QCD and Baryon Polarization

Lecture 5:

Hyperon and Heavy Flavor Baryon Polarization I

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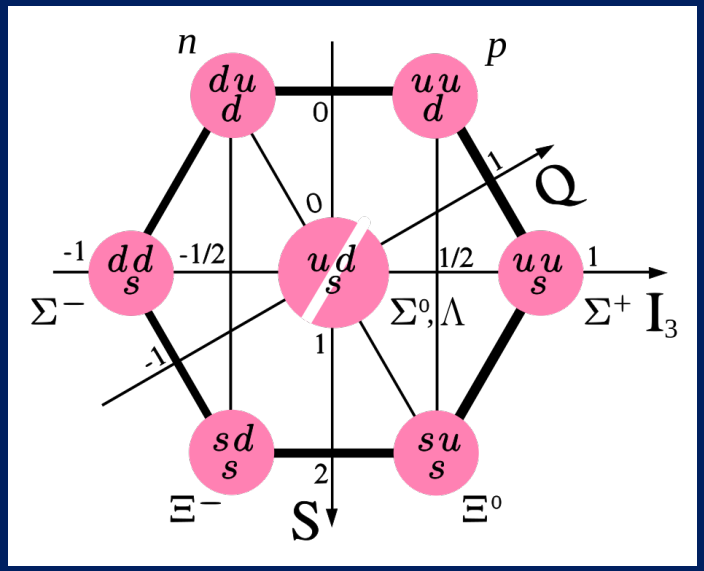
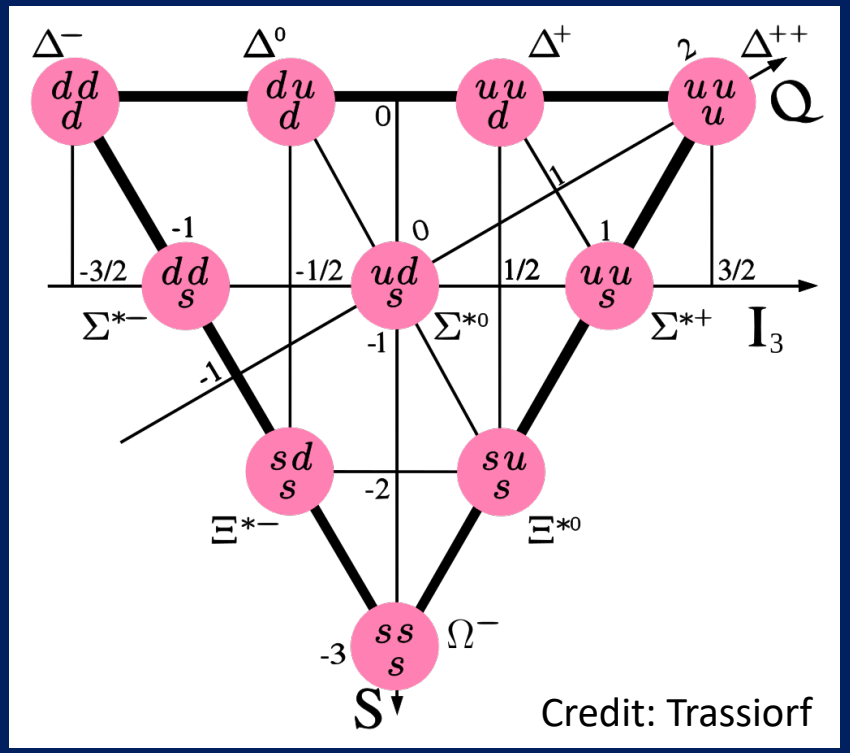
uds baryon octet (spin-1/2) and decuplet (spin-3/2)





Hyperon: a baryon containing one or more strange quarks, but no charm or beauty

To note:

- Σ^+, Σ^- not particle-antiparticle pair!
- Only Ξ^-, Ξ^0 - no Ξ^+ made of quarks (rather than antiquarks)
- Ω^- and all octet hyperons have $c\tau$ ~2-9 cm, except for Σ^0 (10^{-11} m)

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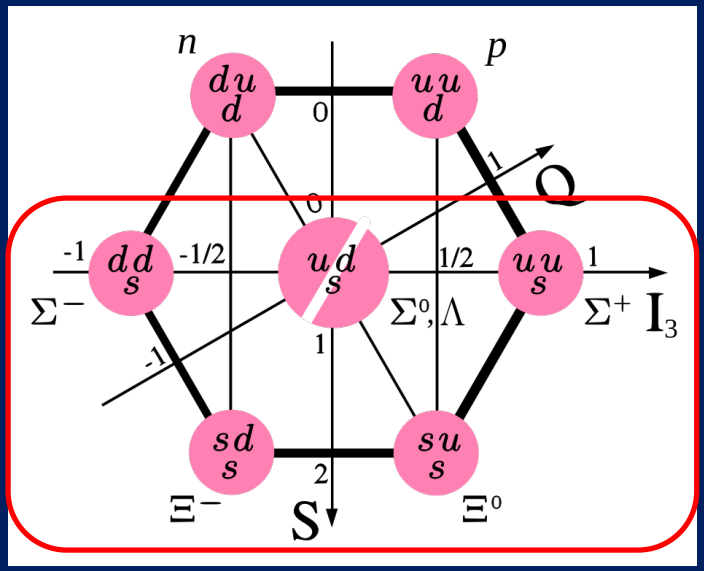

