Collins Asymmetry at RHIC

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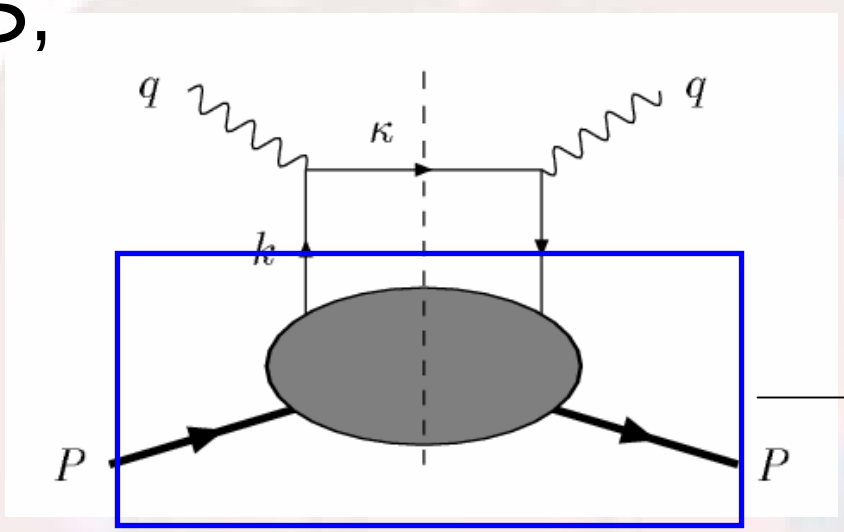
Outline

- Transversity in general
- Collins Mechanism
- Collins asymmetry in Hadronic reactions
- Universality of the Collins function
- Conclusion

Parton distributions

- In DIS,



→ **Quark distribution matri**
Φ(P,k)

$$W^{\mu\nu} = \int d^4k \,\mathrm{Tr}\,[\Phi(P,k)\gamma^\mu(\not{k}+\not{q})\gamma^\nu]$$

$$\Phi_{\alpha\beta}(P,k) = \int \frac{d^4\xi}{(2\pi)^4} e^{-ik\cdot\xi}\langle PS|\overline{\psi}_\beta(\xi)\psi_\alpha(0)|PS\rangle$$

Gauge links

Leading order quark distribution

- $\Phi_{\alpha\beta}$ expands at leading order,

$$\Phi_{\alpha\beta}(P,k) = \frac{1}{2}[q(x)\gamma_\mu P^\mu \longleftarrow \text{Unpolarized}$$
$$+\Delta q_L(x)\lambda\gamma_5\gamma_\mu P^\mu \longleftarrow \text{helicity}$$
$$+\delta q_T(x)\gamma_5 \not{P} \not{S}_T] \longleftarrow \text{transversity}$$

