Lepton Asymmetry in Polarized Drell-Yan

J.Kodaira (Hiroshima)

at RADCOR02 & Loops and Legs
September 2002

Lepton spin asymmetry in Drell-Yan
at RHIC-SPIN is investigated

1. Polarized Drell-Yan

   Spin d.o.f. is Interesting and Important

2. Anti-symmetric Part of Hadronic Tensor

   Lepton Asymmetry

3. QCD Corrections

   Just Calculation

4. Numerical Studies

   Results on Z pole

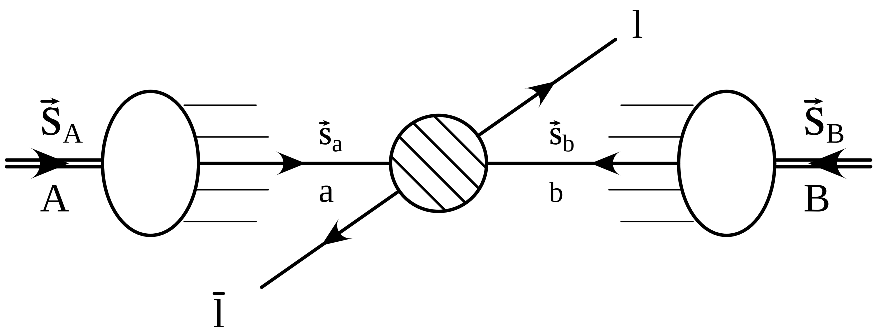
5. Summary

in collaboraiton with

Hiroshi Yokoya (Hiroshima)

♣ Polarized Drell-Yan

Why Polarized Drell-Yan?



- Measurement of PDFs
  - Longitudinal
  - Transverse
- Role of Spin

  Interaction is Sensitive to Spin Structure

  - In the Standard Model
    Higgs, CP Property, ...
  - Beyond the Standard Model
    Anomalous Coupling, New Gauge Bson, SUSY, ...

Many Advantages and Much Interests

♣ Anti-symmetric Part of Hadronic Tensor

- Parton Level Cross Section (For "γ")

$$d\hat{\sigma} \propto \hat{W}_{\mu\nu} L^{\mu\nu} = \left(\hat{W}^S_{\mu\nu} + \hat{W}^A_{\mu\nu}\right)\left(L^{S\,\mu\nu} + L^{A\,\mu\nu}\right)$$
$$= \hat{W}^S_{\mu\nu} L^{S\,\mu\nu} + \hat{W}^A_{\mu\nu} L^{A\,\mu\nu}$$

To prove $\hat{W}^A_{\mu\nu}$, Need $\hat{L}^A_{\mu\nu}$

$\hat{W}^S_{\mu\nu}\ (q\bar{q})$ is Essnetially the SAME
for Polarized and Unpolarized Drell-Yan

$\Uparrow$

Chiral Structure of Int.

$d\hat{\sigma}(\lambda_q\,,\,\lambda_{\bar{q}})$: $d\hat{\sigma}(+,+) = d\hat{\sigma}(-,-) = 0$

- Lepton Helicity and Anglar Distribution

Simple Tool to Extract $\hat{W}^A_{\mu\nu}$

$$\frac{d\hat{\sigma}^{(0)}(\lambda\,,\,\lambda_l)}{dQ^2 d\cos\theta^*} = \frac{\pi\alpha^2}{12Q^4} e_q^2 \left(1 + \cos^2\theta^* + 2\lambda\lambda_l \cos\theta^*\right)\delta(1-z)$$

where $z = \dfrac{Q^2}{\hat{s}}$

$\lambda\ (\lambda_l)$: quark (lepton) helicity

♣ QCD Corrections

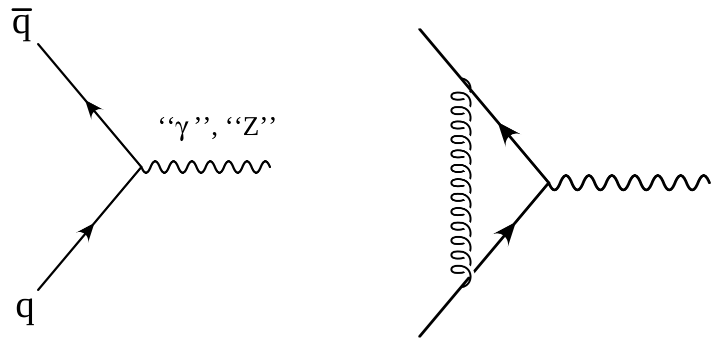
$\mathcal{O}(\alpha_s)$ Correction with Massive Gluon

