Lambda production in electron-proton collisions

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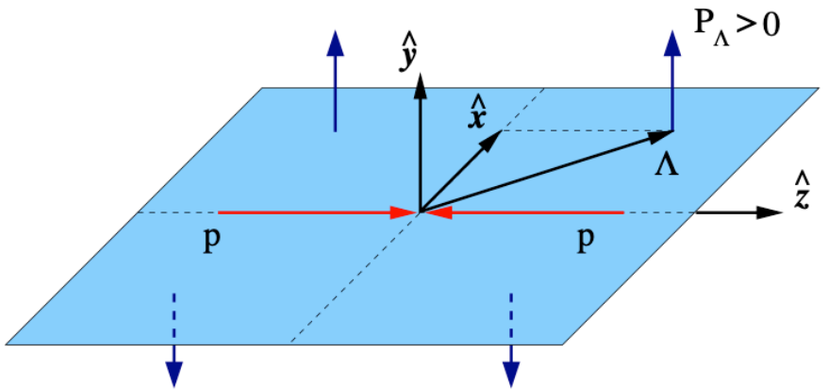
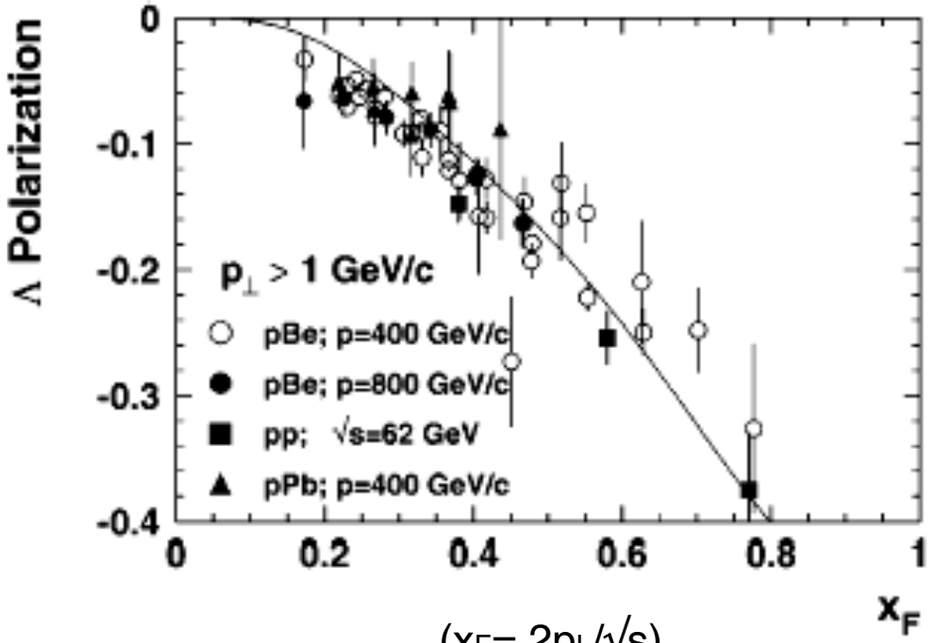
Why Lambda?

- Final state "polarimetry"
  - Self-analyzing weak decay: Lambda polarization can be measured from the angular distribution of its daughter particles, $\Lambda \rightarrow p\pi^+$(Br~64%) $\Lambda \rightarrow n\pi^0$ (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

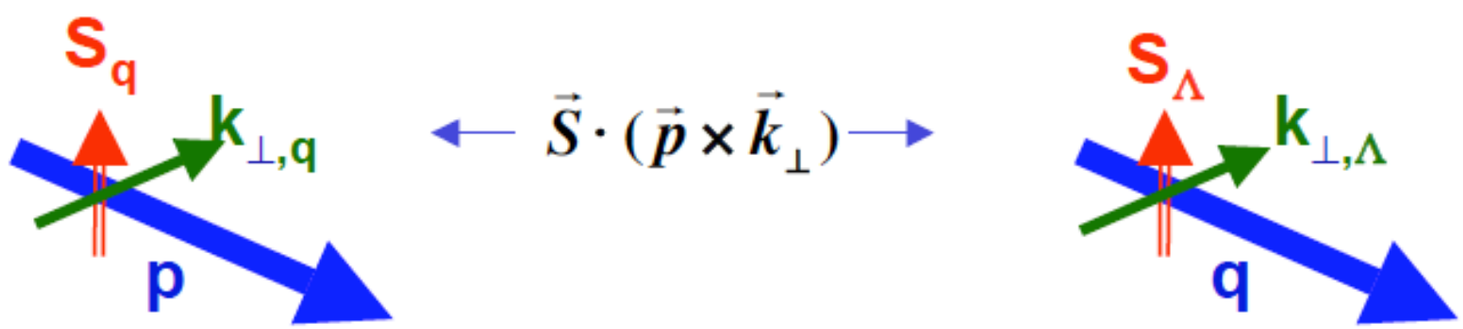


($x_F = 2p_L/\sqrt{s}$)