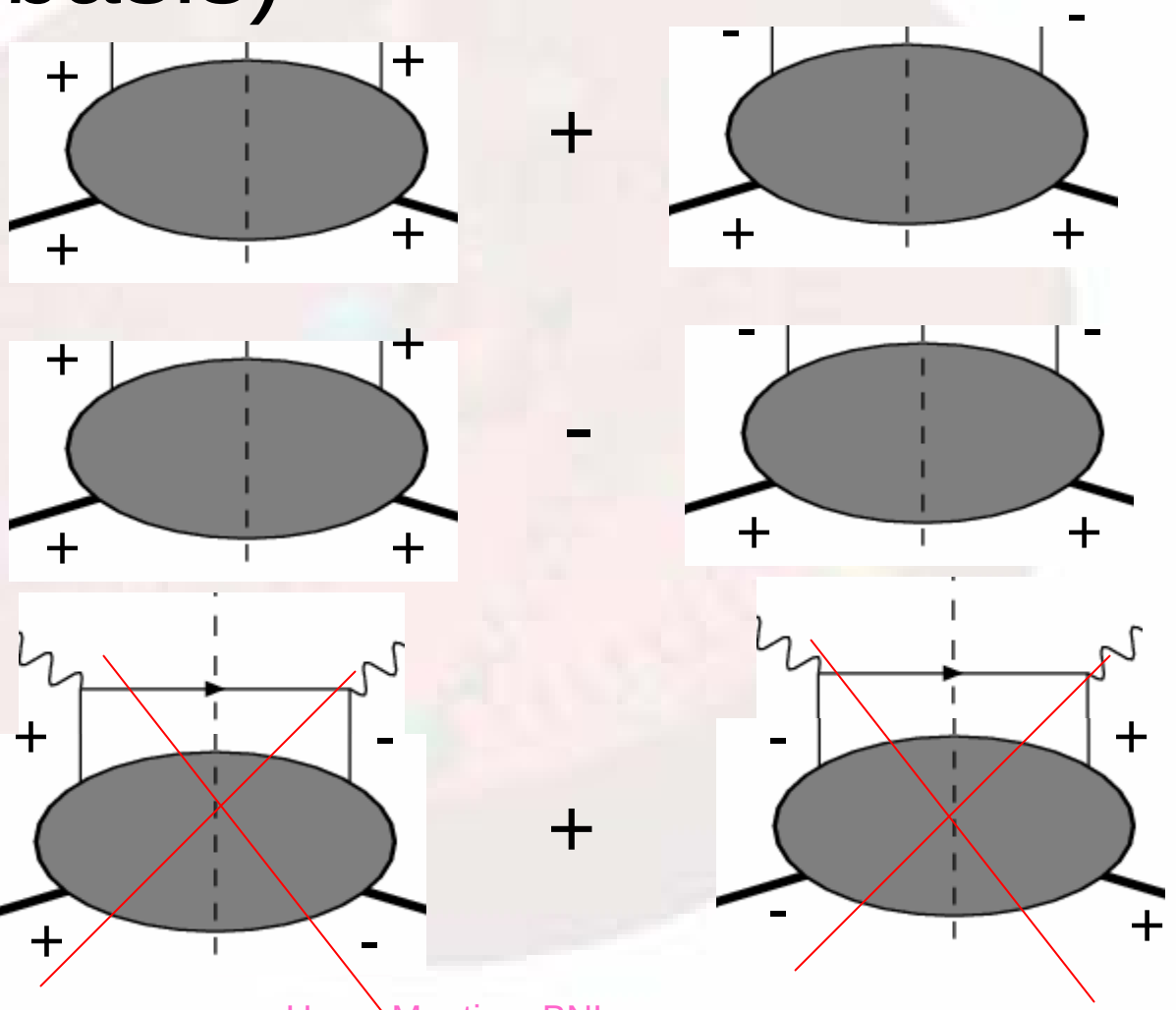
- Although a leading-twist distribution, transversity is chiral-odd, and doesn't contribute to the DIS structure function

Probability representation (helicity basis)

q(x)