$$\frac{d\sigma(\lambda_A, \lambda_B, \lambda_l)}{dQ^2 dcos\theta}$$

$\lambda_{A,B}$: Proton′s Helicity

Scheme Dependence: Discussed Later

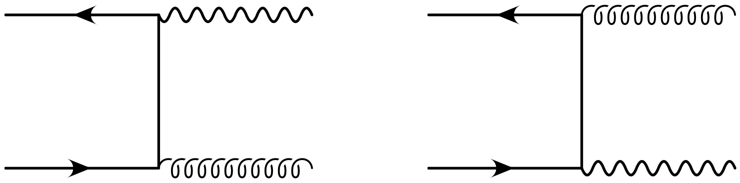
- Virtual



$$\frac{d\hat{\sigma}^V(\lambda, \lambda_l)}{dQ^2 d\cos\theta^*} = \frac{d\hat{\sigma}^{(0)}(\lambda, \lambda_l)}{dQ^2 d\cos\theta^*}\ \delta(1-z)$$
$$\times \left[1 + \left(\frac{\alpha_s}{\pi} C_F\right)\left(-\frac{1}{2}\ln^2\frac{Q^2}{\kappa^2} + \frac{3}{2}\ln\frac{Q^2}{\kappa^2} - \frac{7}{4} + \frac{\pi^2}{6}\right)\right]$$

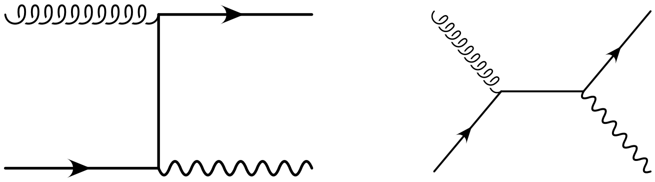
κ^2 : gluon mass

- Gluon Radiation



$$\frac{d\hat{\sigma}^B(\lambda,\lambda_l)}{dQ^2 d\cos\theta^*} = \frac{d\hat{\sigma}^{(0)}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^{**}}\ LB^B\ 2\ \left(\frac{\alpha_s}{2\pi}C_F\right)$$
$$\times\ \left[\delta(1-z)\left(\frac{1}{2}\ln^2\frac{Q^2}{\kappa^2} - 2\ \ln^2 2\right) + \frac{1+z^2}{(1-z)_+}\ln\frac{Q^2}{\kappa^2}\right.$$
$$\left. +2(1+z^2)\frac{\ln z}{1-z} + 2(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+\right]$$
$$+\ DY^B(z,\cos\theta^*;\lambda,\lambda_l)$$

- Gluon Compton



$$\frac{d\hat{\sigma}^C(\lambda,h,\lambda_l)}{dQ^2 d\cos\theta^*} = \frac{d\hat{\sigma}^{(0)}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^{**}}\ LB^C\ \frac{\alpha_s}{2\pi}P_{qg}(z;\lambda,h)$$
$$\times\ \left[\ln\frac{Q^2}{\kappa^2} + \ln\left(\frac{1-z}{z^2}\right) + \ln\left(\frac{1+z-c+cz}{4z}\right)\right]$$
$$+\ DY^C(z,\cos\theta^*;\lambda,h,\lambda_l)$$

Negative Mass ($-\kappa^2$) for Initial Gluon

h is Polarization of Gluon

- Mass Singularity and Factorization

$$\frac{d\hat{\sigma}^{A+B}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^*} = \frac{d\hat{\sigma}^{(0)}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^{**}}\ LB^B \times\left[\delta(1-z) + 2\frac{\alpha_s}{2\pi}P_{qq}(z)\ \ln\frac{Q^2}{\kappa^2}\right] + \frac{d\hat{\sigma}^{A+B,F}}{dQ^2 d\cos\theta^*}$$