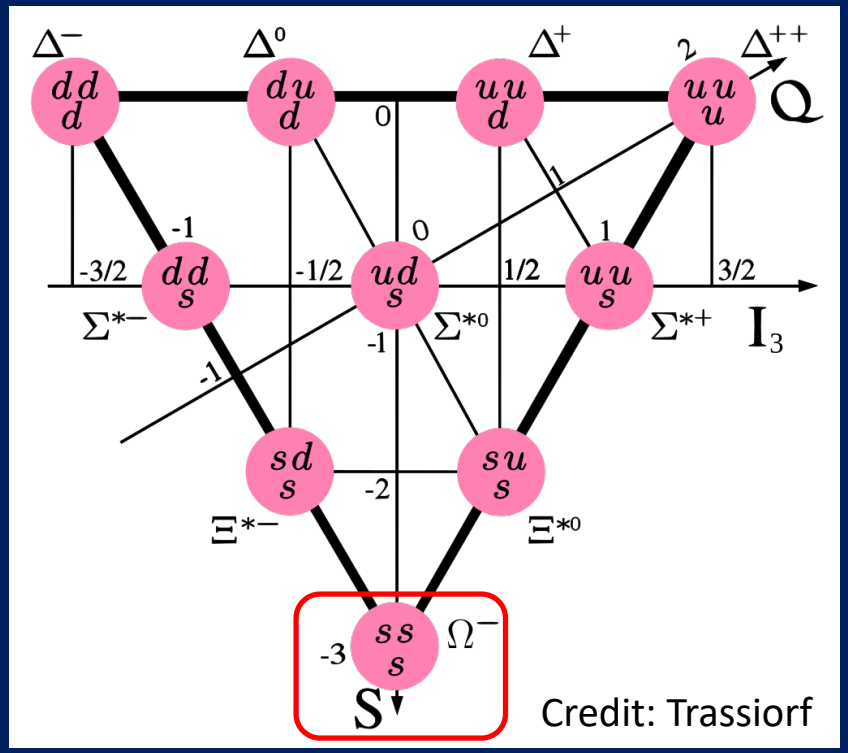

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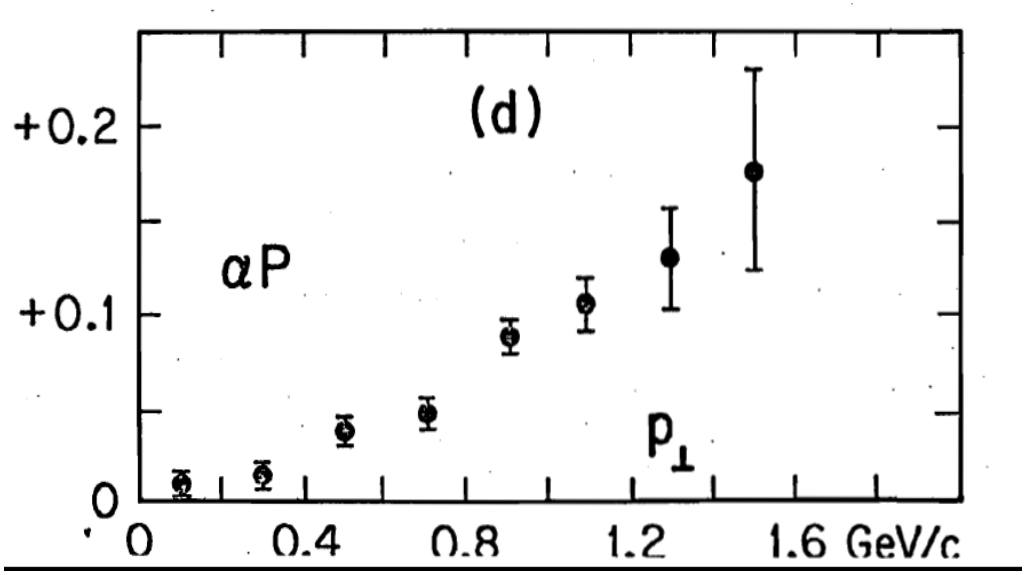
Hyperon polarization from unpolarized collisions

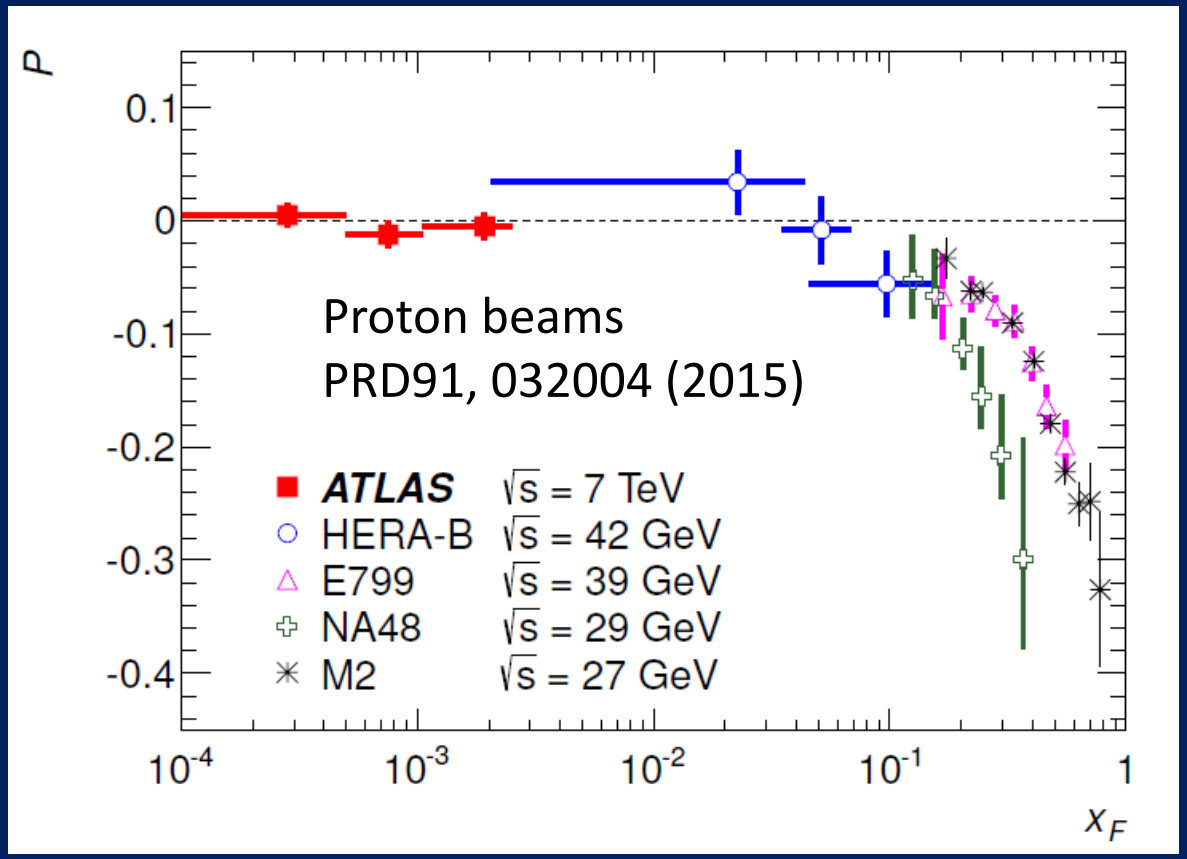
Λ° Hyperon Polarization
in Inclusive Production
by 300 GeV Protons on
Beryllium

PRL36, 1113 (1976)



- 1976 lambda polarization discovery: p+Be, 300 GeV beam
- Polarization transverse to production plane up to ~20% for forward-angle lambda production
- Confirmed 1977 at CERN, p+Pt, 24 GeV beam (and by various proton-nucleus and proton-proton experiments afterwards . . .)

Observed for forward lambda production: large Feynman-x (x_F)