Theoretical Understanding

Polarizing distribution

Polarizing 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}	$H_1, H_{1T}^\perp$

} Lambda

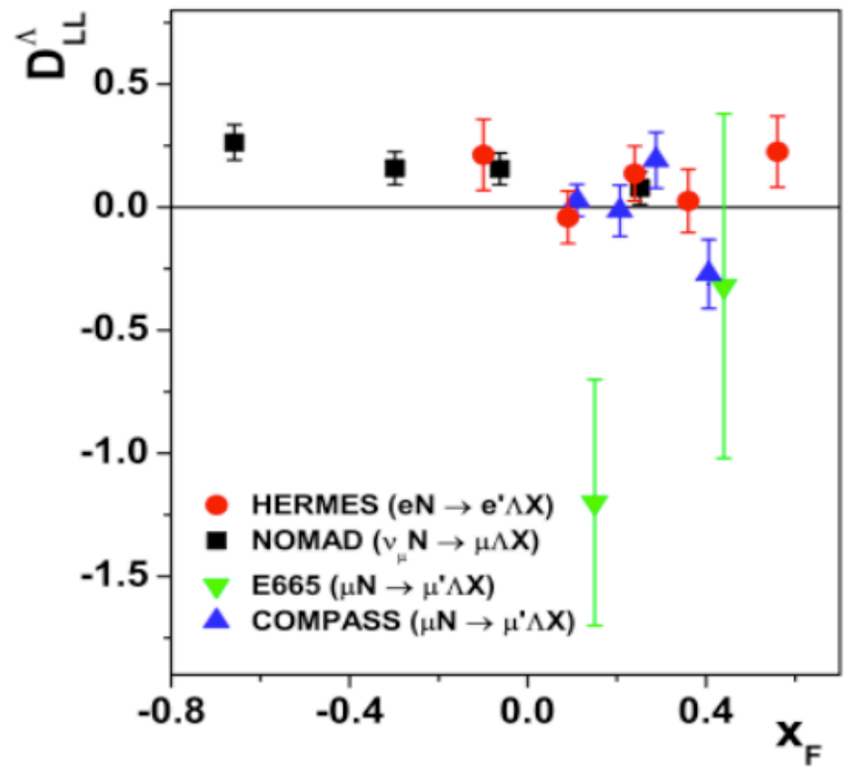
TMD FFs

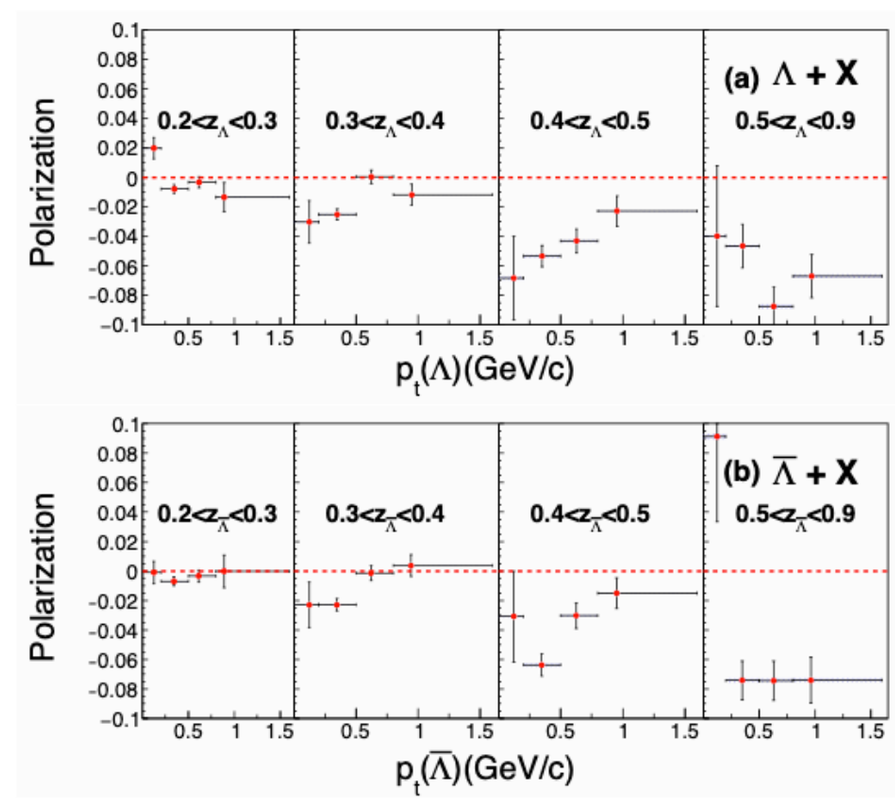
Can not distinguish them in hadron-hadron reactions