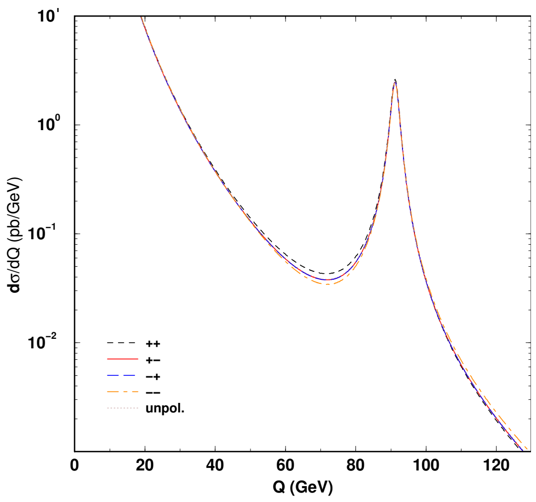
$$\frac{d\hat{\sigma}^{C}(\lambda,h,\lambda_l)}{dQ^2 d\cos\theta^*} = \frac{d\hat{\sigma}^{(0)}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^{**}}\ LB^C \times\left[\frac{\alpha_s}{2\pi}P_{qg}(z;\lambda,h)\ \ln\frac{Q^2}{\kappa^2}\right] + \frac{d\hat{\sigma}^{C,F}}{dQ^2 d\cos\theta^*}$$

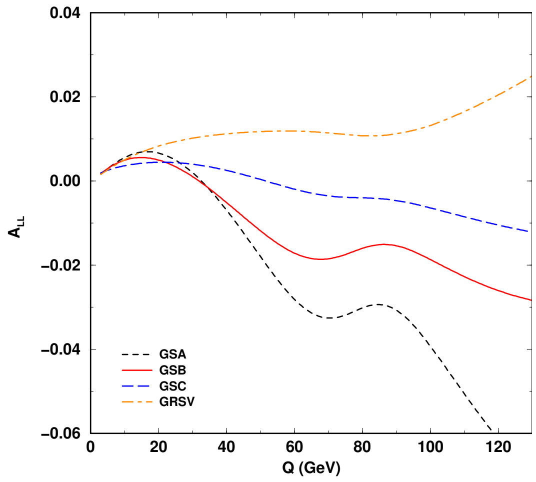
Factorization of Mass Singularity

$$\frac{d\sigma(\lambda_A,\lambda_B,\lambda_l)}{dQ^2 d\cos\theta} = \frac{1}{4}\sum_f\sum_\lambda\int dx_A\int dx_B\left(q_f(x_A,Q^2)+\lambda\lambda_A\Delta q_f(x_A,Q^2)\right) \times\ \left(\bar{q}_f(x_B,Q^2)-\lambda\lambda_B\Delta\bar{q}_f(x_B,Q^2)\right)\left[\frac{d\hat{\sigma}_f^{(0)}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^*}+\frac{d\hat{\sigma}_f^{A+B,F}(\lambda,\lambda_l)}{dQ^2 d\cos\theta^*}\right]$$
$$+\frac{1}{4}\sum_f\sum_{\lambda,h}\int dx_A\int dx_B\left(q_f(x_A,Q^2)+\lambda\lambda_A\Delta q_f(x_A,Q^2)\right) \times\left(g(x_B,Q^2)+h\lambda_B\Delta g(x_B,Q^2)\right)\frac{d\hat{\sigma}_f^{C,F}(\lambda,h,\lambda_l)}{dQ^2 d\cos\theta^*} + (A\leftrightarrow B)$$

♣ Results on Z pole

- Polarized Drell-Yan at RHIC
  - Bourrely and Soffer, PLB 152('93), NPB 423('94)
  - Kamal, PR D57 ('98)
  - ...





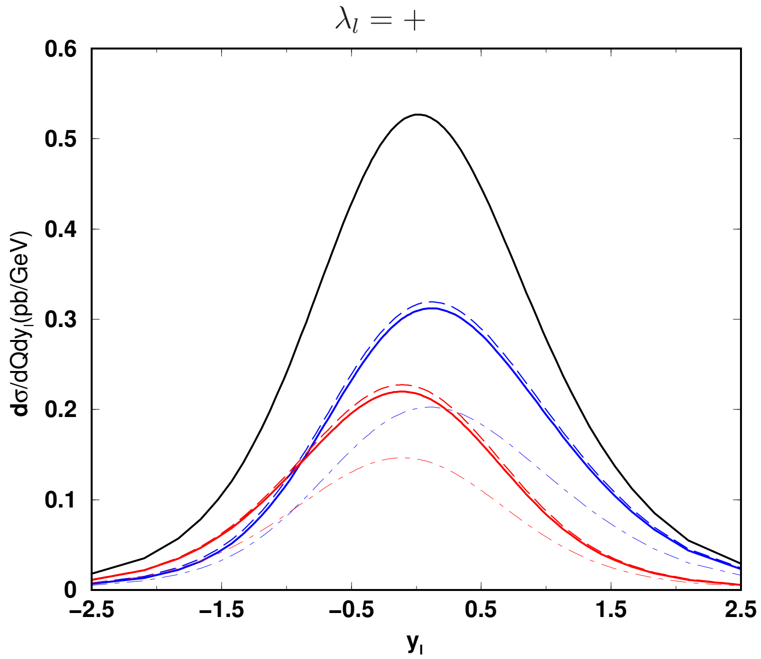
◦ 10pb lepton pair(1-flavor) in 80(GeV)$\leq Q \leq$ 100(GeV)

