Possible Spin Physics at J-PARC

Xiangdong Ji
Maryland Center for Fundamental Physics
University of Maryland

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Outline

- Introduction to hadron spin physics
- J-Parc spin possibilities
  - Drell-Yan process
  - Double longitudinal spin asymmetry
  - Double transverse spin asymmetry
  - Single spin asymmetry
- Conclusion

Introduction to hadron spin physics

- Spin is one of the most fundamental properties of any hadronic state (proton, neutron,…)
  - Quantum number generated by Lorentz symmetry
- Unlike elementary particles (quarks, leptons and gauge bosons), a hadron spin is the **total angular momentum** of a composite quark-gluon many-particle system:
  - It is a result of the vector sum of quark spin, gluon spin, quark and gluon orbital angular momentum.
  - Relative sizes of the different contributions reflect underlying QCD dynamics.

Key questons

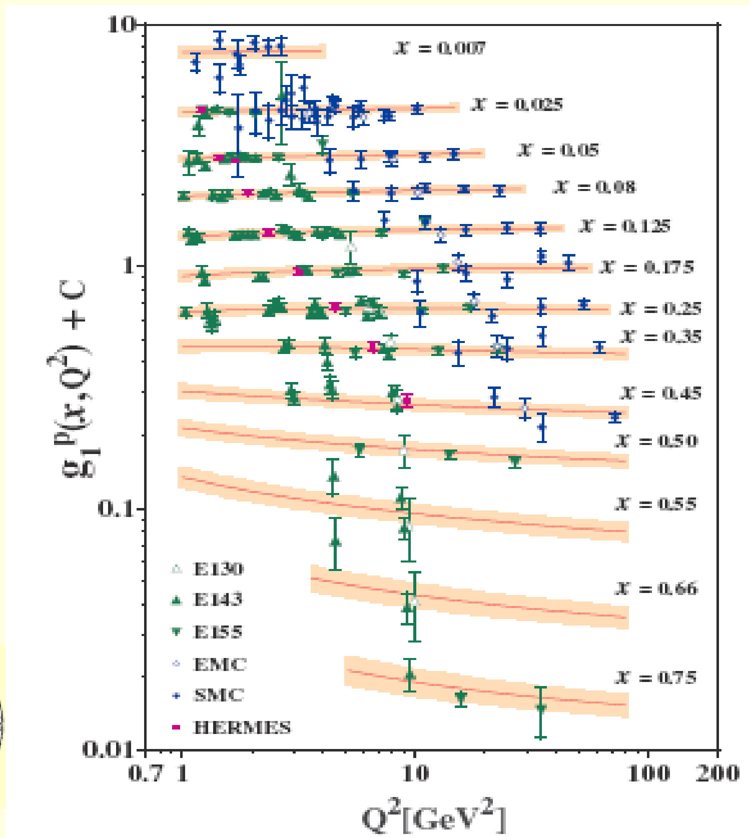
- **How do individual angular momentum components contribute to the spin?**
  - Where does the proton/neutron spin come from?
  - How important is the role of the gluons?
  - Orbital motion of the quarks?
- **What are the emerging hadron-spin-related physics phenomena?**
  - Novel parton distributions
    - Transversity distribution
    - Sivers function
  - Single transverse spin asymmetry

The spin of the proton: status

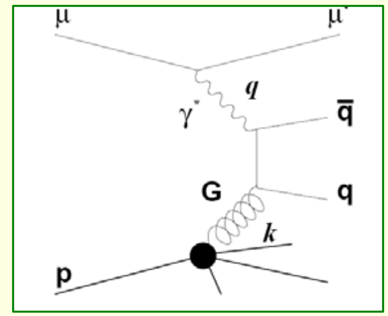
- Quark helicity contribution
  - Measured very well, except at large and small Feynman x, as well as the quark sea.
- Gluon helicity contribution
  - Initial measurements are encouraging, but more accurate measurements are needed.
- Orbital contribution
  - Can be measured through generalized parton distributions. Initial sensitivity study through vector production on trasnversely polarized target shows great promise.

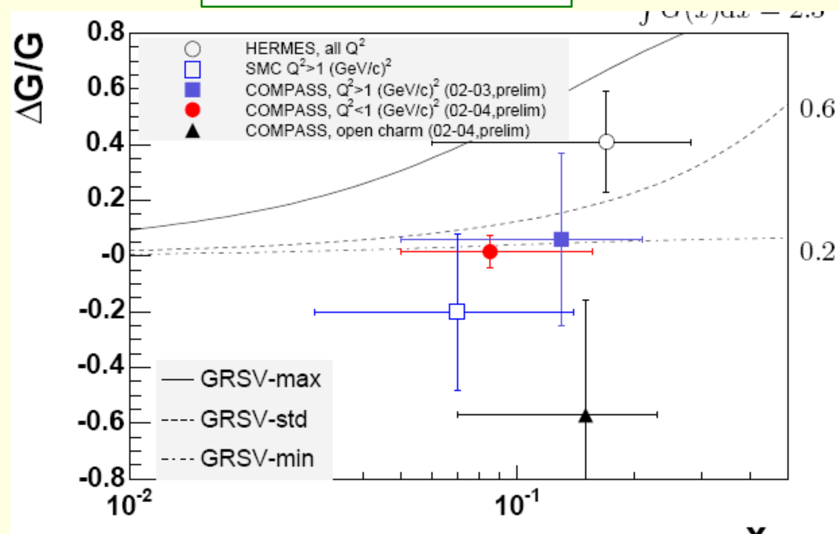
Experimental measurements (I)