Δq_L

δq_T
$(h_1, \Delta_T q)$

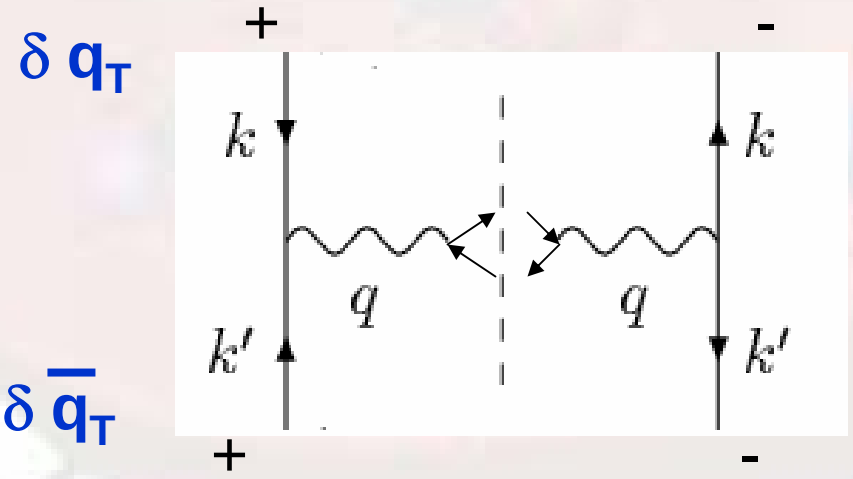


Measuring transversity is difficult

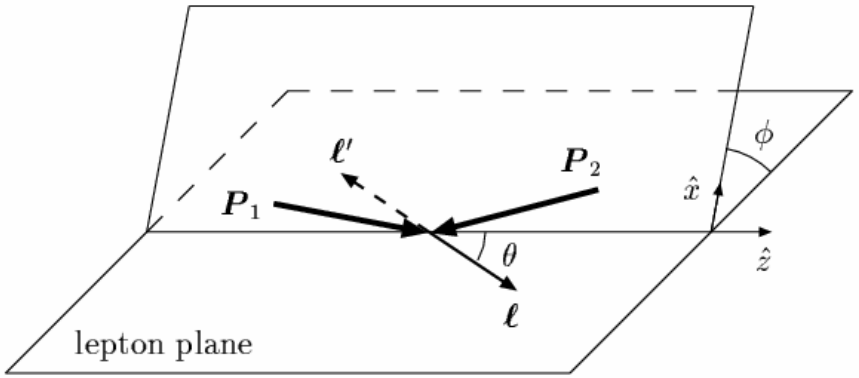
- Have to multiply another chiral-odd object (distribution or fragmentation)
  - Drell-Yan and other processes in hadronic collisions
  - Two-hadron production in DIS
  - Semi-inclusive single hadron production in DIS