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

Existing Data

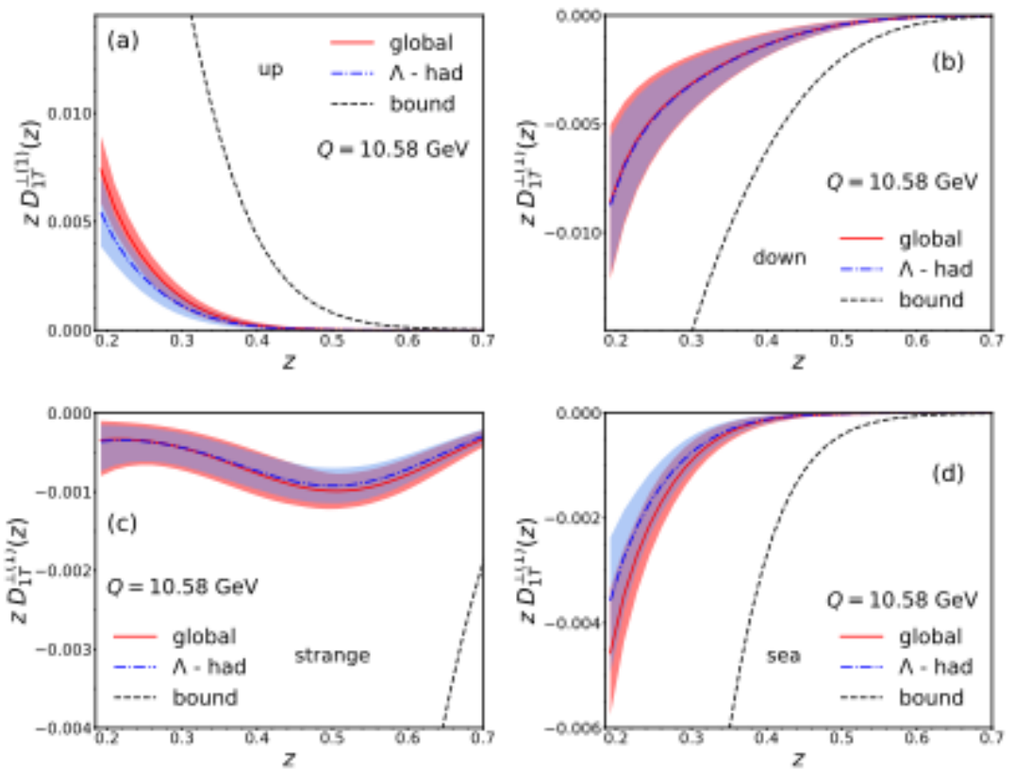
- Longitudinal
  - e^+e^-: ALEPH(PLB'96), OPAL(EPJC'98)
  - Lepton-nucleon E665(EPJC'00), HERMES(PRD'01),NOMAD(NPB '01), COMPASS(EPJC'09)
  - Proton-proton: STAR(PRD'09, PRD'18)
- Transverse
  - e+e-: Belle (PRL'19)
  - Fixed target pp: E704 (PRL'97), DISTO(PRL'99)
  - Lepton-nucleon: COMPASS
  - Proton-proton: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