- Q-evolution in inclusive spin structure function $g_1(x)$



- Two leading-hadron production in semi-inclusive DIS

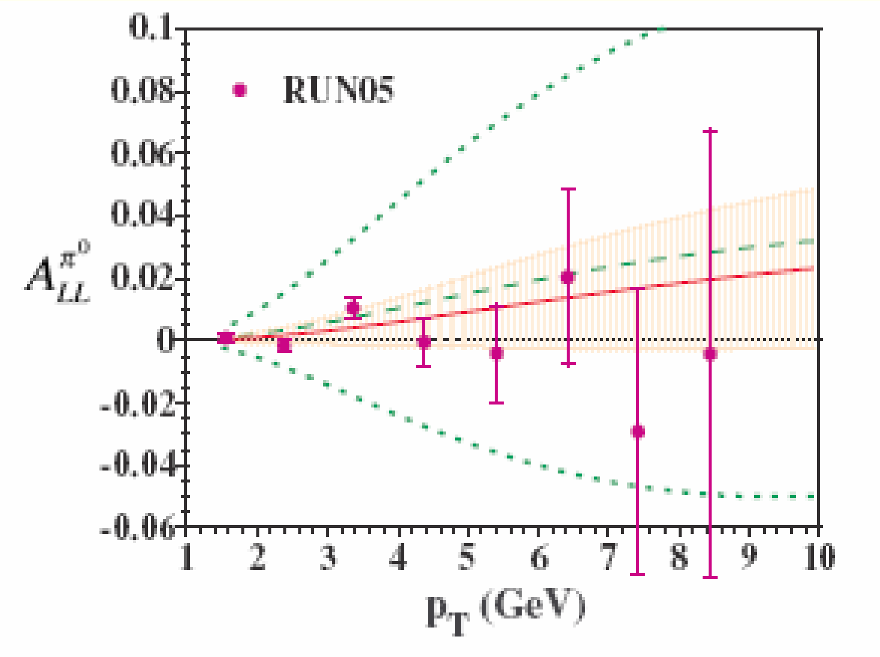




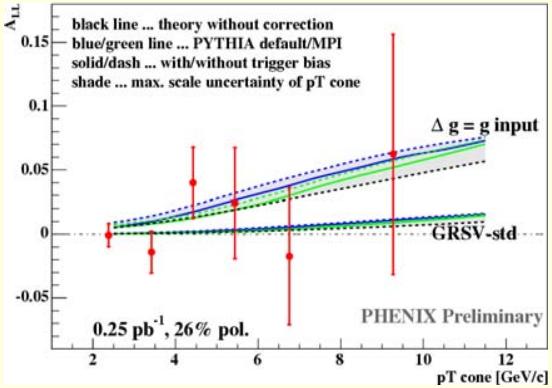
$\Delta G/G$ is small or has a node around $x_g \approx 0.1$

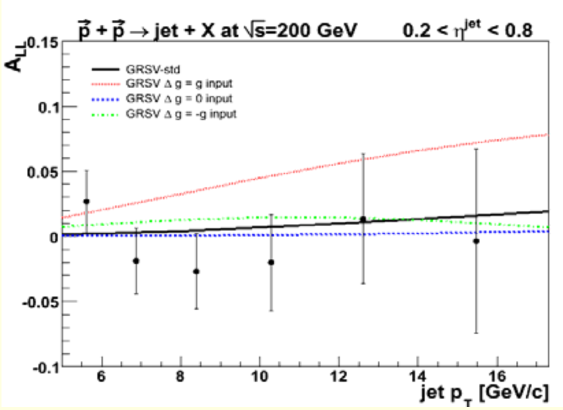
Experimental measurements (II)

- □ production in polarized PP collision at RHIC



- Two jet production in polarized PP collision at RHIC

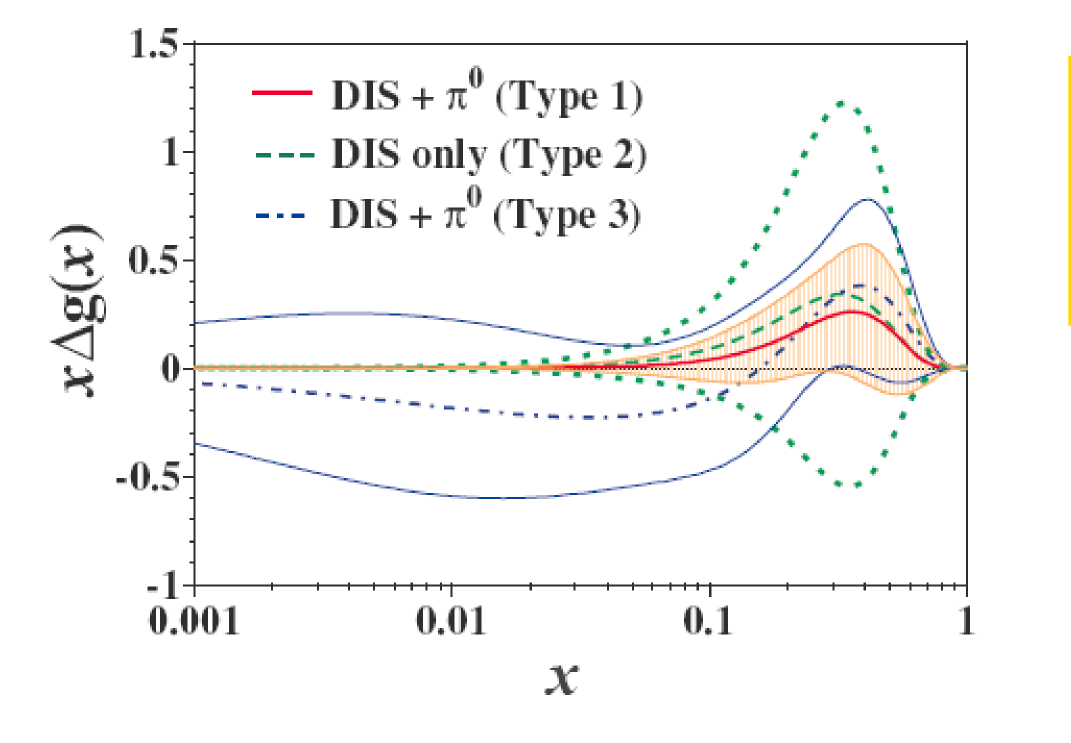




Fit to data

- Generally depend on the function forms assumed.