Drell-Yan is an ideal place

- Combining two transversity distributions in Drell-Yan lepton pair production



Angular distribution of the lepton pair

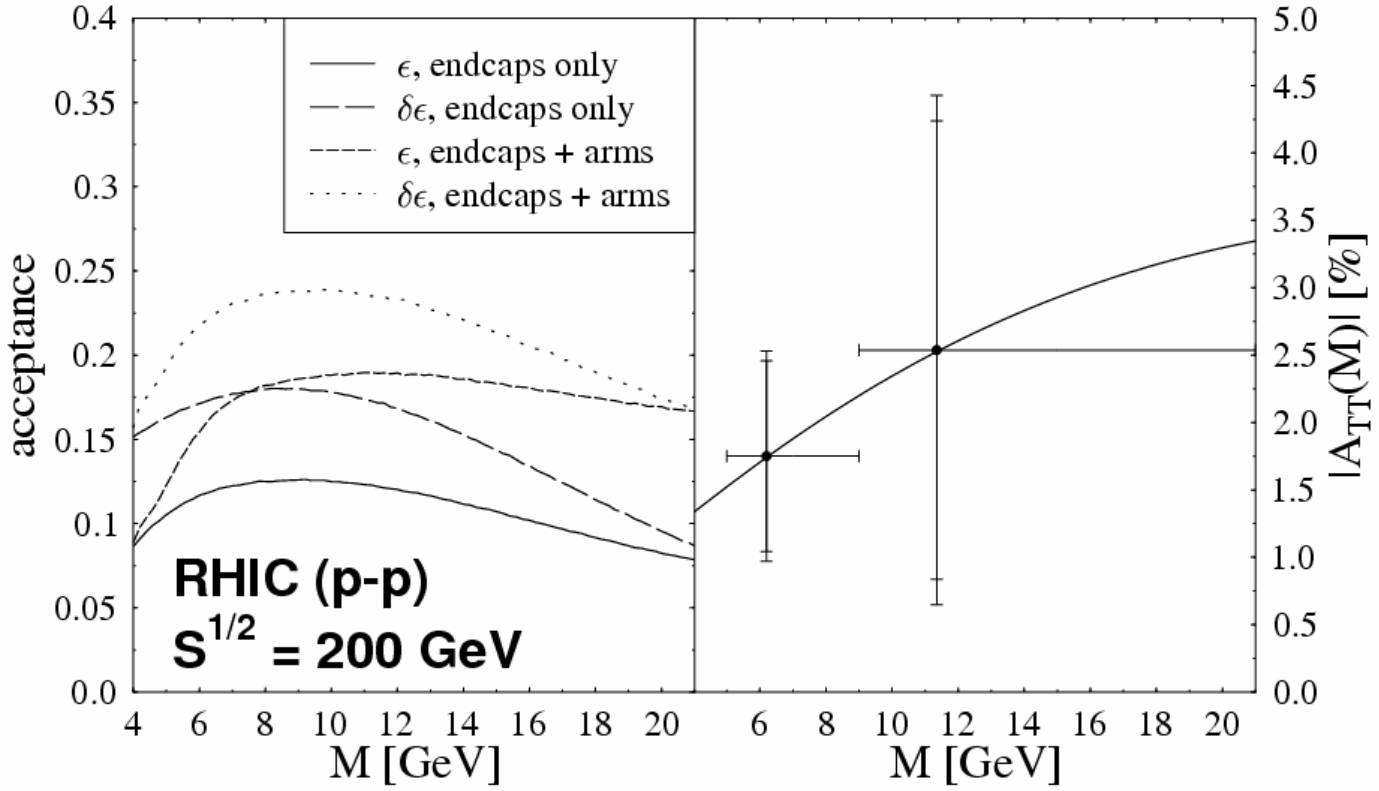


- Double transverse spin asymmetry

$$A_{TT}^{\mathrm{DY}} = \frac{\mathrm{d}\sigma(\boldsymbol{S}_{1\perp}, \boldsymbol{S}_{2\perp}) - \mathrm{d}\sigma(\boldsymbol{S}_{1\perp}, -\boldsymbol{S}_{2\perp})}{\mathrm{d}\sigma(\boldsymbol{S}_{1\perp}, \boldsymbol{S}_{2\perp}) + \mathrm{d}\sigma(\boldsymbol{S}_{1\perp}, \boldsymbol{S}_{2\perp})}$$
$$= |\boldsymbol{S}_{1\perp}||\boldsymbol{S}_{2\perp}| \frac{\sin^2\theta \, \cos(2\phi - \phi_{S_1} - \phi_{S_2})}{1 + \cos^2\theta}$$
$$\times \frac{\sum_a e_a^2 \, \Delta_T f_a(x_1) \Delta_T \bar{f}_a(x_2) + [1 \leftrightarrow 2]}{\sum_a e_a^2 \, f_a(x_1) \bar{f}_a(x_2) + [1 \leftrightarrow 2]}$$