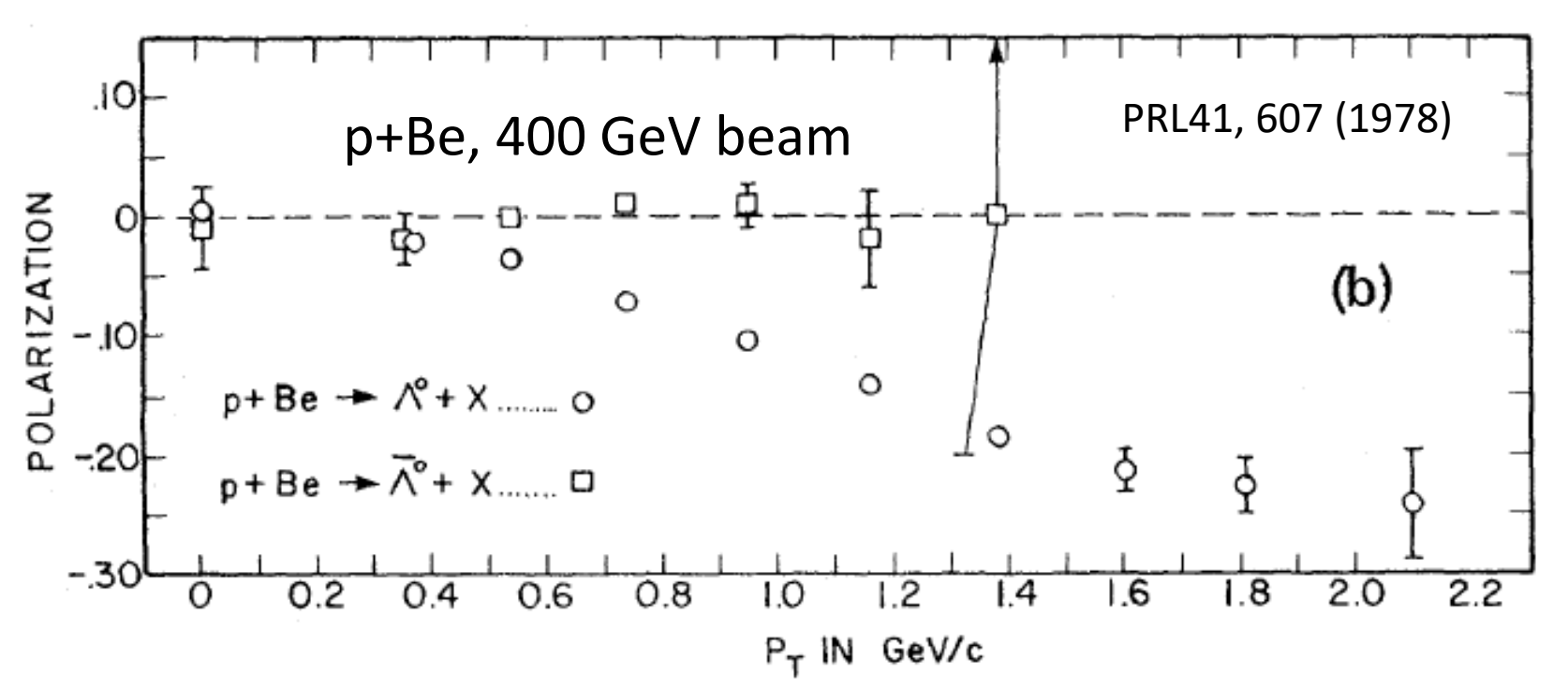


$$x_F = \frac{p_L}{|\max p_L|} \text{ in c.m. frame}$$

x_F is a signed, dimensionless kinematic variable ranging from -1 to 1.

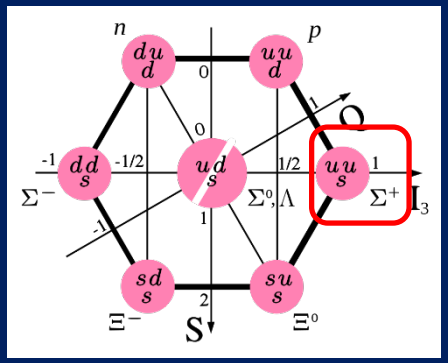
Note that sign convention is reversed from original discovery on previous slide!

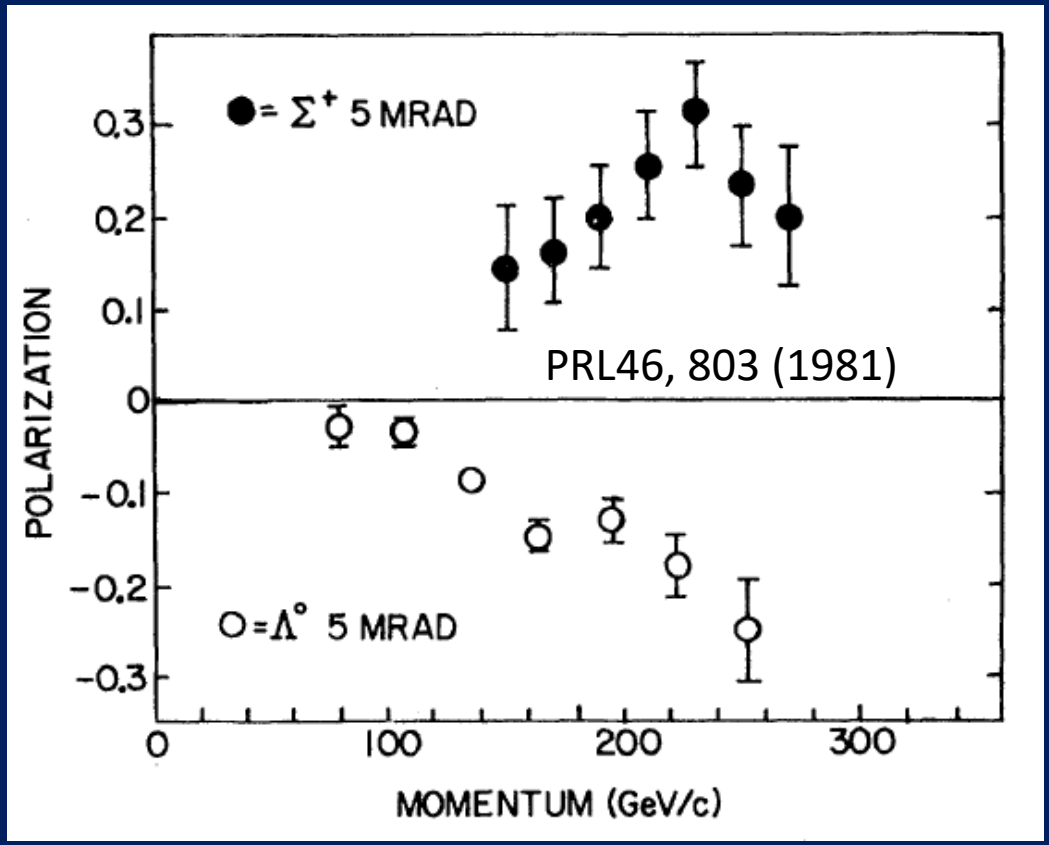
No observed antilambda polarization



- 1978: No antilambda polarization
- And lambda polarization now measured up to p_T = 2.2 GeV, polarization ~25%. (Same sign convention as compilation of measurements in ATLAS paper)