Hirai, Kumano, Saito, hep-ph/0603213 (ACC)

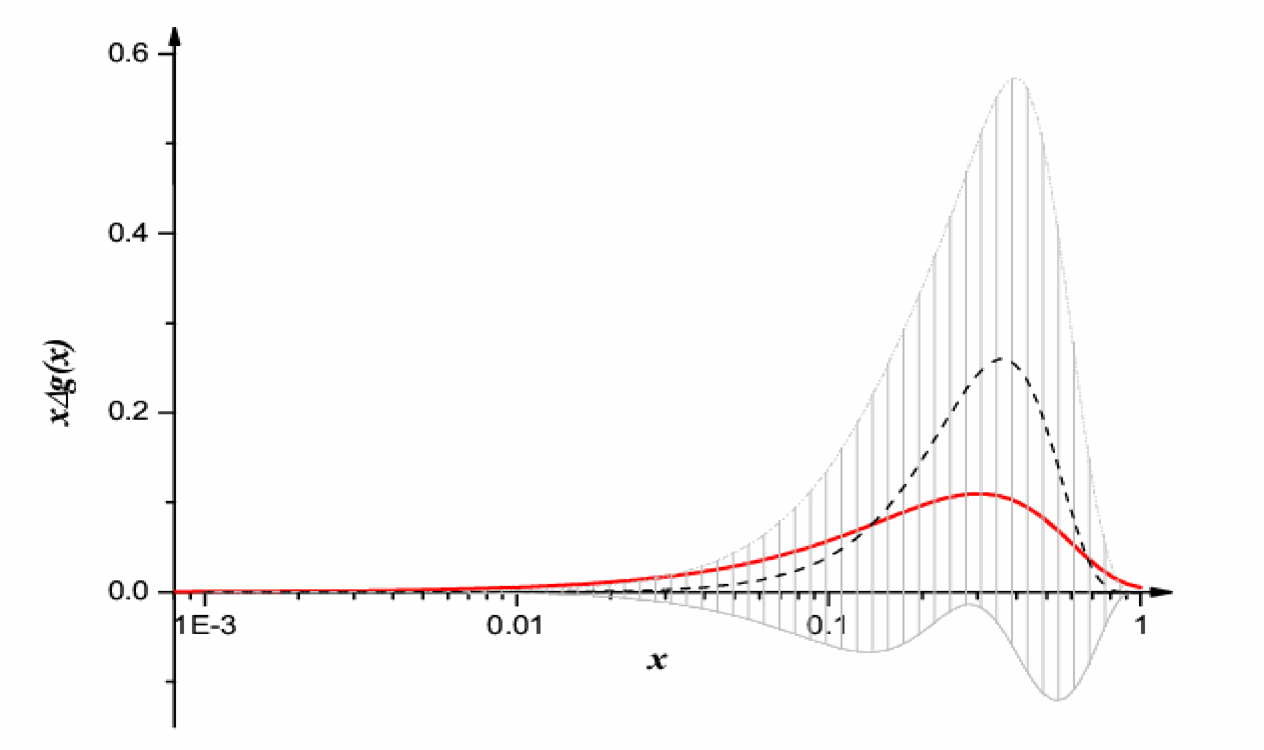


$\Delta g = 0.31 \pm 0.32$ type-
$= 0.47 \pm 1.0$ type-2
$= -0.56 \pm 2.16$ type-

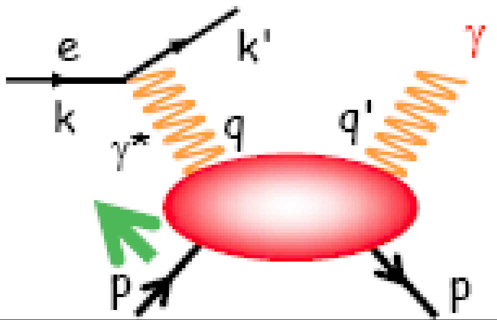
Type-3 fit assumes gluon polarization is negative at small x.

Bag model calculation

- Chen & Ji, hep-ph/0612174



Orbital contribution



At one value of x only

Ingredients:

1) GPD Modeling

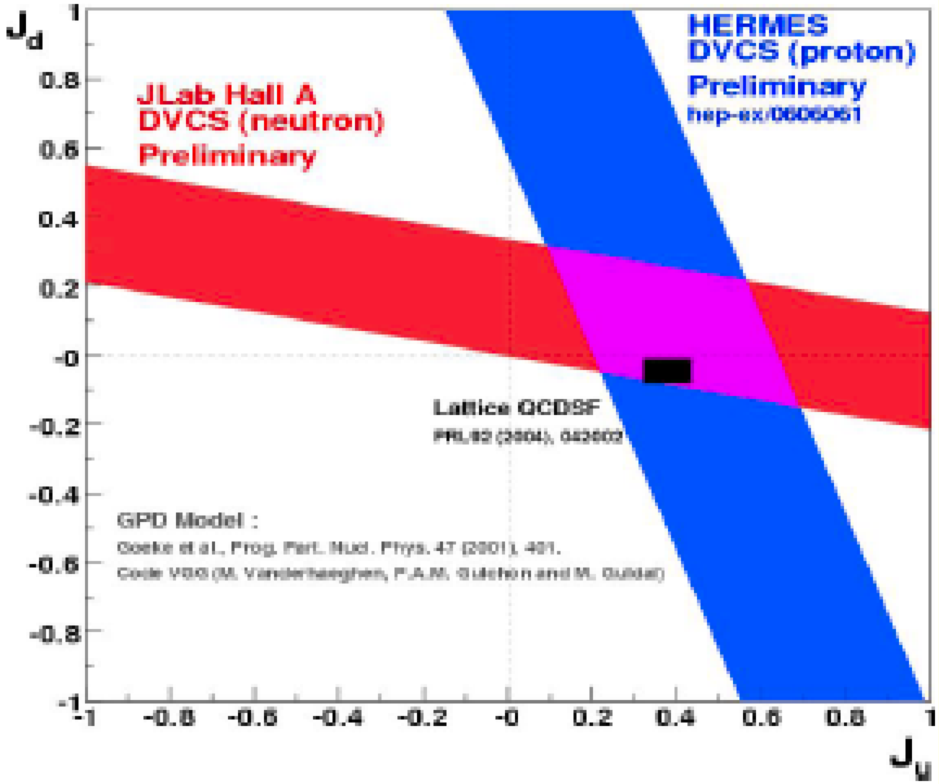
2) HERMES $^1H(e,e'\gamma)p$

(transverse target spin asymmetry)

3) Hall A $^2H(e,e'\gamma p)n$

Or independent:

Lattice QCD!