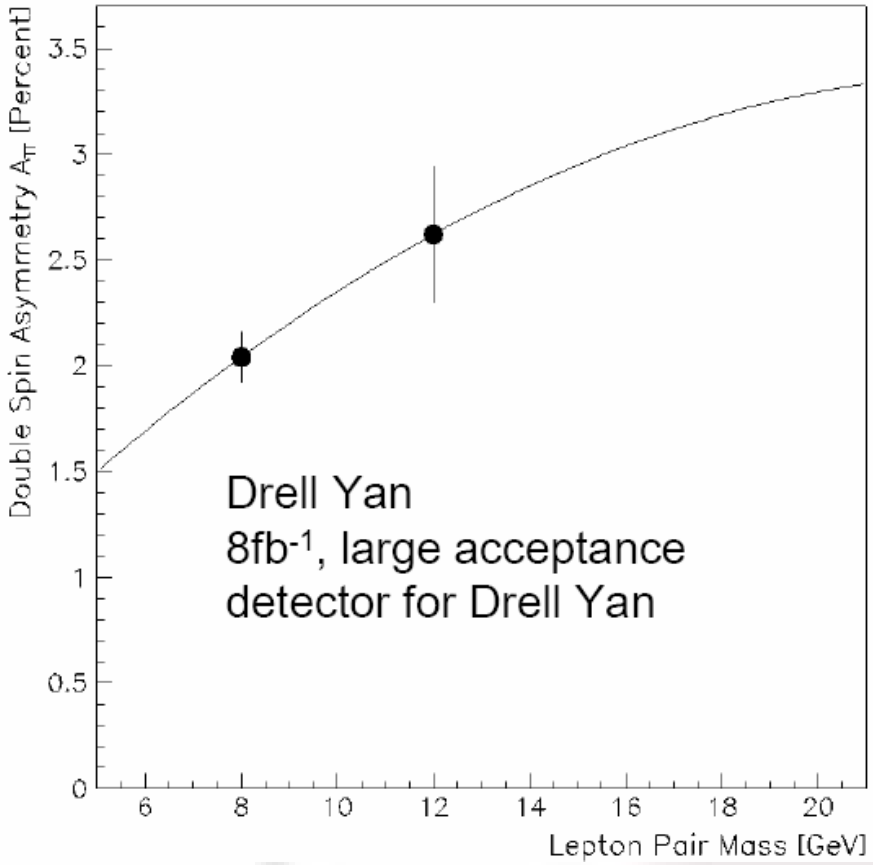
RIKEN BNL Research Center

Predictions at RHIC



Vogelsang, et al, PRD, 1999

Dedicated Drell-Yan study at RHIC II

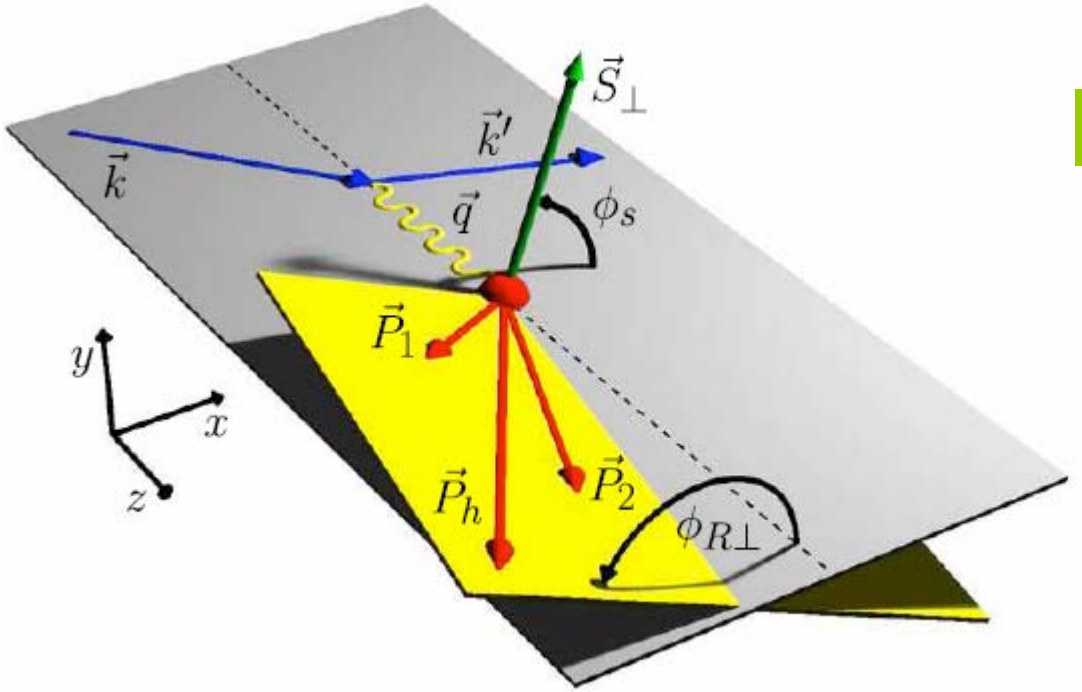


projections for 10 weeks of running, 5-10% higher polarization, with RHIC II luminosities and large acceptance

Matthias Grosse-Perdekamp

Two-hadron interference frag. fun.

- In DIS



Seidl's talk

$$A_{UT}(\phi_{R\perp},\phi) \propto \delta q_T(x) H_1^{\pi\pi}(z, M_{\pi\pi}^2)$$