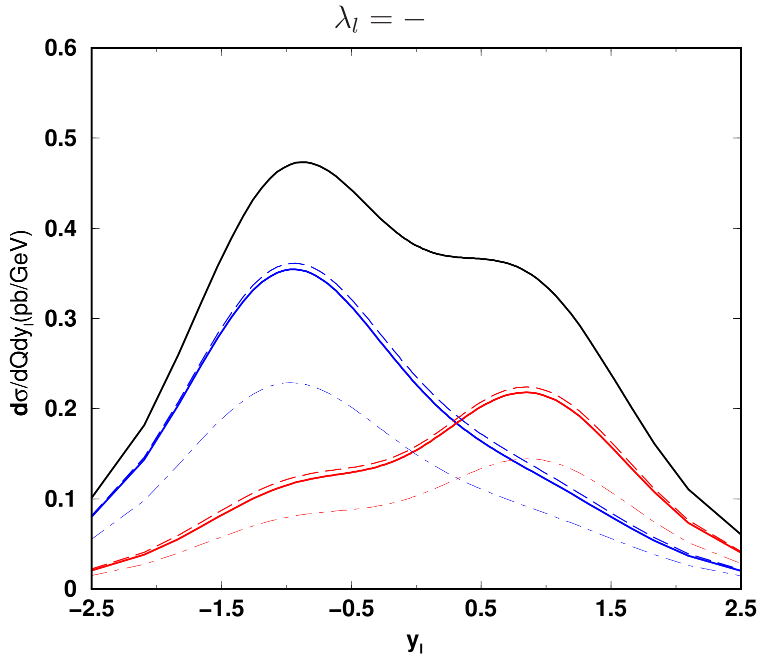
◦ Double Spin Asymmetry

$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-} - d\sigma_{-+} + d\sigma_{--}}{d\sigma_{++} + d\sigma_{+-} + d\sigma_{-+} + d\sigma_{--}}$$

- Helicity Distribution of Lepton
  - $\sqrt{s}$=500GeV, Q =91.2GeV,
  - PDFs: MRST and GRSV

$(\lambda_A\,,\,\lambda_B) = (+\,,\,-)$ Polarization of Protons

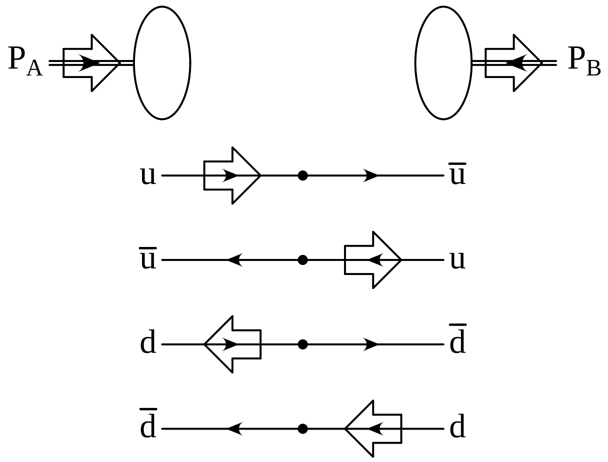




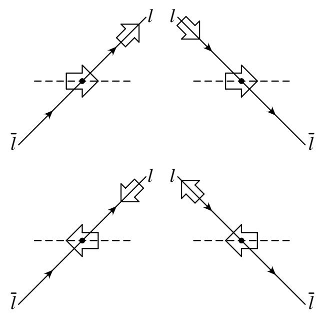
Up Quark , Down Quark

♢ Flavor Contributions and Chiral Structure

1. Polarized PDF : $\Delta u > 0$, $\Delta d < 0$
2. Angular Momentum Conservation
3. V−A Coupling is larger than V+A Coupling
4. Lorentz Boost