→ **Tremendous progress to constrain quark angular momenta**

Emerging Parton distribution from the nucleon spin: Transversity

- It's one of the three twist-2 distributions describing the parton physics at high-energy
- It is the density of transversely polarized quarks in a transversely polarized nucleon.
- It is chirally-odd: correlations of left and right-handed quarks in the nucleon
- It is closely related to the axial charge: the quark helicity contribution to nucleon helicity.
- …

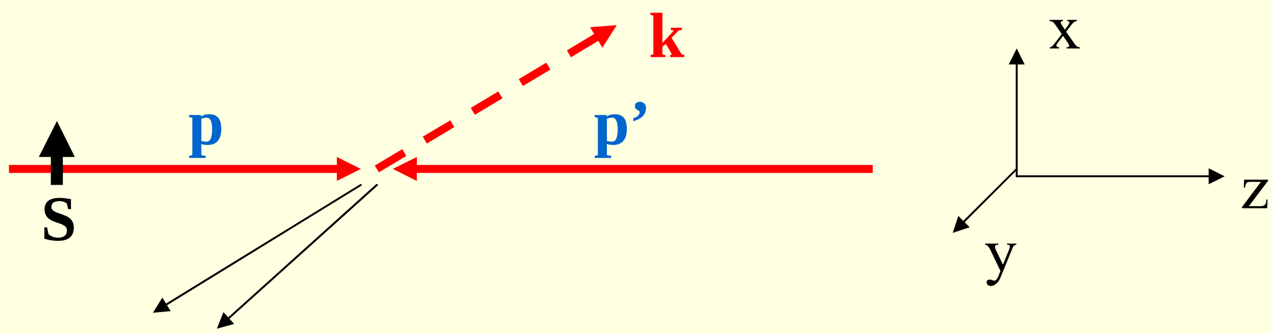
Ideas for experimental measurement

- In pp(p-bar) scattering
  - Drell-Yan: transversely polarized proton, cleanest
  - …
- In e-p scattering
  - Collins effects, two hadron production
  - Lambda production
  - Twist-3 fragmentation
  - …

It will take a lot of more effort to measure the transversity distribution than other twist-2 one!

Emerging phenomenon from the nucleon spin: Single Spin Asymmetry

- Consider scattering of a transversely-polarized spin-1/2 hadron (**S**, **p**) with another hadron, observing a particle of momentum **k**



The cross section can have a term depending on the azimuthal angle of **k**

$$d\sigma \sim \vec{S}\cdot(\vec{p}\times\vec{k})$$

which produce an asymmetry A_N when **S** flips: SSA

Why Does SSA Exist?

- SSA is proportional to

  Im (F_N * F_F)

  where F_N : the normal helicity amplitude

  and F_F : a spin flip amplitude

- Thus its existence requires
  - Helicity flip: one must have a reaction mechanism for the hadron to change its helicity (in a cut diagram).
  - Final State Interactions (FSI or ISI): to general a phase difference between two amplitudes.

  The phase difference is needed because the structure

  $\mathbf{S} \cdot (\mathbf{p} \times \mathbf{k})$ formally violate time-reversal invariance.

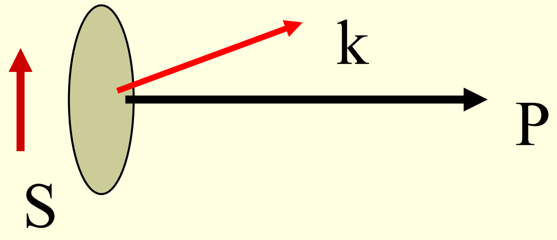
pQCD mechanisms for SSA

- QCD factorization introduces non-perturbative hadron structure functions which help to enhance the SSA relative to that in parton model
  - Twist-3 matrix effects (Efremov-Teryaev-Qiu-Sterman)

    hadron spin-flip through gluons and hence the quark mass is replaced by Λ_{QCD}.
  - Transverse-momentum-dependent (TMD) parton distribution (Sivers function)

    non-perturbative generation of ISI or FSI phases

    a twist-2 effect: no 1/Q suppression



A unified picture for SSA

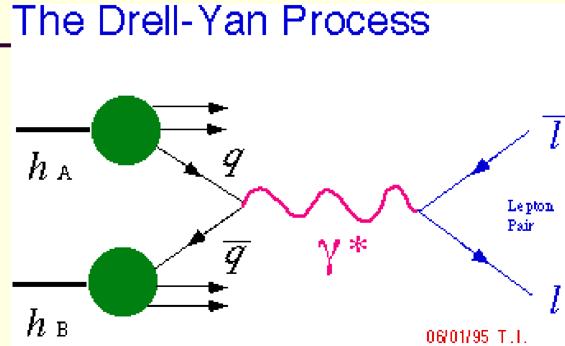
- In DIS and Drell-Yan processes, SSA depends on Q and transverse-momentum P_γ
  - At large P_γ, SSA is dominated by twist-3 correlation effects (Afremov& Teryaev, Qiu & Sterman)
  - At moderate P_γ, SSA is dominated by the k_γ-dependent parton distribution/fragmentation functions
- Ji, Qiu, Vogelsang, & Yuan, Phys.Rev.Lett.**97:082002,2006**

The two mechanisms at intermediate P_γ generate the same physics!