Collins,Heppelmann,Ladinsky, 94
Jaffe,Jin,Tang, 97
Bacchetta,Radici, 04,06

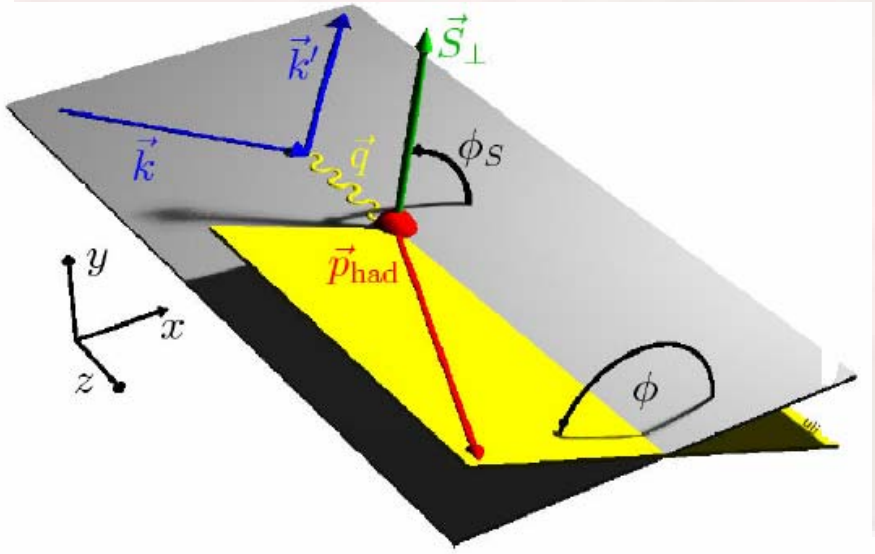
Semi-inclusive DIS

- Collins fragmentation function is chiral-odd

- Combining with the quark transversity leads to single transverse-spin asymmetry in SIDIS
- Opening a whole window of SSAs in SIDIS

Semi-Inclusive DIS at Low P_T

- Transverse Momentum Dependent (TMD) Parton Distributions
- Novel Single Spin Asymmetries

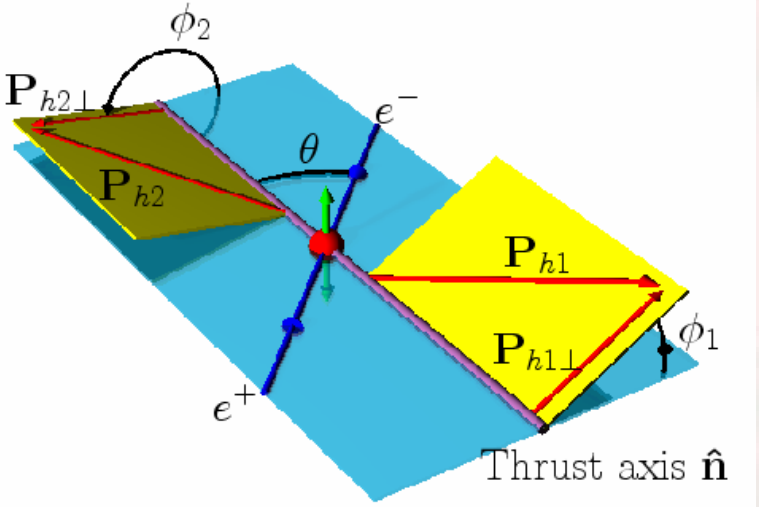


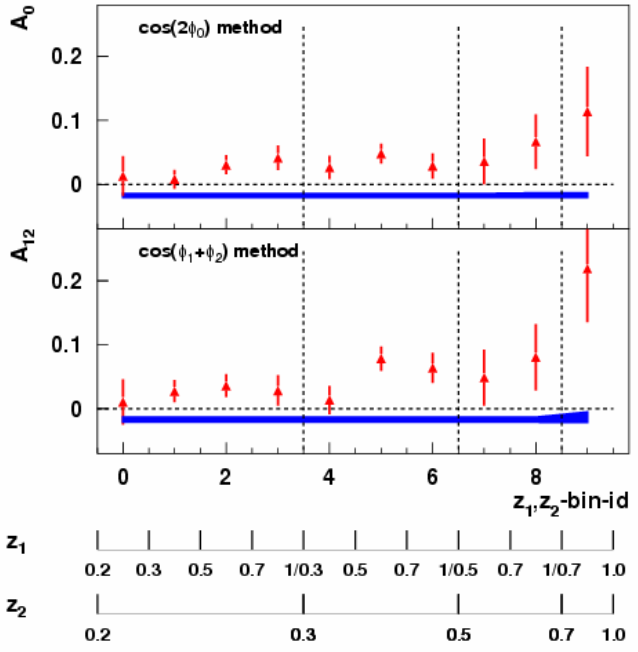
Interested kinematics:
$Q^2 \gg P_{?}$,
Forward $x_F > 0.1$

Seidl' talk

e^+e^- collisions play important roles in this game

- Reliable place to extract the information on the Collins function and the interference (two-hadron) fragmentation function