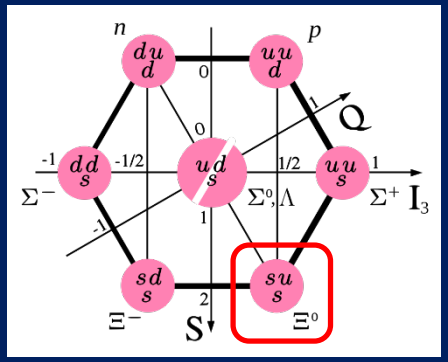
Σ^+ polarized with opposite sign

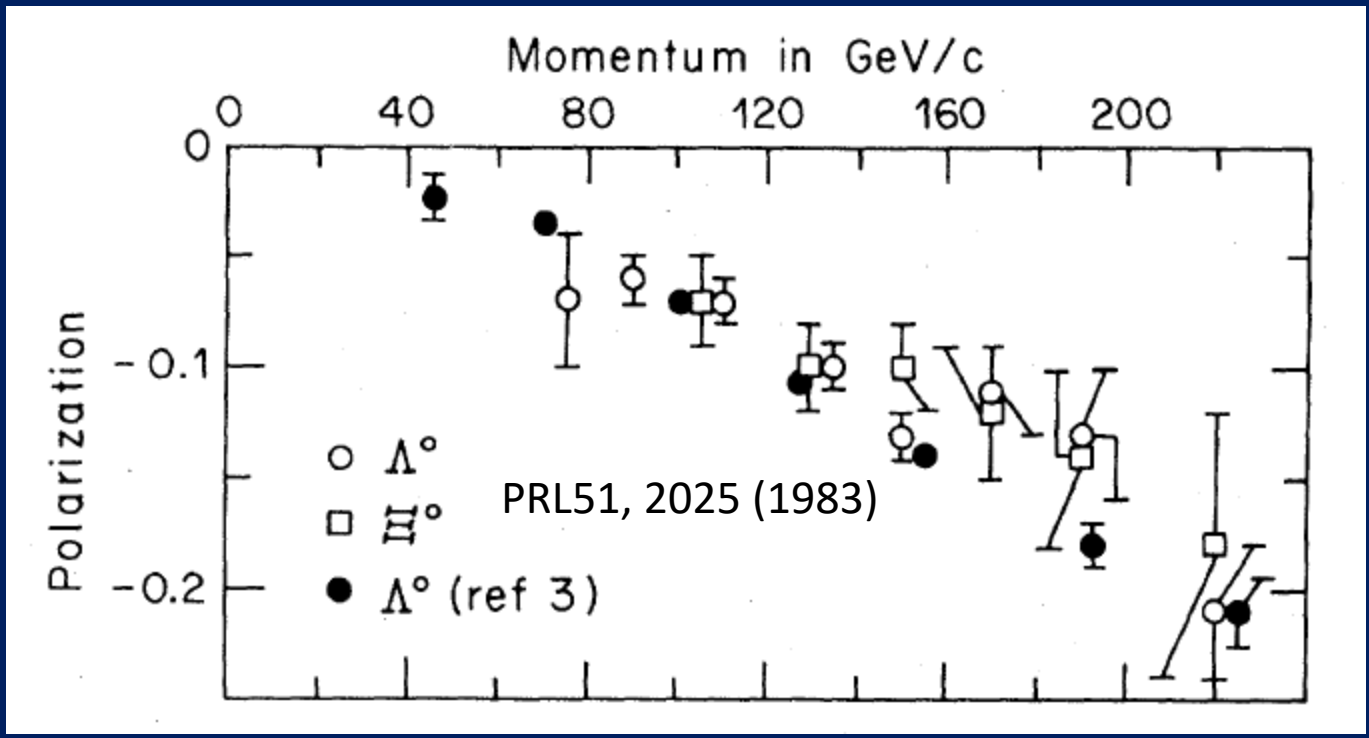




- 1981: p+Be, 400 GeV beam

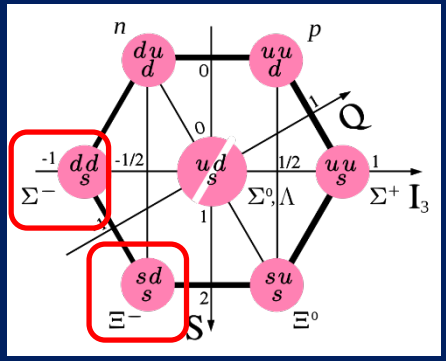
Ξ^0 polarization similar to Λ^0