J-PARC hadron spin physics (primary beam)

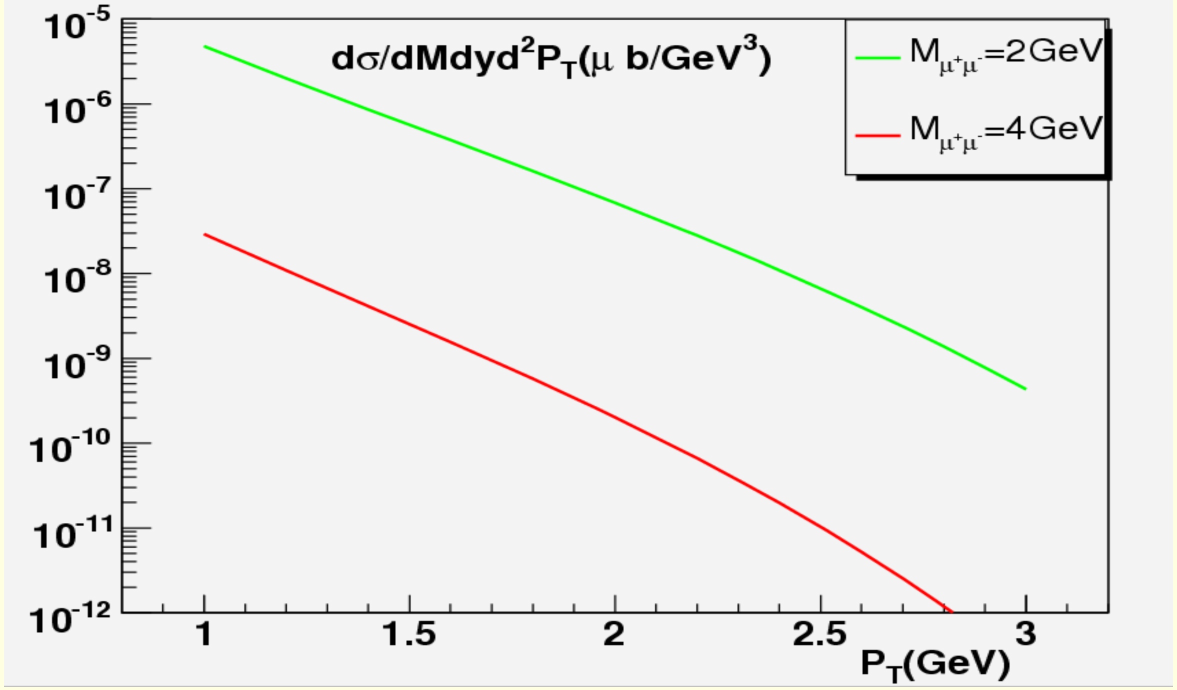
- Assume
  - 50 GeV polarized proton beam (longitudinal and transverse)
  - Unpolarized and polarized proton, deuteron and He-3 target (various polarization combinations)
- Processes
  - Drell-Yan: cleanest process to learn about parton physics
  - Hadron productions: pQCD?

General remarks about Drell-Yan



- pQCD condition requires the invariant mass of the lepton pair, M, to be large ⑦ $☹_{QCD}$
- The fixed target center-of-mass energy at J-PARC is Sqrt(s) = 10 GeV.
- Therefore, ♦ = M/s = $x_1 x_2$ is very large, for which there is a significant threshold effort.
  - Large perturbative corrections must be resummed
  - Possible large higher twist effect.

Drell-Yan Cross Section at J-Parc



No. of events is large when q_t < 2 GeV
and invariant mass of the lepton pair < 2-3 GeV

Longitudinal double spin asymmetry

- Longitudinally polarized proton scattering on longitudinally polarized proton, deuteron, He-3 targets. The spin asymmetry is sensitive to quark and antiquark polarizations in leading order.

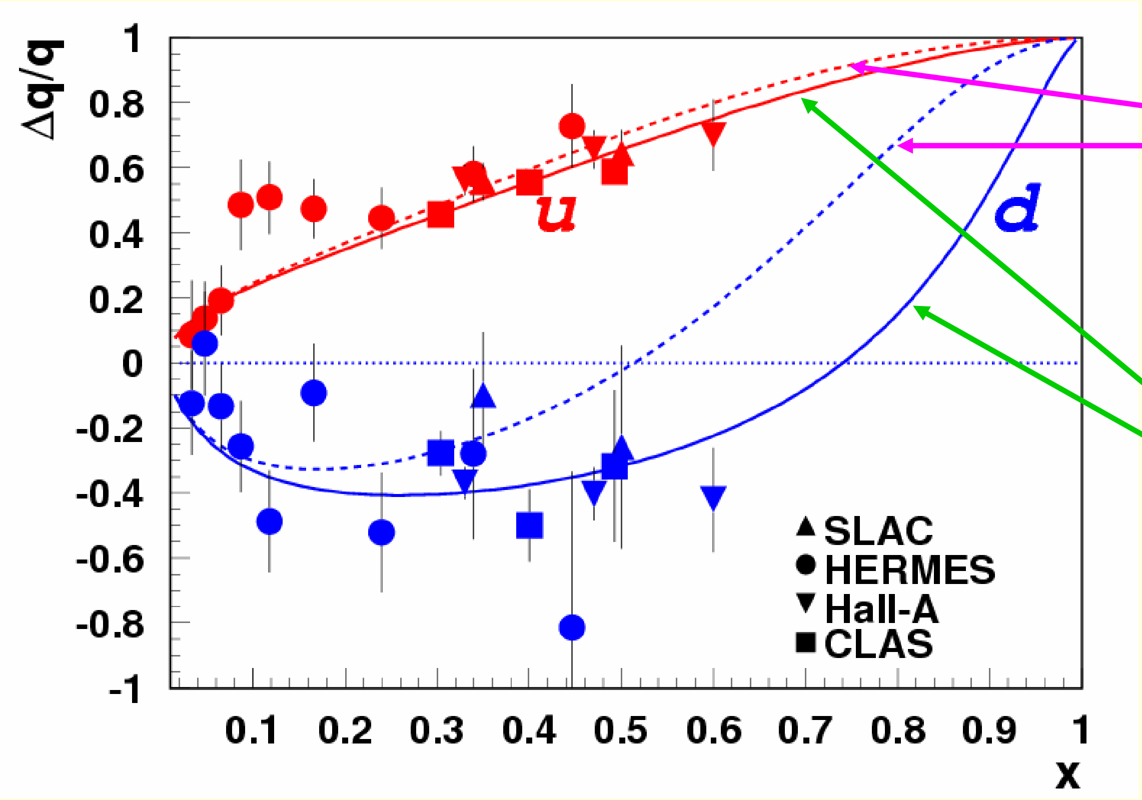
$$A_{LL}^{DY}(x_1, x_2) = \frac{\sum_q e_q^2 \left[\Delta q(x_1)\Delta \bar{q}(x_2) + \Delta q(x_1)\Delta \bar{q}(x_2)\right]}{\sum_q e_q^2 \left[q(x_1)\bar{q}(x_2) + q(x_1)\bar{q}(x_2)\right]}$$