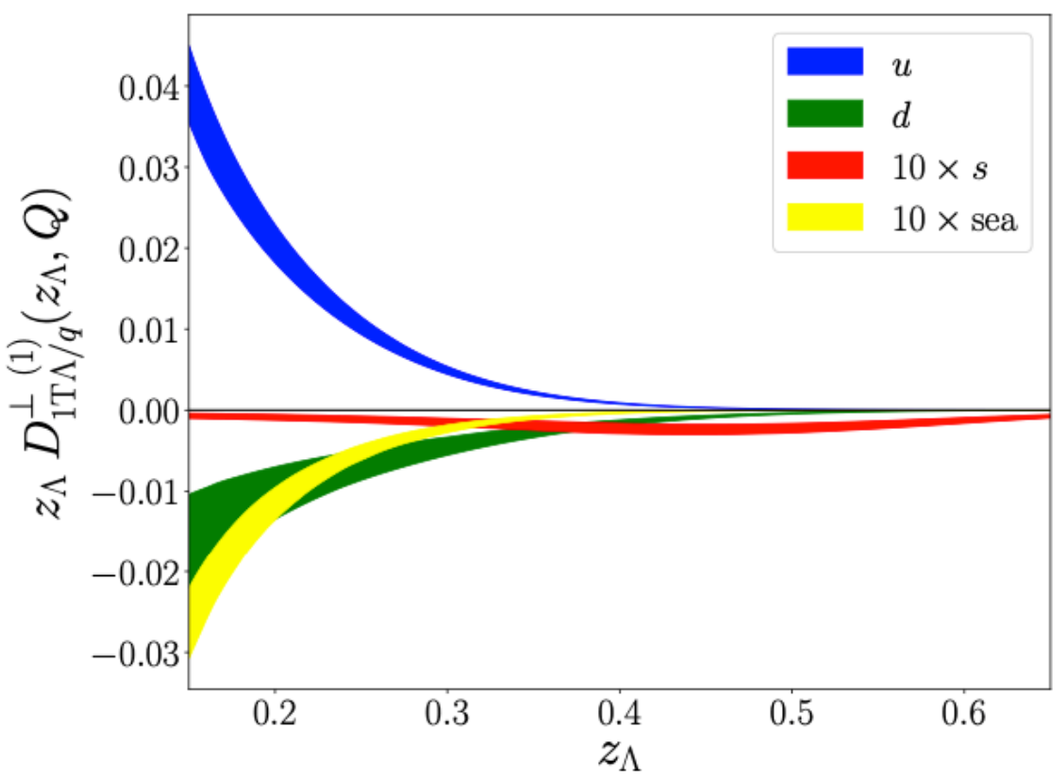


Polarizing FFs extracted from Belle data

D'Alesio, Murgia, Zaccheddu arXiv:2003.01128

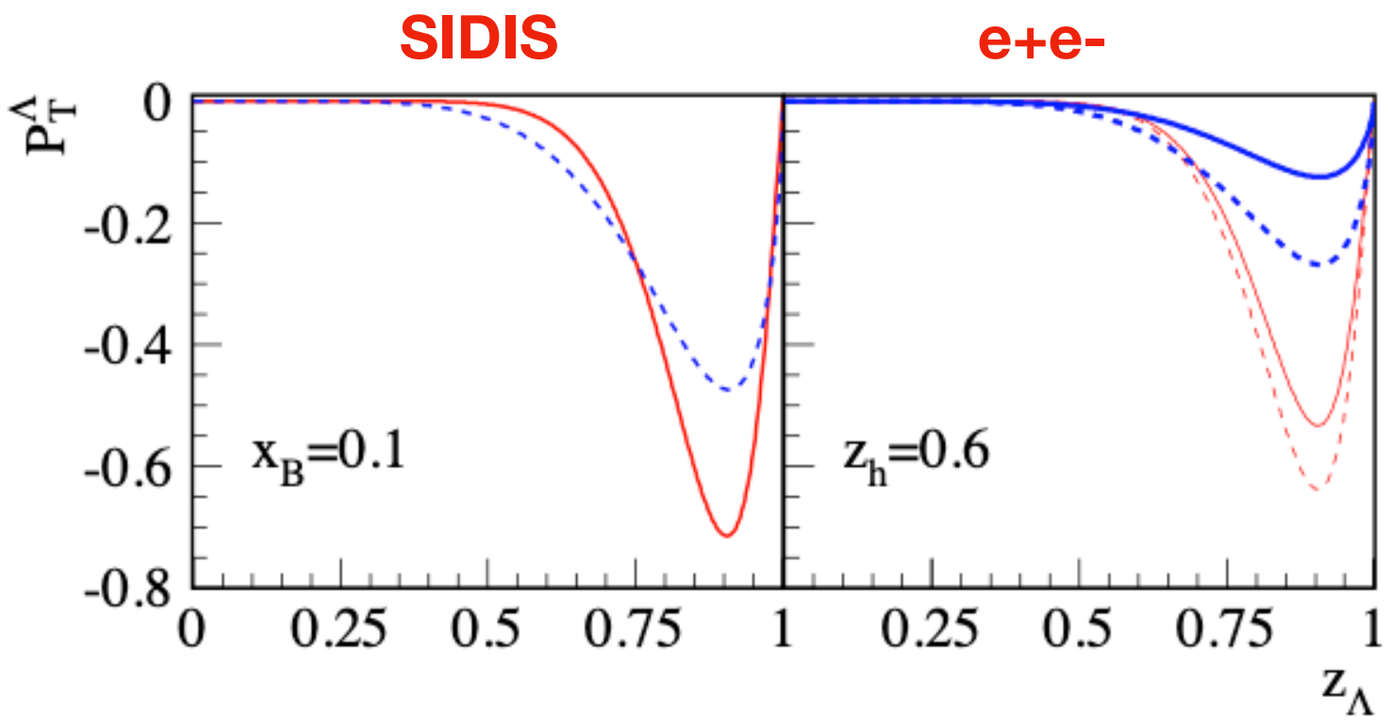


Callos, Kang, Terry arXiv:2003.04828



- Polarizing FFs by fitting Belle Lambda data

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

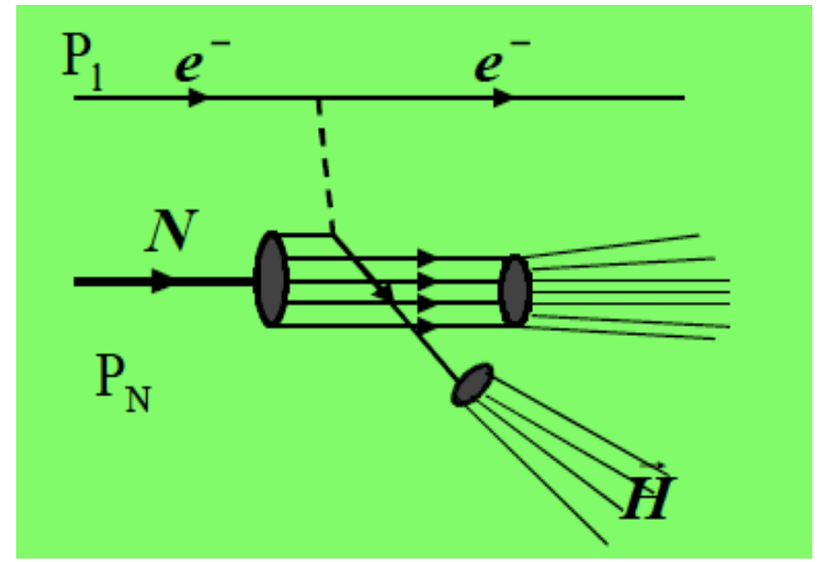
- Polarization of scattered quark:

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:

  - $p_N = 0, P_l \neq 0: \quad P_\Lambda = P_l D(y) \frac{\Sigma_f e_f^2 q(x,Q^2) \Delta D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)} \rightarrow$ clean measurement of pol. FFs