- 1983: p+Be, 400 GeV beam
- Similar results for p+Cu and p+Pb

Σ^- polarized similarly to Σ^+; Ξ^- similarly to Ξ^0



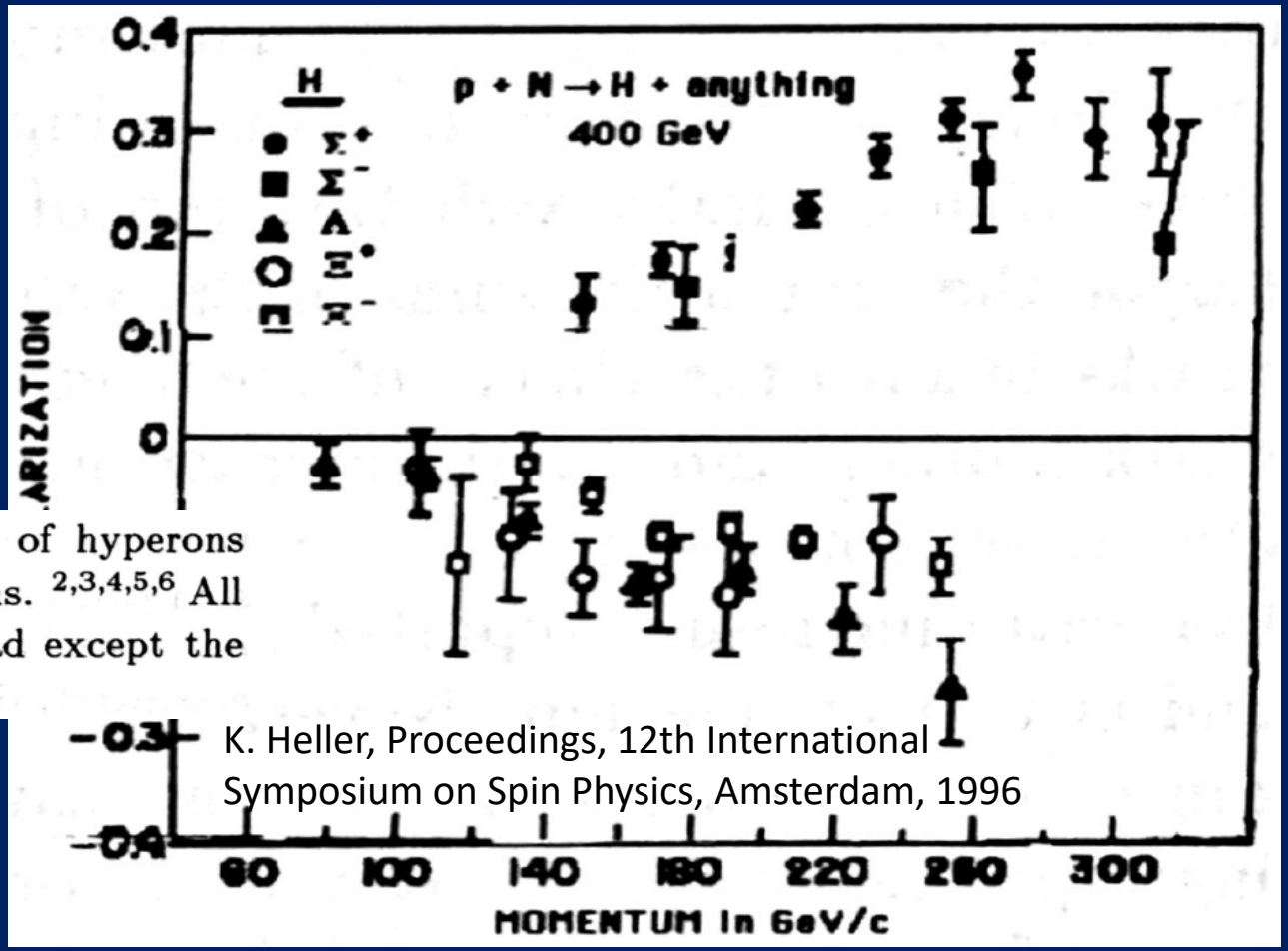
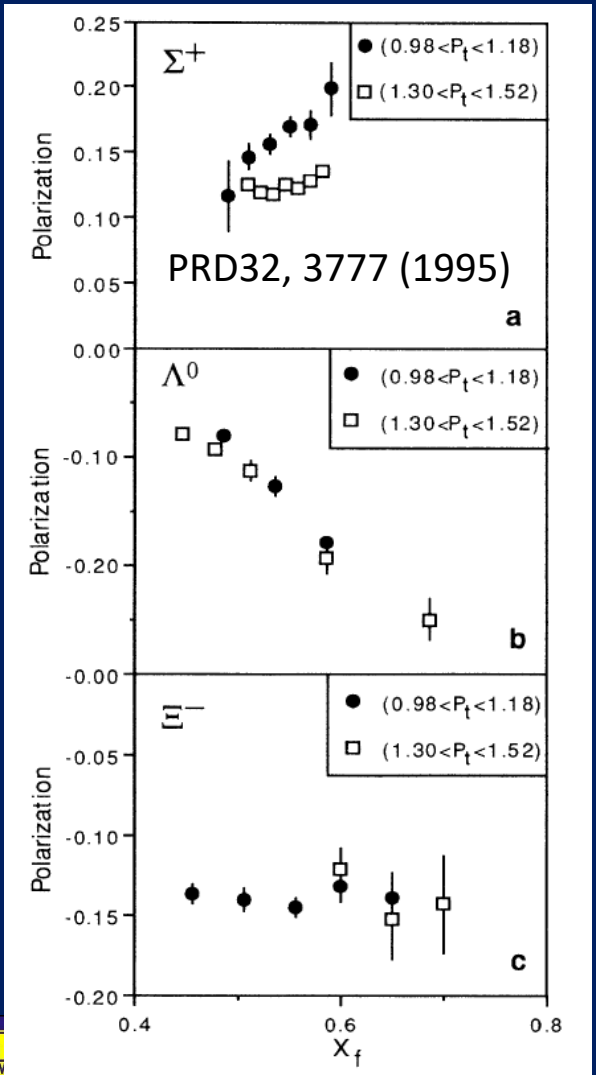
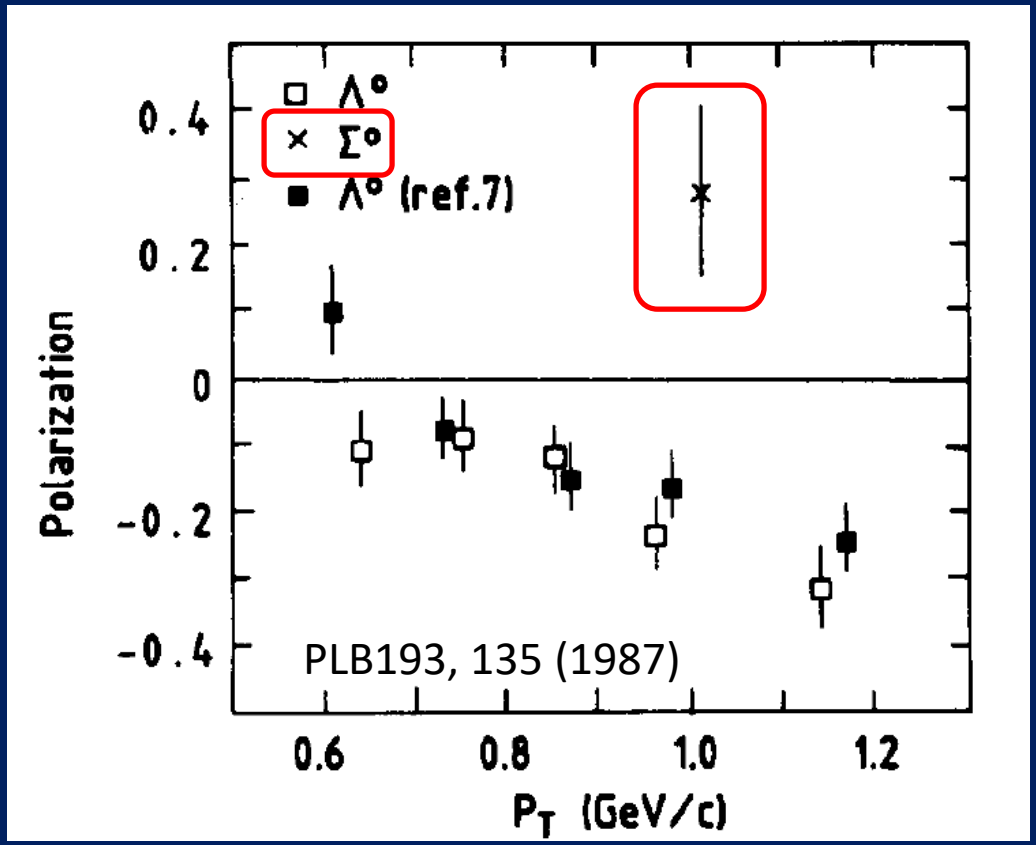