$$\begin{aligned} x_F &= x_1 - x_2 \\ x_1 &= \frac{M}{\sqrt{s}} e^{y} \\ x_2 &= \frac{M}{\sqrt{s}} e^{-y} \end{aligned}$$

Large x parton distribution

- Large ♦ requires large x_1 (quark) and x_2 (antiquark).
- Ideal to measure polarized up quark distribution at large x!
- Large x parton distribution is usually very much suppressed, difficulty to measure accurately.
- Little information is available.

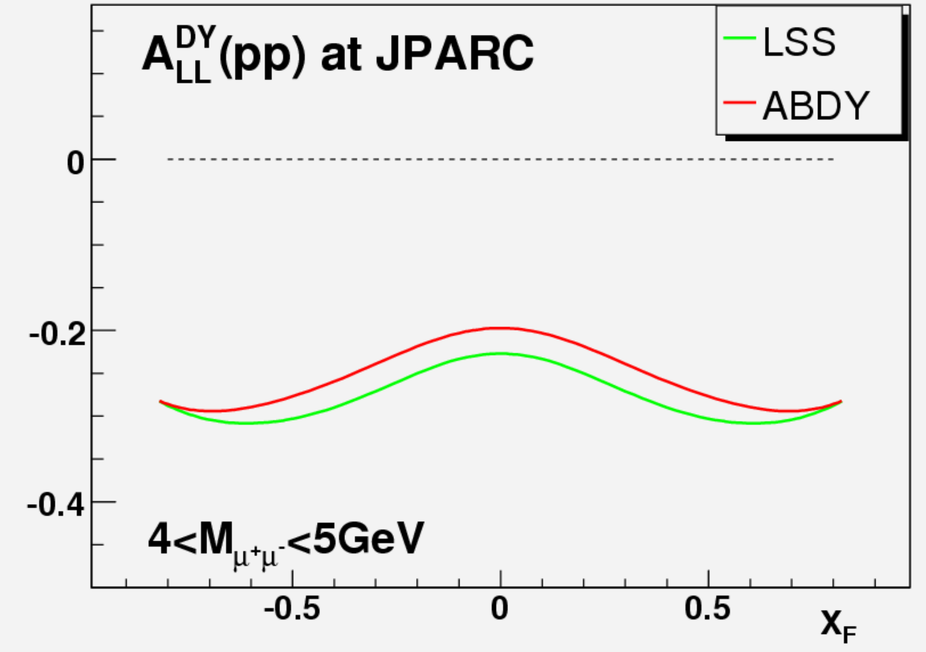
Quark orbital angular momentum contribution at large-x

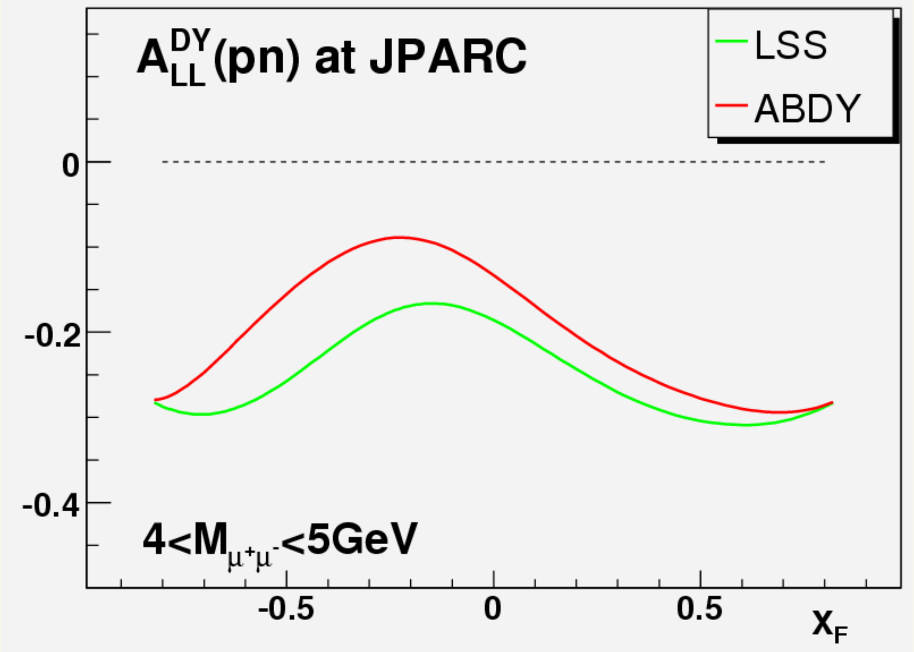


Power counting rule
Brodsky-Burkardt-Schmidt 95
Leader-Sidorov-Stamenov 98
$q^-/q^+ \sim (1-x)^2$

Quark-orbital-angular Momentum contribution
Avakian-Brodsky-Deur-Yuan,07
$q^-/q^+ \sim (1-x)^2 \log^2(1-x)$