PDF

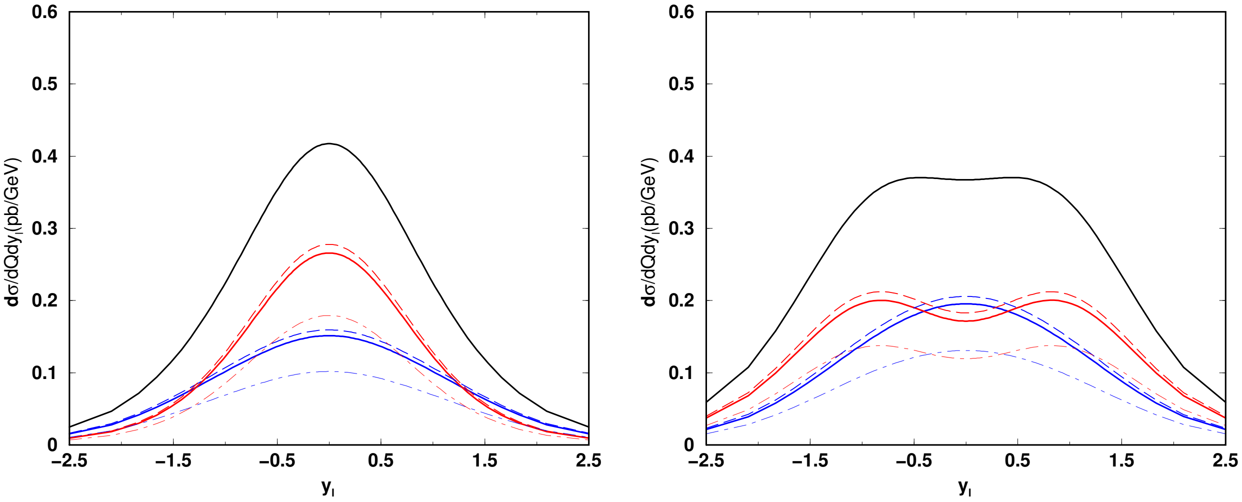


Decay of Z

1. → Dominant Configulation of Quark Spin
2. → Dominant Configulation of Z Spin
   → Dominant Configulation of Decay Lepton
3. → $\bar{u}u$ and $d\bar{d}$ Dominant
4. → $\langle x_{\mathrm{BJ}}\rangle_u \gg \langle x_{\mathrm{BJ}}\rangle_d$

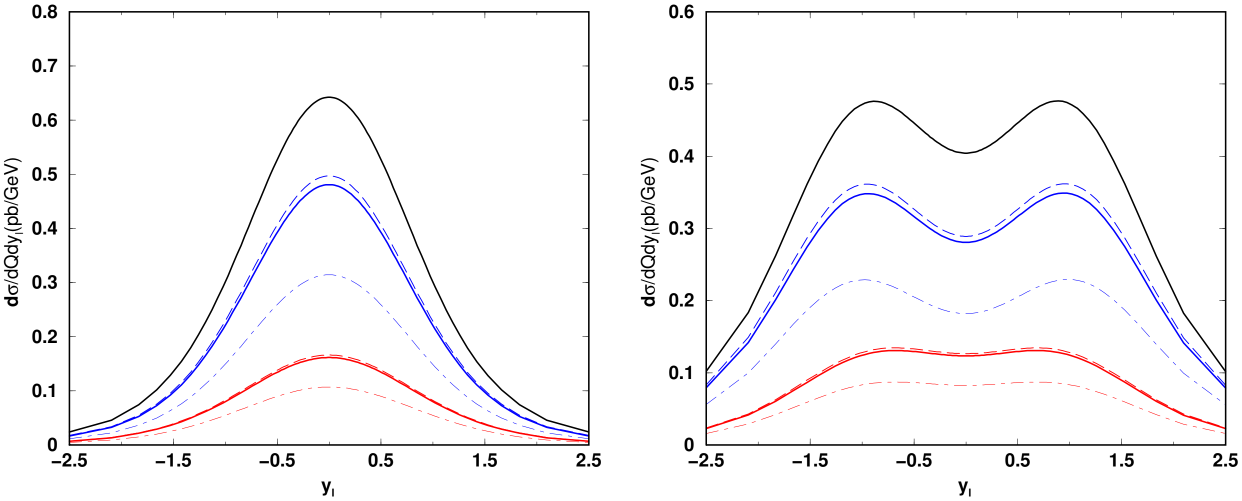
$(\lambda_A\,,\,\lambda_B) = (+\,,\,+)$ Polarization of Protons