Figure 1: The polarization of hyperons produced by 400 GeV protons. [2,3,4,5,6] All production angles are 5 mrad except the Ξ^o which is 3.5 mrad.

K. Heller, Proceedings, 12th International Symposium on Spin Physics, Amsterdam, 1996

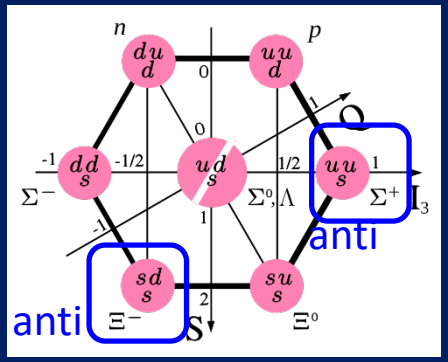
Other hyperon polarization measurements



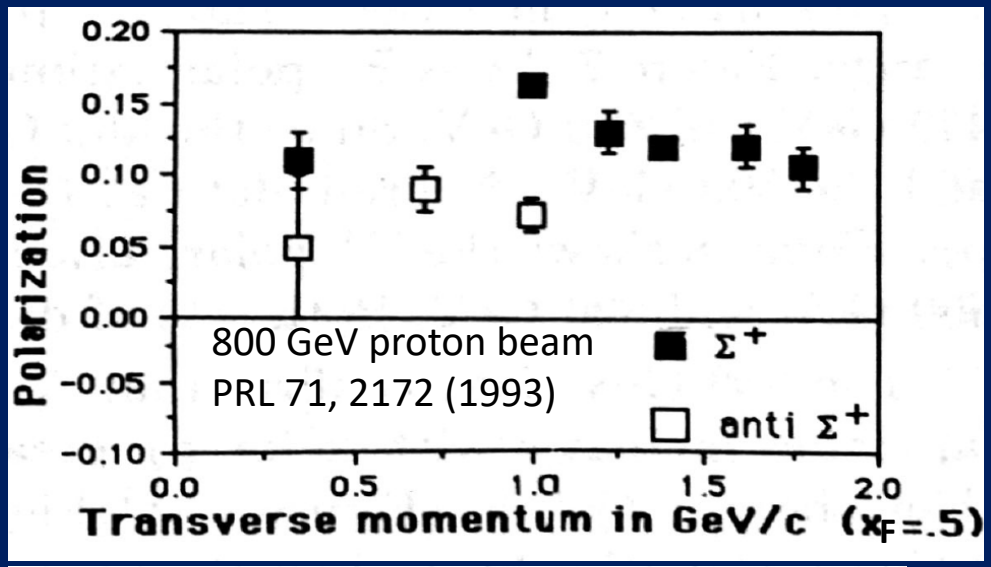


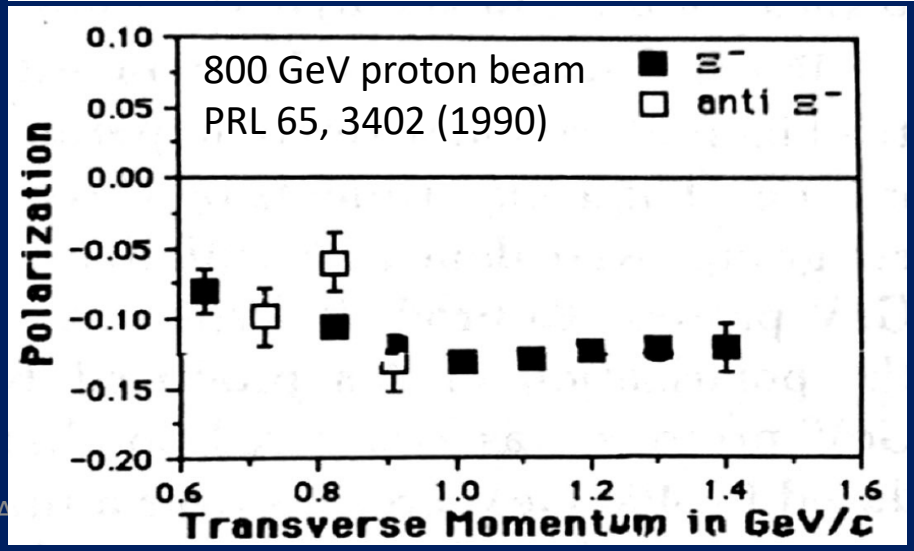
- p_T dependence for Σ^+ but not Λ^0 or Ξ^-
- Σ^0 appears to have same sign polarization as Σ^+, Σ^- but opposite from Λ (both uds)

Another surprise: Polarized antibaryons from (unpolarized) proton beams!



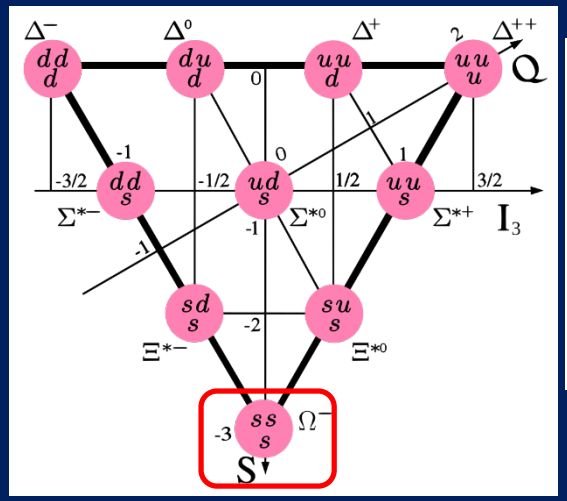
No valence quarks in produced baryons same as valence quarks in proton beam, but polarization still observed for particles produced in the more forward region