A_{LL} for pp and pn collisions at JPARC





LSS: Leader-Sidorov-Stamenov 98
ABDY: Avakian-Brodsky-Deur-Yuan,07

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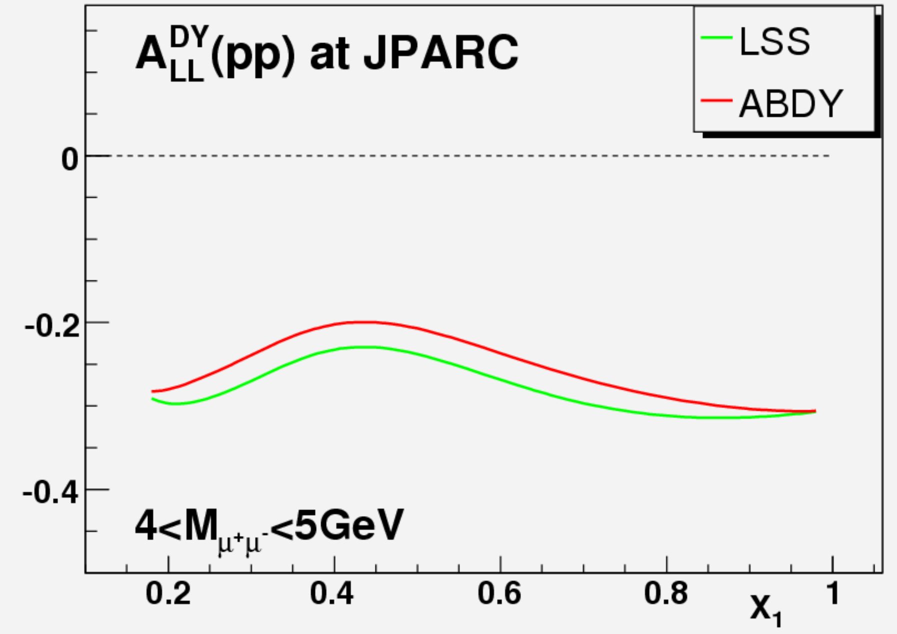
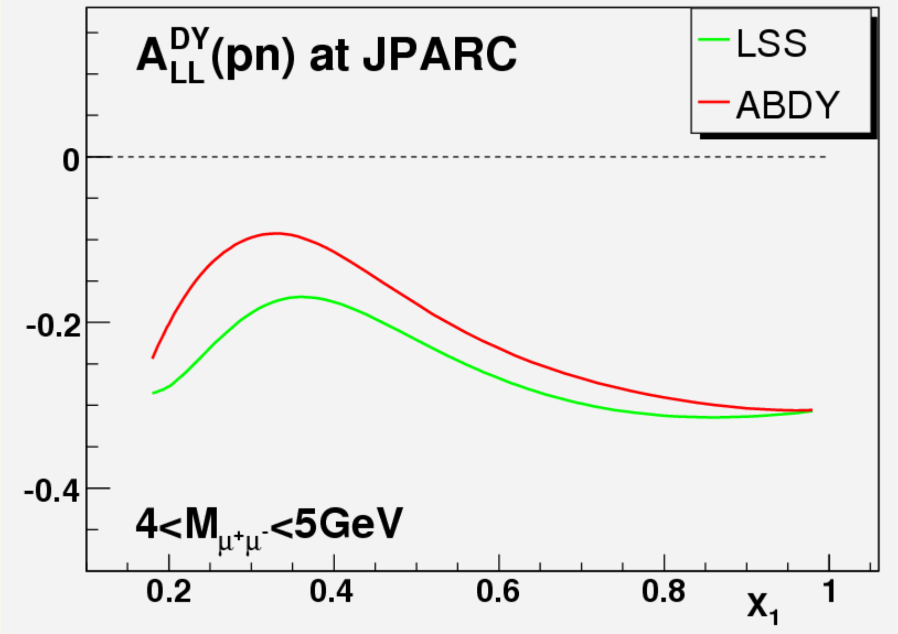