$\lambda_l = +$ $\lambda_l = -$



$(\lambda_A\,,\,\lambda_B) = (-\,,\,-)$ Polarization of Protons

$\lambda_l = +$ $\lambda_l = -$

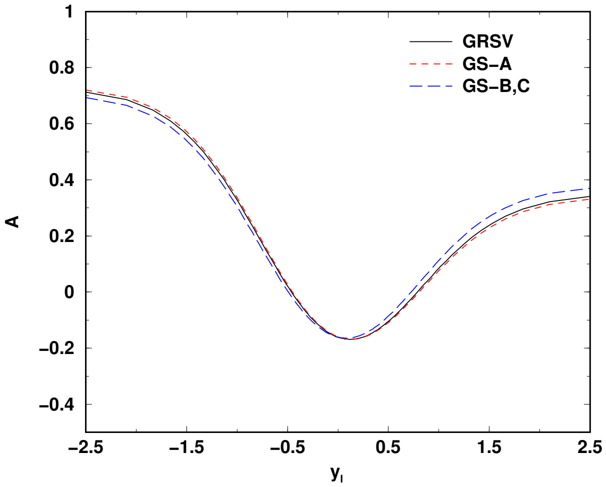


- Lepton Helicity Asymmetry

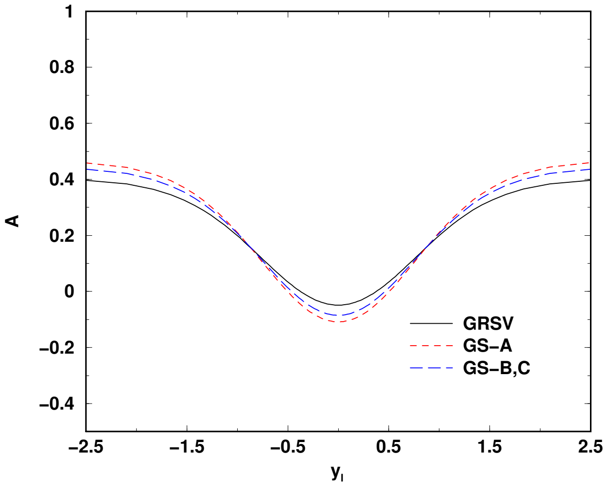
$$A \equiv \frac{d\sigma(\lambda_l = -1) - d\sigma(\lambda_l = +1)}{d\sigma(\lambda_l = -1) + d\sigma(\lambda_l = +1)}$$

With MRST, GRSV and GS(A,B,C) Parametrizations

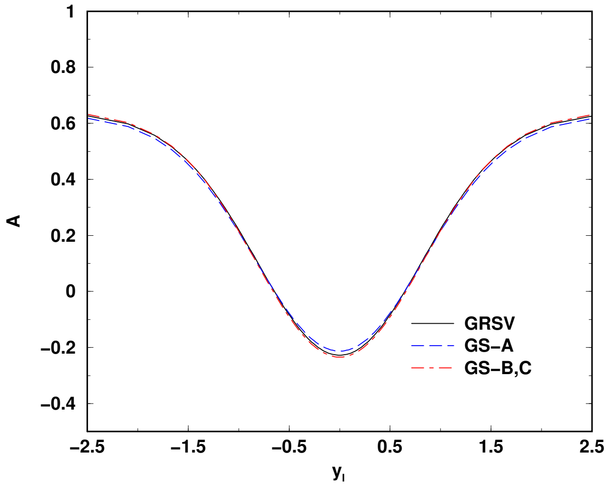
$(\lambda_A\,,\,\lambda_B) = (+\,,\,-)$



$(\lambda_A\,,\,\lambda_B) = (+\,,\,+)$



$(\lambda_A\,,\,\lambda_B) = (-\,,\,-)$



♣ Summary

- Measuring the Polarized Drell-Yan Process

$\Downarrow$

Meaningful to investigate both
Soft Part(PDFs) and Hard Part

- Lepon Helicity and Angular Distributions in Polarized Drell-Yan Process up to $\mathcal{O}(\alpha_s)$ was Calculated
- Numerical Results on Z Pole was Reported
- Flavor Decomposition was Studied
- Large Asymmetry of Lepton Helicity
- PDF Dependence is Weak (Unfortunately!!)
- Scheme Dependence
  Must Convert Factorization Scheme to $\overline{\text{MS}}$

Not Yet Done
Expected Numerically Small

- Theoretically Some Interests

but

Experimentally Difficult!?