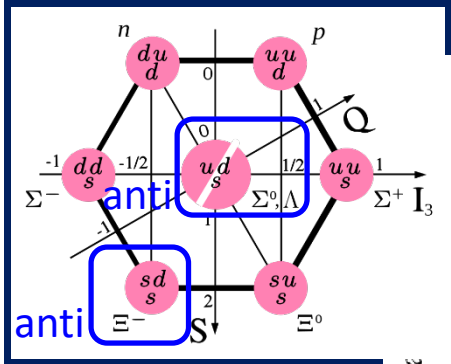


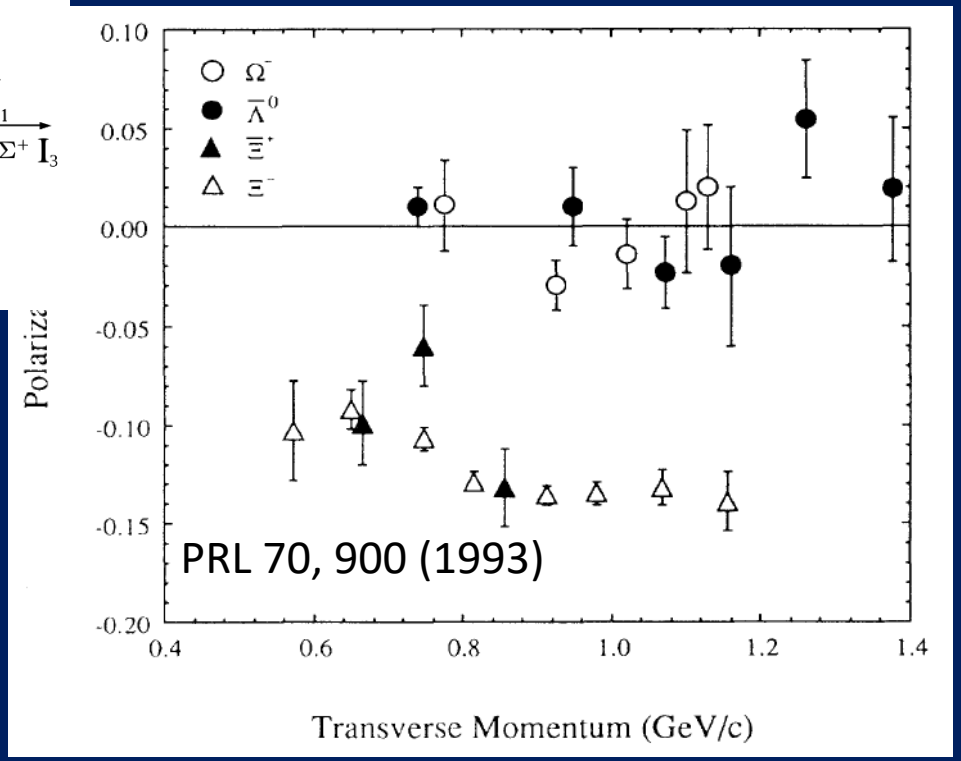


K. Heller, Proceedings, 12th International Symposium on Spin Physics, Amsterdam, 1996

But no Ω^- polarization





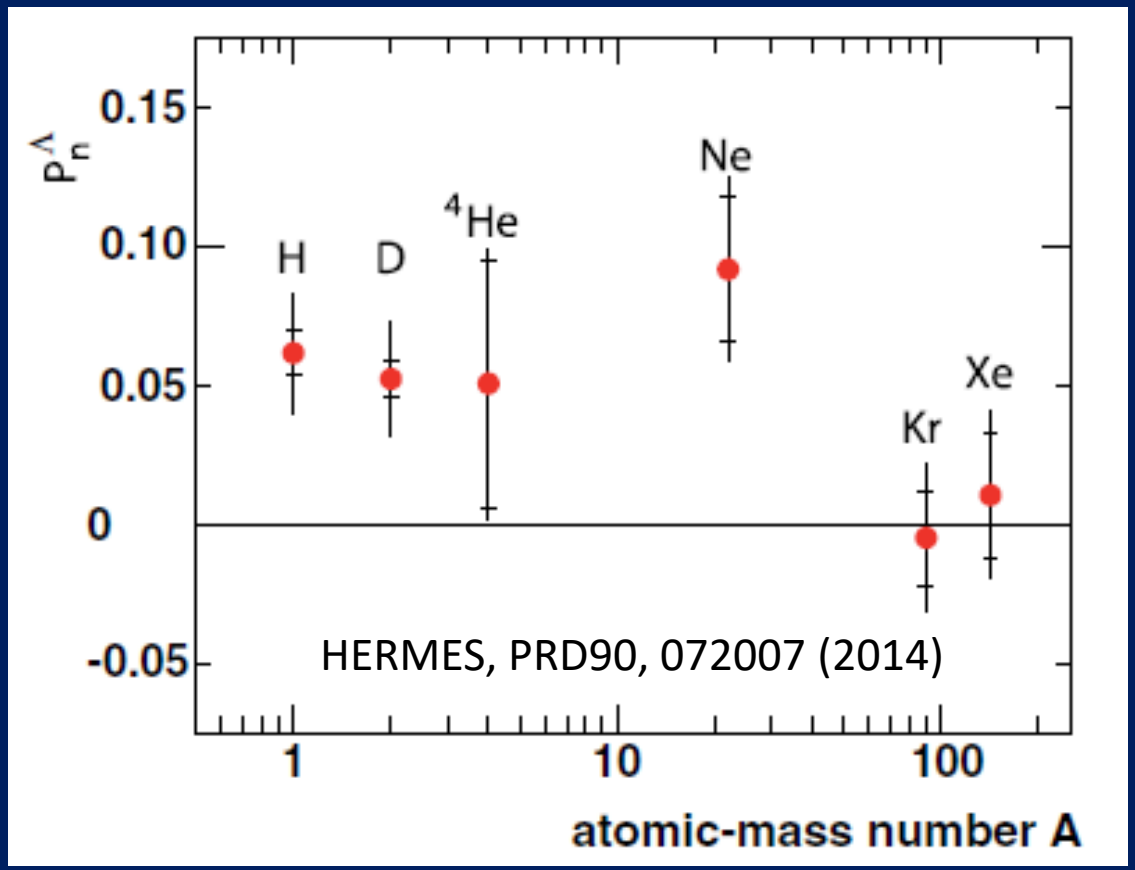


- Ω^-: 800 GeV p beam on Be target, $0.3 < x_F < 0.7$
- Why polarization for some forward hyperons with no valence quarks in common with proton, but not others??

Λ^0 polarization using beams other than protons

- Same sign and general x_F dependence for neutron beams
- But for K^- and Σ^- beams, positive polarization at positive x_F
- And for π^- beam, positive polarization but at negative x_F (backwards production)
- Consistent with zero for π^+ and K^+ beams
- Some data also from hyperon beam
- … Hadron-hadron collisions are complicated! Can we isolate possible contributing mechanisms using simpler collision systems??

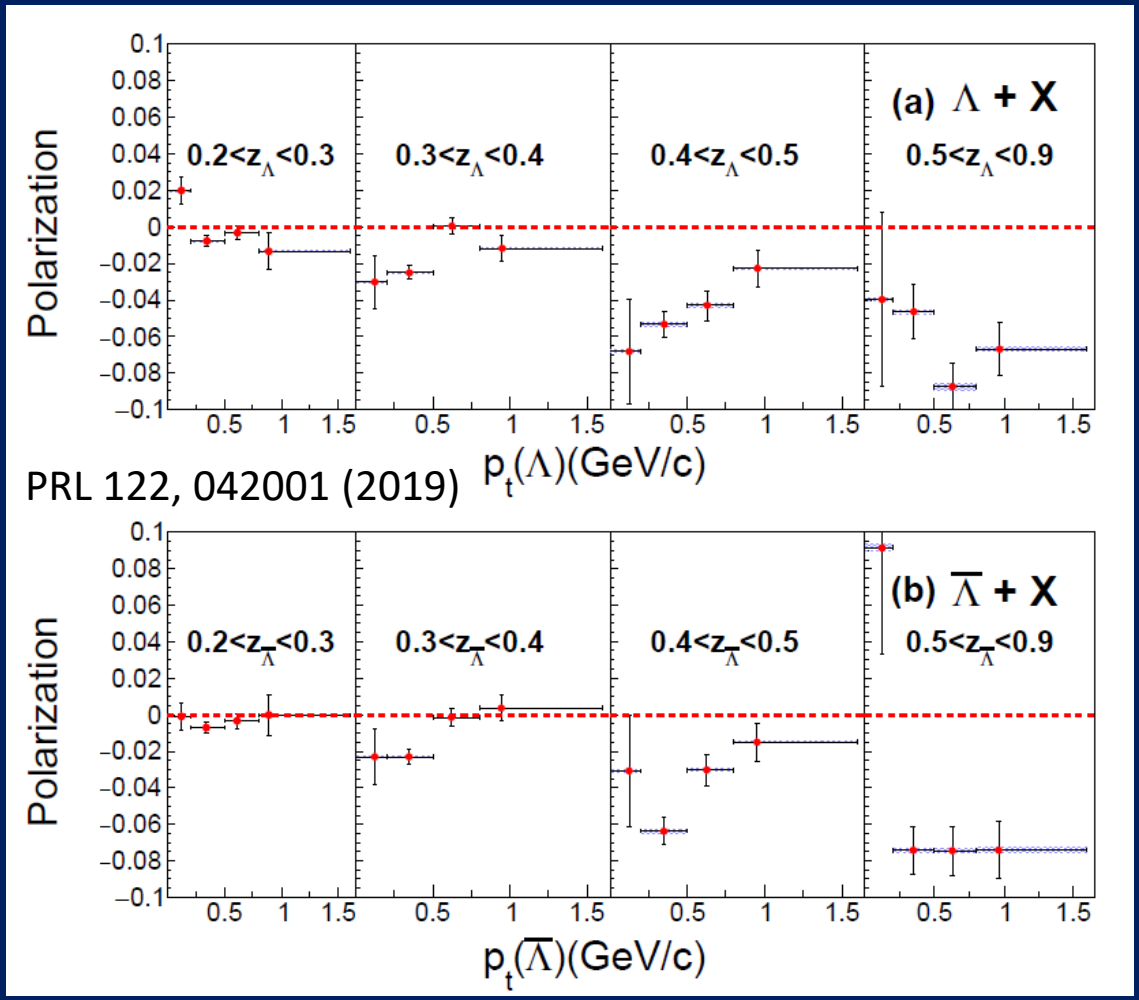
Lambda polarization observed in semi-inclusive deep-inelastic lepton-nucleon scattering



- 27 GeV electron beam on various (unpolarized) targets
- Moderate but nonzero Λ polarization observed in *both forward and backward* directions

Lambda and antilambda polarization recently observed in e^+e^- by Belle!

- Larger polarization for both Λ and $\overline{\Lambda}$ as increase momentum fraction *z* of outgoing (anti)quark carried by hyperon
- No initial-state hadron—*must* be purely a hadronization effect here!