  - $p_N \neq 0, P_l = 0: \quad P_\Lambda = P_N \frac{\Sigma_f e_f^2 \Delta q(x,Q^2) \Delta D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)} \rightarrow$ pol. FFs and pol. PDFs

Transverse Spin Transfer to Λ in ep

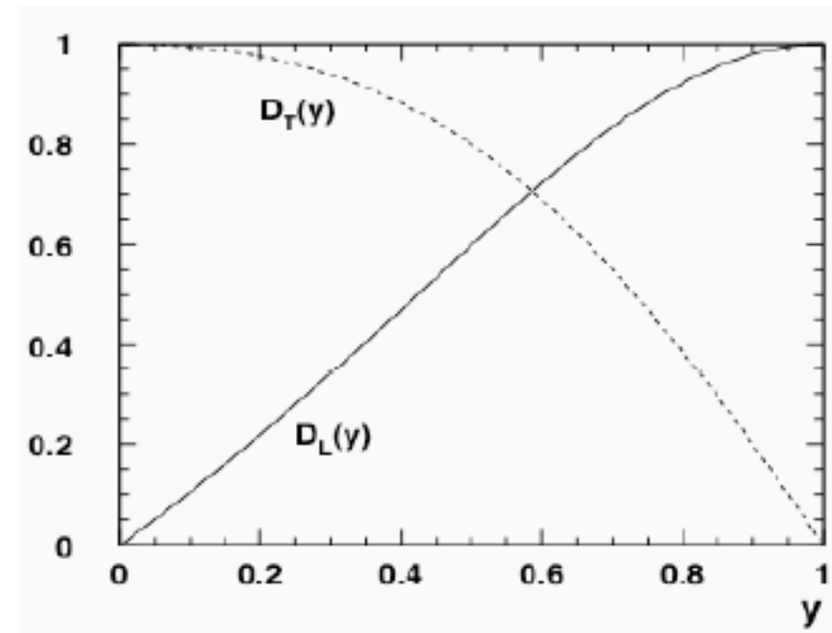
- Polarization of struck quark from polarized nucleon beam:

transiversity

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

unpol. pdf

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



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

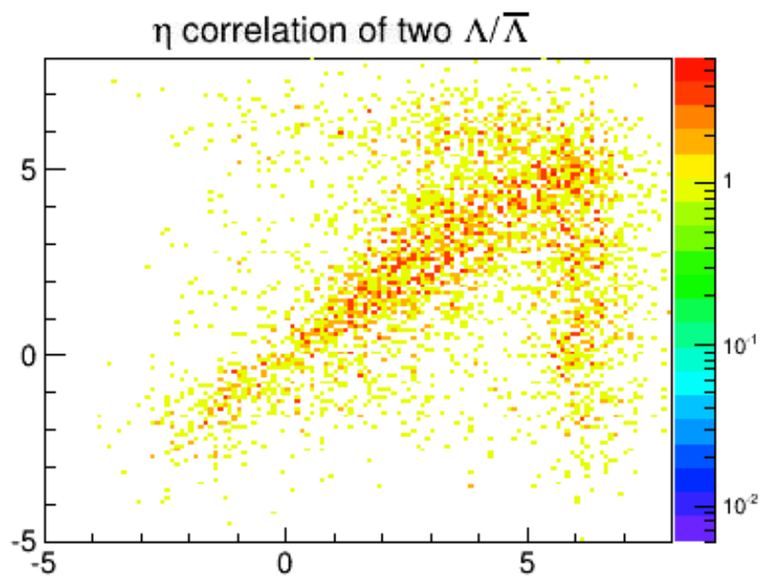
- Polarization of of Λ in the current region:

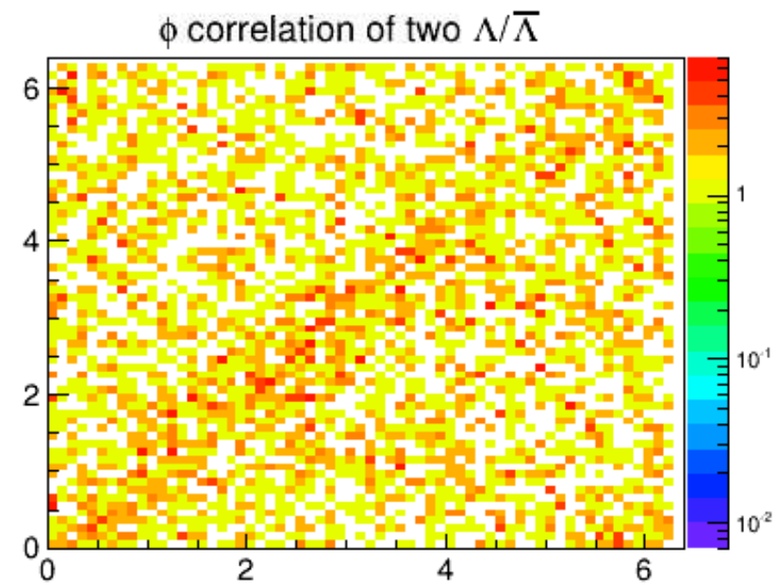
$$P_\Lambda = P_N \frac{\Sigma_f e_f^2 D_T(y)\delta q(x,Q^2)\Delta_T D_f^\Lambda(z,Q^2)}{\Sigma_f e_f^2 q(x,Q^2) D_f^\Lambda(z,Q^2)}$$

