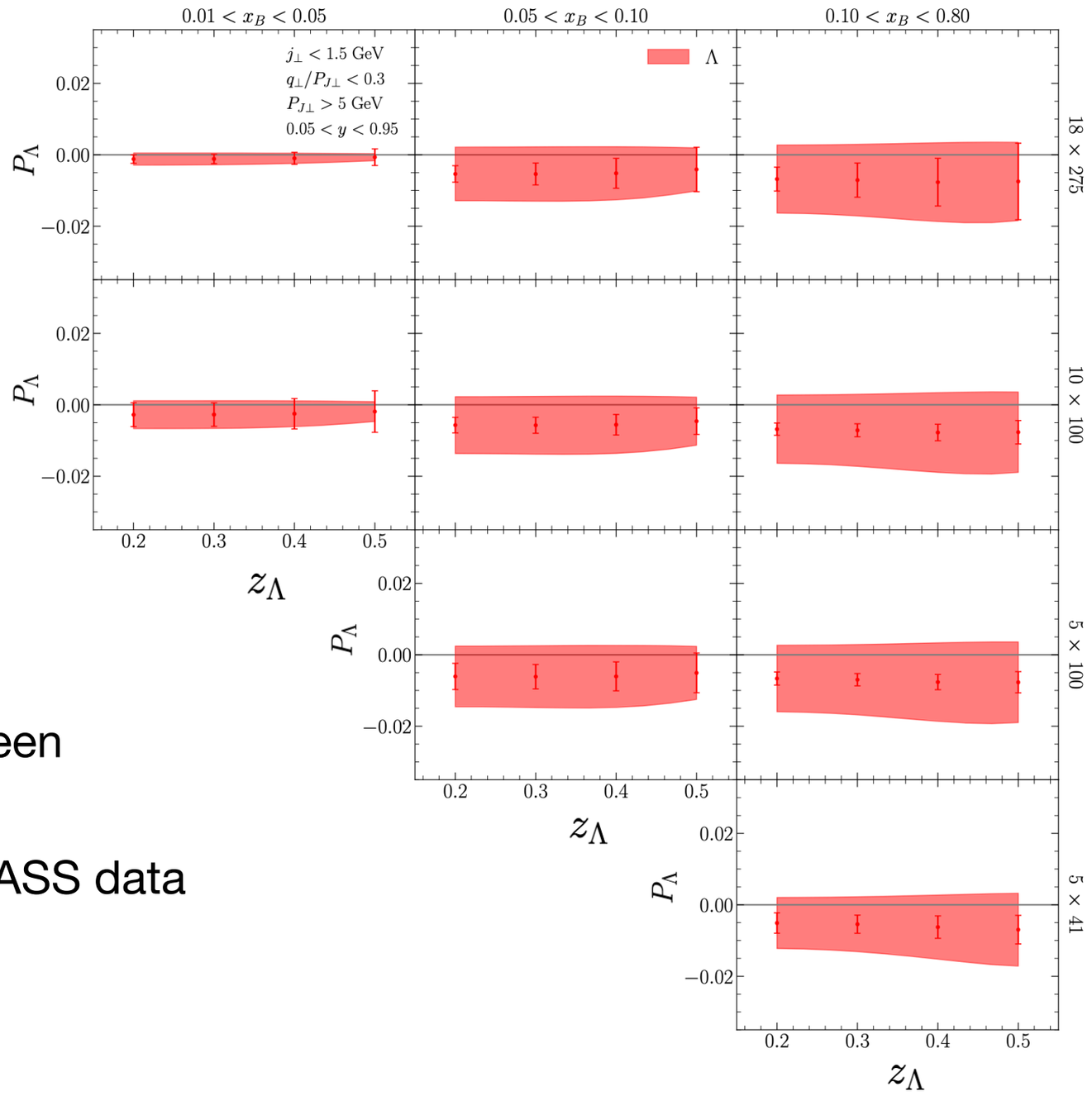


- Consistent distributions (e.g. $j_\perp$) between PYTHIA and theoretical curves
- TMD PFF extracted from Belle data

from J. Terry

Spin transfer to Lambda in jet





- Consistent distributions (e.g. $j_\perp$) between PYTHIA and theoretical curves
- Transversity FF extracted from COMPASS data

from J. Terry

Summary

- Lambda as a final state “polarimetry”, suitable tool for studying 3-D distributions and fragmentation functions.

- Impact studies for Lambda production at EIC for spontaneous polarization and spin transfer in SIDIS and Lambda-in-jet processes

- Publication in prepration

Thank you for your attention!