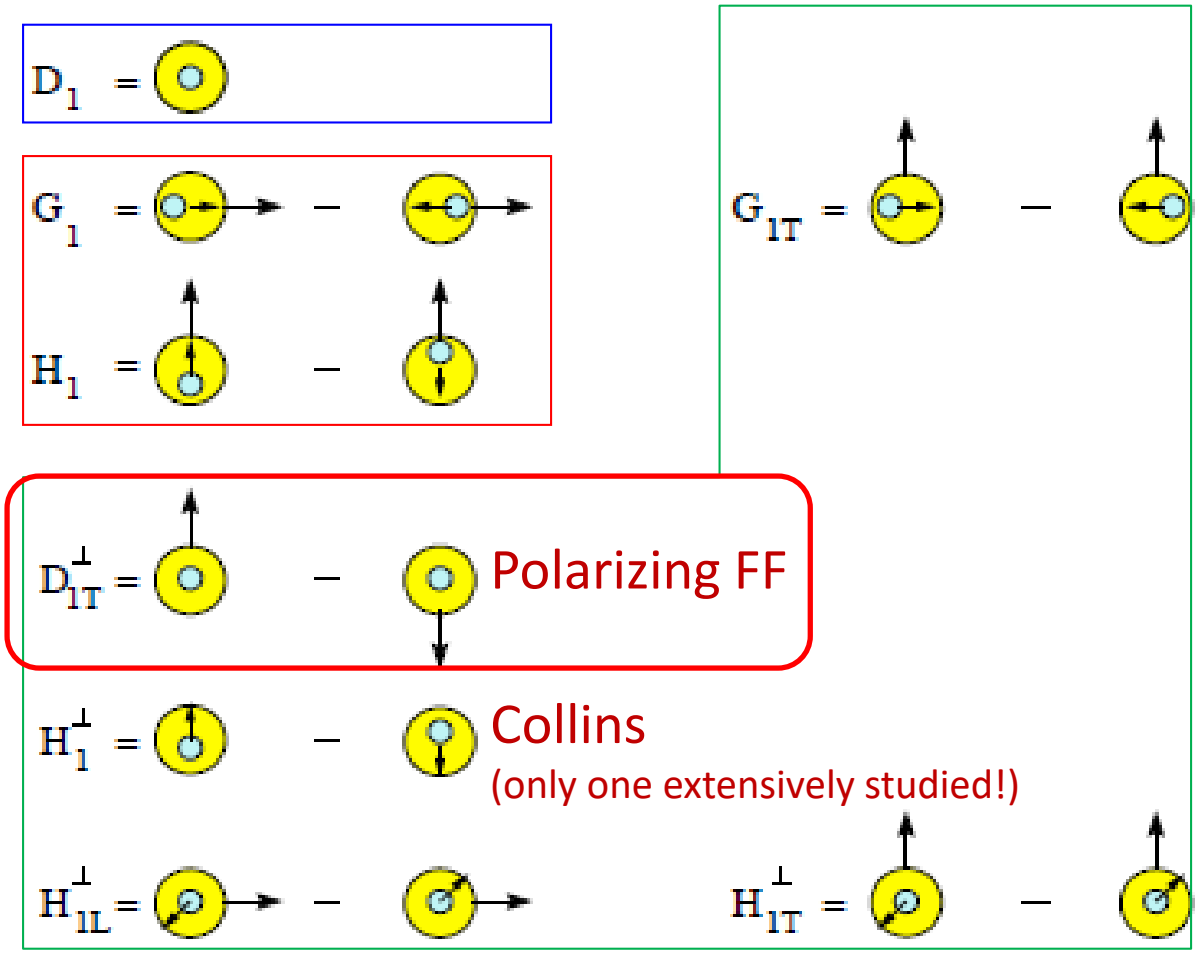
Spin-spin and spin-momentum correlations in hadronization: Transverse-momentum-dependent fragmentation functions

Unpolarized

Spin-spin correlations

Spin-momentum correlations

Transverse-momentum-dependent FFs

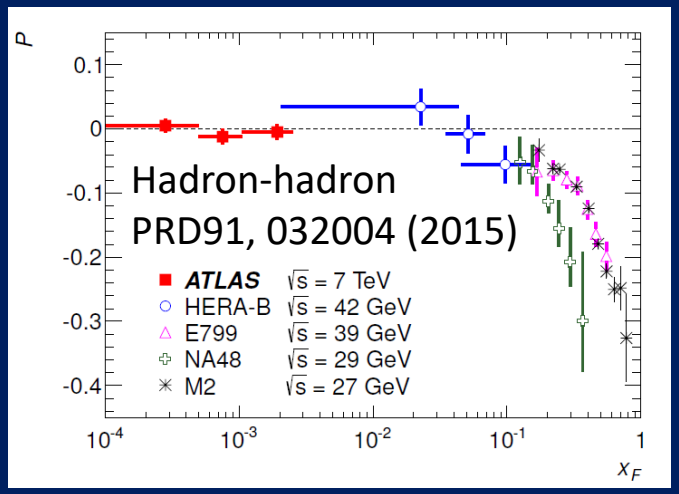


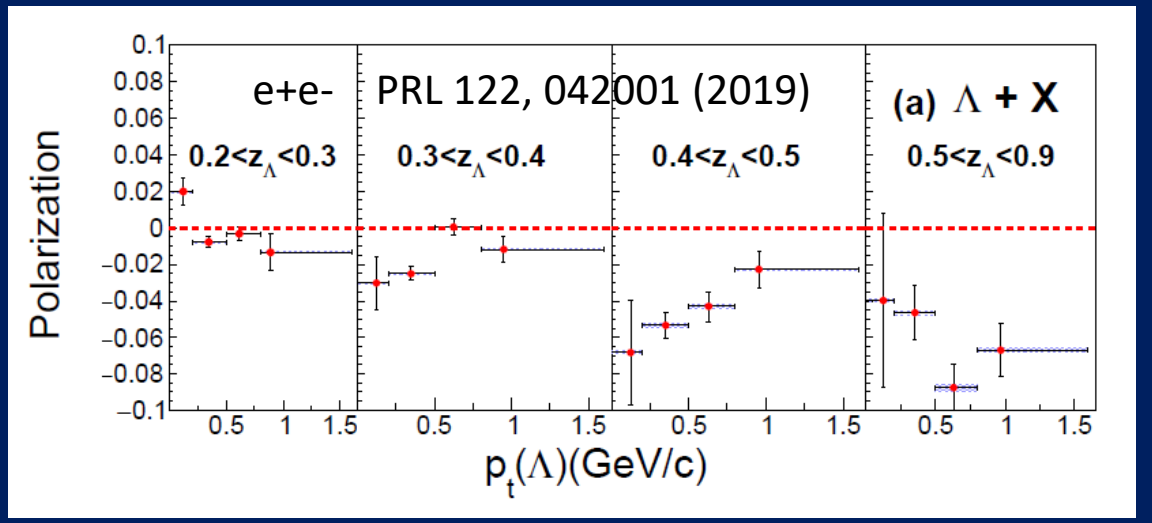
"Spontaneous" hyperon polarization generated (at least partly) in hadronization

- With the "clean" Belle results, it's now clear that there are significant contributions to hyperon polarization from nonperturbative spin-momentum correlation effects in hadronization

- Phenomenological work still relatively early, but focused on
  - Polarizing tranverse-momentum-dependent fragmentation function, e.g. Anselmino et al., PRD63, 054029 (2001), D'Alesio et al., arXiv:2003.01128
  - Polarizing twist-3 collinear hadronization correlator , e.g. Gamberg et al., JHEP 01, 111 (2019)

Additional contributions to polarization in hadron-hadron collisions?





- Similarly to single-spin asymmetries observed in scattering off of transversely polarized protons, seem to get much larger effects in hadron-hadron collisions than simpler systems
- Still more to understand about these striking spin-dependent phenomena!

Summary: Lecture 5

- Two remarkable effects involving transversely polarized baryons were independently discovered in 1976:
  - Asymmetries up to ~40% in the direction of forward pion production depending on the spin direction of a transversely polarized proton beam
  - Spontaneous transverse polarization of up to ~20% of forward lambda hyperons in unpolarized proton nucleus collisions

Summary: Lecture 5

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  - Asymmetries up to ~40% in the direction of forward pion production depending on the spin direction of a transversely polarized proton beam
  - Spontaneous transverse polarization of up to ~20% of forward lambda hyperons in unpolarized proton nucleus collisions
- Still working to understand these large effects
- Next lecture will also look at heavy flavor baryon polarization and proposed mechanisms

Extra

Prompt vs. nonprompt (anti)lambda polarization at Belle