Artru, Mekhfi 1991

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

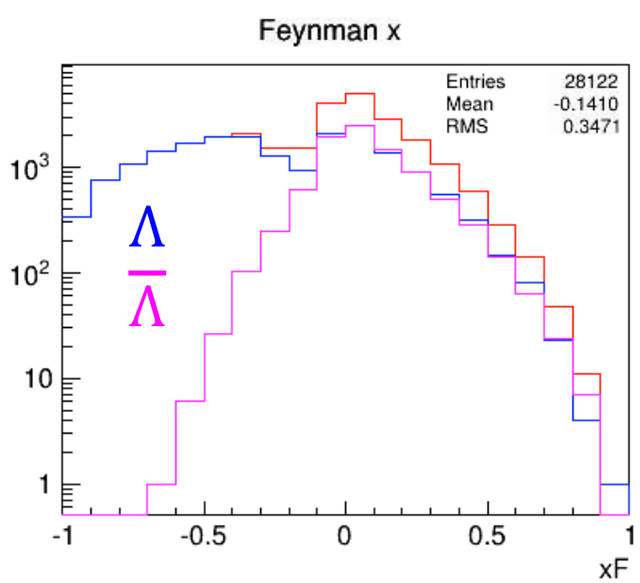
Other observables

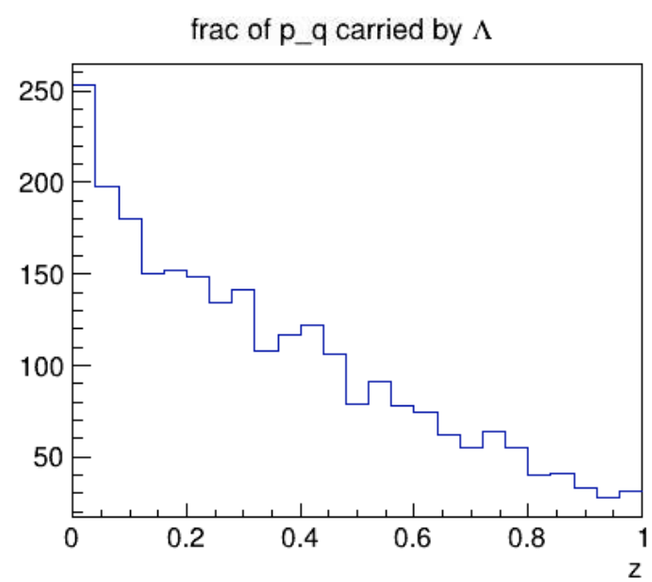


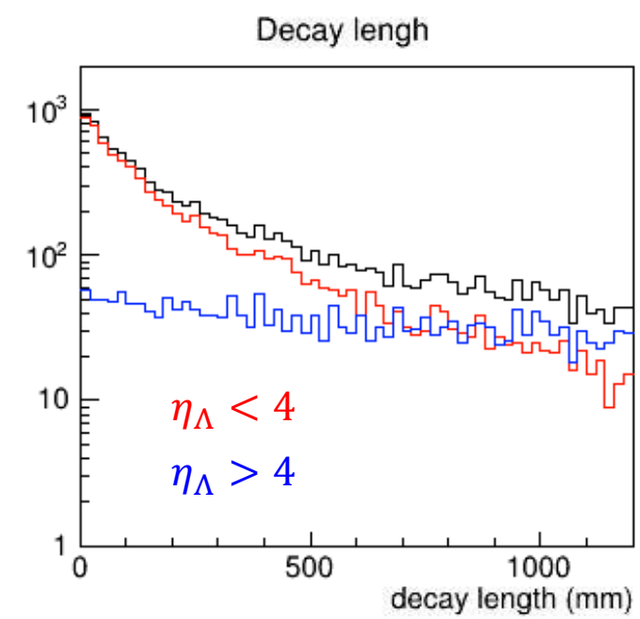


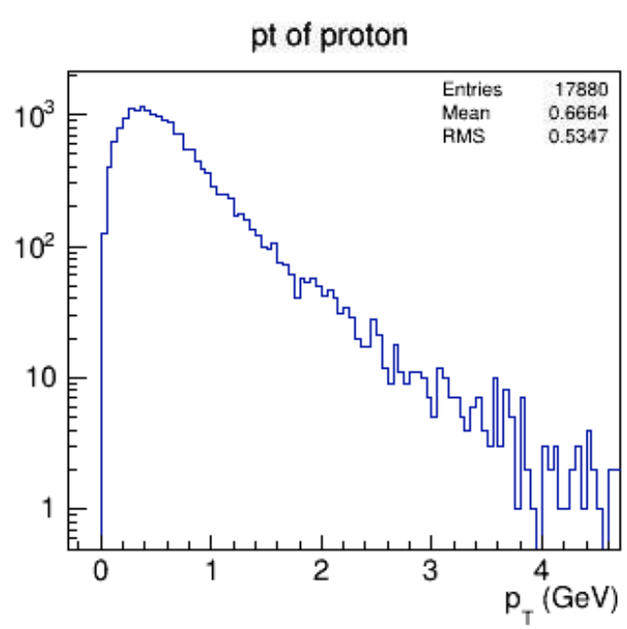
- Spin correlation between di-lambda production
- Lambda/Anti-lambda, Lambda/K0s cross section ratios: hadron number transfer, strangeness suppress

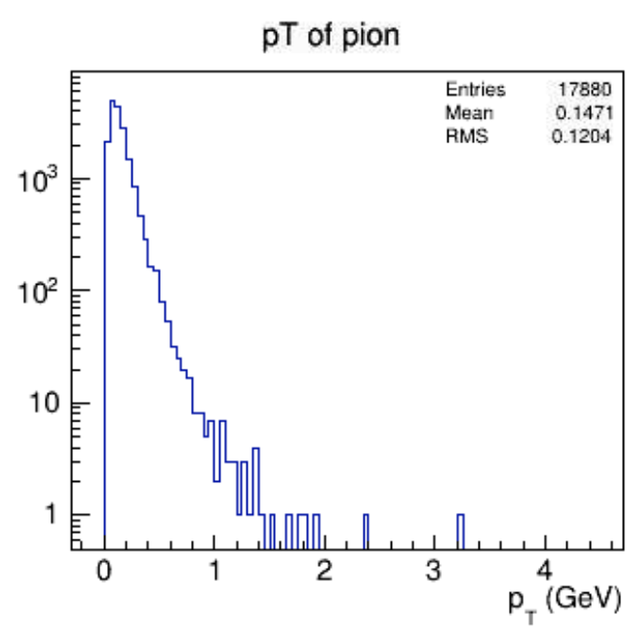
Kinematics


Feynman x
Entries 28122
Mean -0.1410
RMS 0.3471
Λ
$\overline{\Lambda}$
xF


frac of p_q carried by Λ
z


Decay lengh
$\eta_\Lambda < 4$
$\eta_\Lambda > 4$
decay length (mm)


pt of proton
Entries 17880
Mean 0.6664
RMS 0.5347
p_T (GeV)


pT of pion
Entries 17880
Mean 0.1471
RMS 0.1204
p_T (GeV)