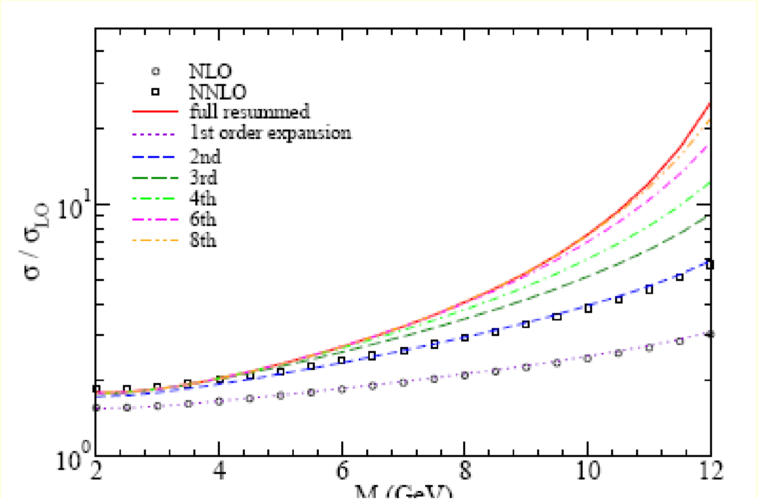
LSS: Leader-Sidorov-Stamenov 98

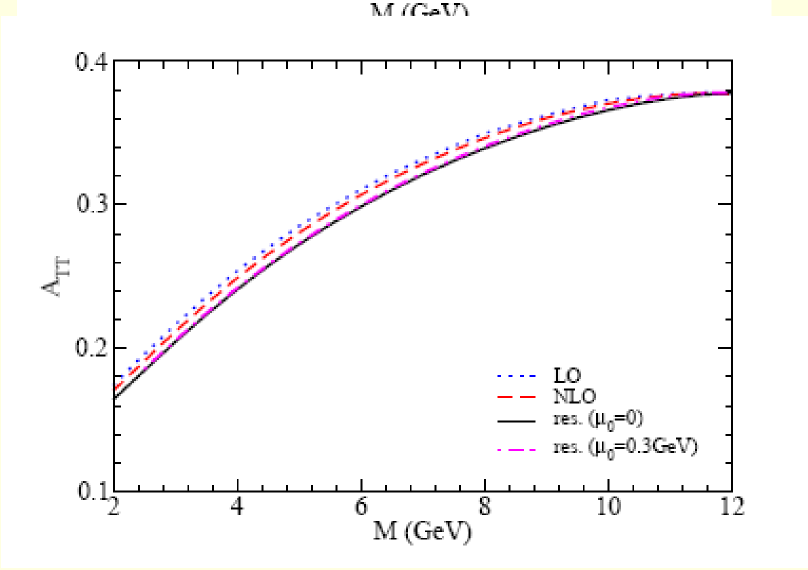
ABDY: Avakian-Brodsky-Deur-Yuan,07

Transversity

- Double transverse polarization asymmetry in Drell-Yan process has never been measured before.
- Transversely polarized beam and target
- Don’t know about the size of the sea quark transversity
  - There is no reason that it is strongly suppressed.
- Large Drell-Yan asymmetry at GSI-PANDA
  - H. Shimuzu, G. Sterman,W. Vogelsang, H. Yokoya Hep-ph/0503270
- Dedicated study (simulations) is needed.

Effects of resummation





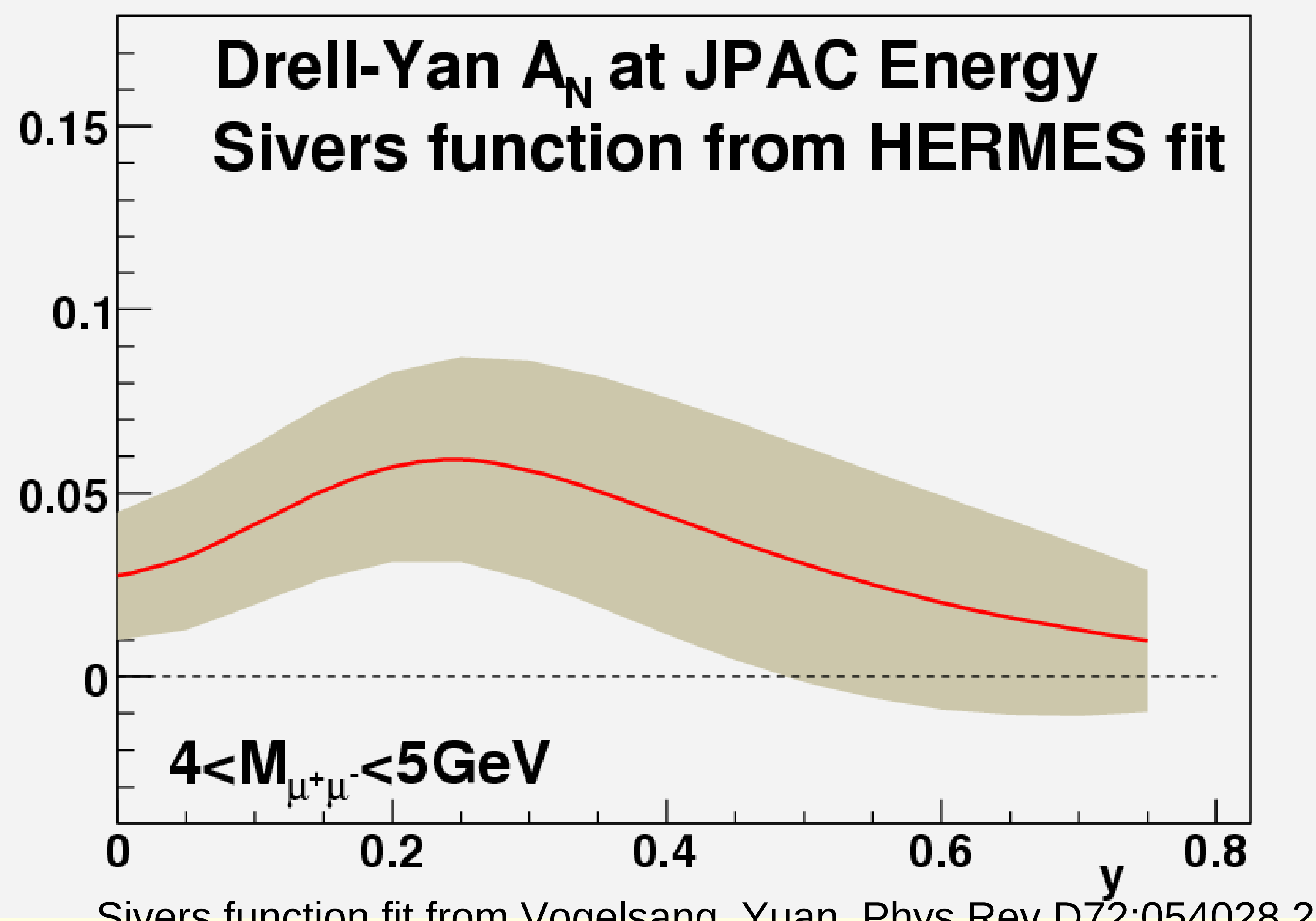
Drell-Yan Study for Sqrt(s) =14.5 GeV.

H. Shimuzu, G. Sterman,
W. Vogelsang, H. Yokoya
Hep-ph/0503270

Single spin asymmetry

- In Drell-Yan collision, the lepton pairs are produced with a transverse momentum imbalance q_T, due to gluon radiation or transverse momentum of the initial quarks.
- When one of the proton is transversely polarized, the lepton pairs produced with different q_T direction have different rate: single spin asymmetry.
- The asymmetry is related to the asymmetric distributions of the quarks in a transversely polarized nucleon (Sivers function)

SSA for Drell-Yan at JPAC (integrated over P_T)



Sivers function fit from Vogelsang, Yuan, Phys.Rev.D72:054028,2005

Conclusion

- At J-Parc, Drell-Yan process with polarized proton beam and targets allows a unique opportunity to learn about the partonic structure of the nuclons.
  - With A_{LL}, one can measure the polarized parton distribution at large x, complementing Jlab 12 program.
  - With A_{TT}, one can measure the transverisity distribution.
  - With A_T one can learn about the mechanisms for the single spin asymmetry, aysmmetric parton distributions, and perhaps twist-3 correlations!

GO SPIN, J-PARC!