Software

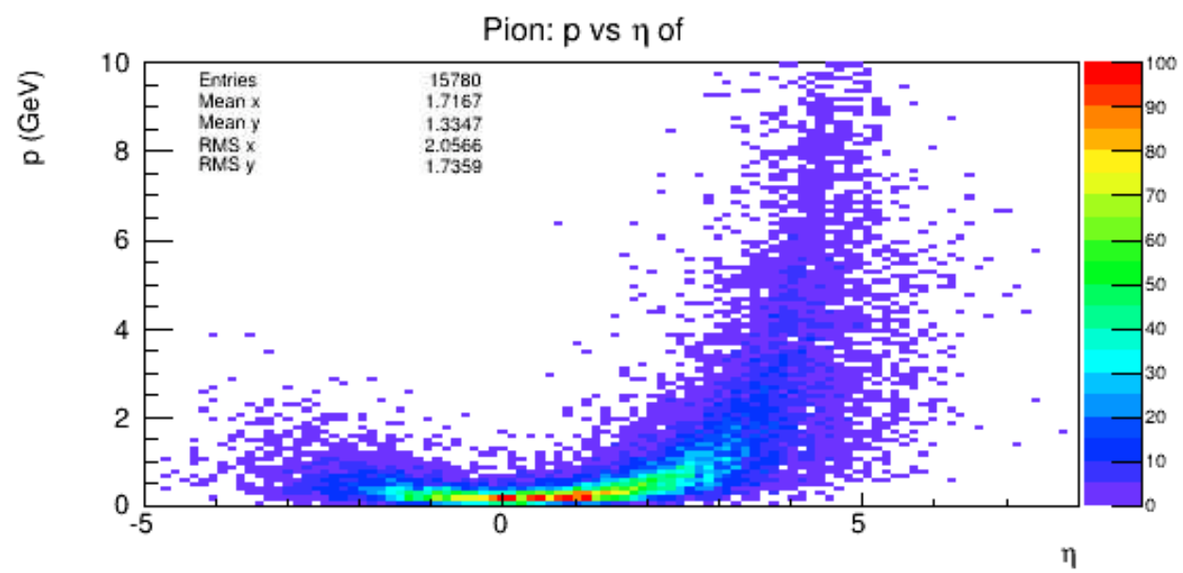
- Platform: EIC nodes at RCF (BNL)
- Generator: PYTHIA_eRHIC, DJANGHO
- Detector simulation:
  - awaiting for official framework, eJana is not ready
  - Fun4All
- Dataset: use e+p data produced by community ??
- Lambda filter for detector simulation ?

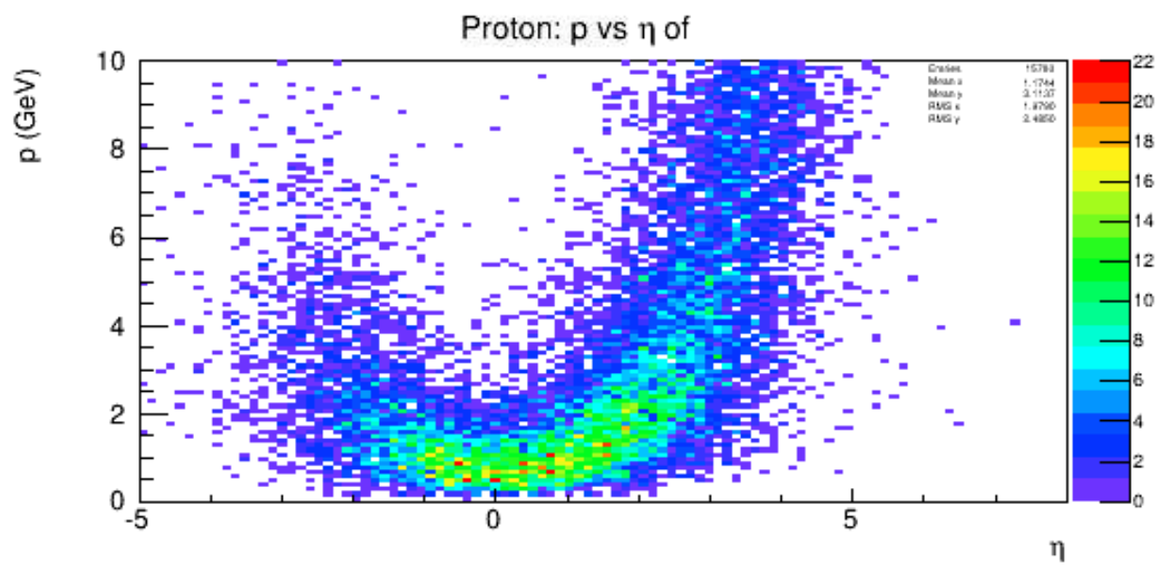
Detector requirement

- Momentum
  - Upper limit -> proton/pion identification
  - Lower limit -> magnet filed
  - General -> resolution

- Forward production
  - Neutron + pi0 channel

- Resolution





Money Plots

- Lambda mass resolutions as function of xxx
- Binned projection on Lambda polarization -> propagate to pol. FFs
- Binned projections

Plan for the next step

- Detector simulation
- Energy configuration