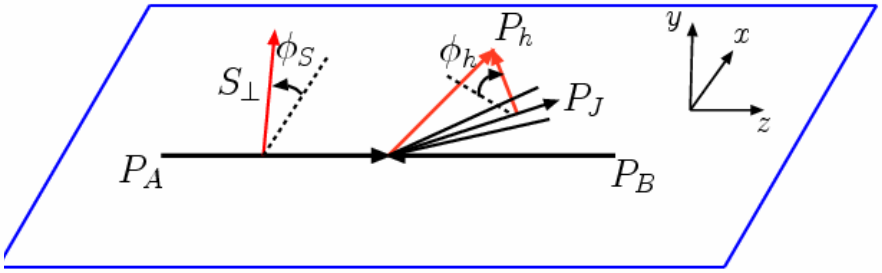
Grosse-Perdekamp's talk

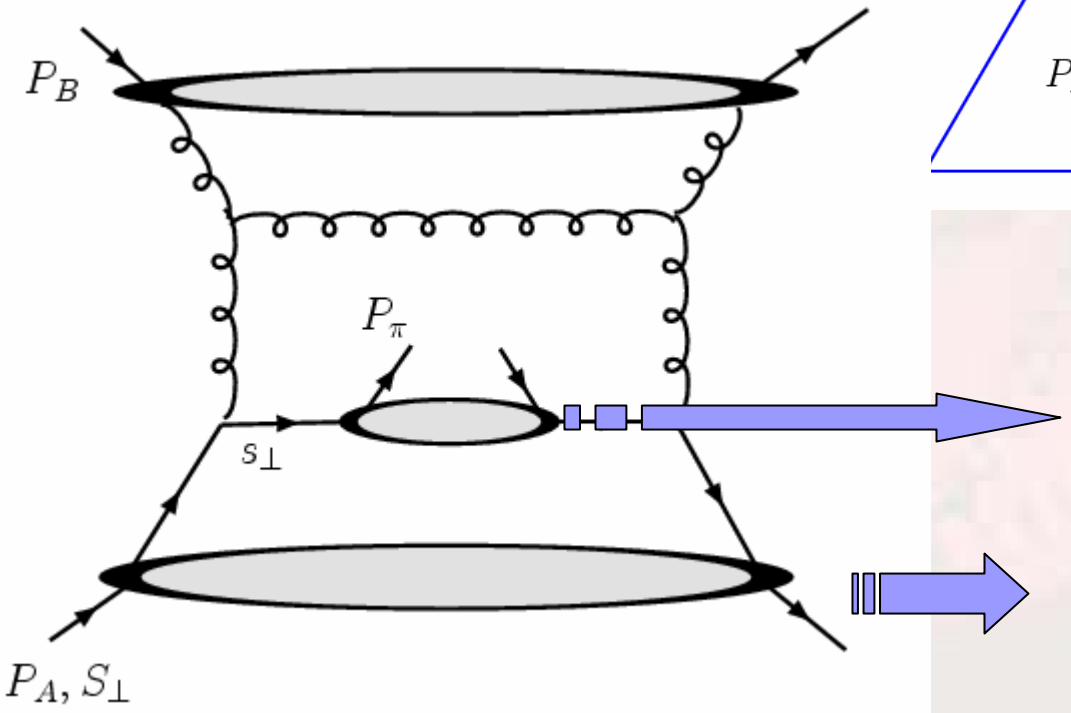
Belle Col., PRL 06

Collins asymmetry in pp collisions

- Collins-Heppelmann effect
  - Collins-Heppelmann-Ladinsky, 94
- Transverse-spin transfer in hard partonic scattering
  - Stratmann-Vogelsang, 92

Azimuthal distribution of hadrons inside a jet (large P_T)





Collins Fragmentation function

Quark transversity distribution

Vogelsang,Yuan, to appear

Differential cross section

$$\frac{d\sigma(S_\perp)}{d\mathcal{P}.\mathcal{S}.} = \sum_{b=q,g} x' f_b(x') x \delta q_T(x) \delta\hat{q}(z_h, P_{hT}) \frac{\epsilon^{\alpha\beta} S_\perp^\alpha}{M_h}$$
$$\times \left[P_{hT}^\beta - \frac{P_B \cdot P_{hT}}{P_B \cdot P_J} P_J^\beta \right] \times H_{qb\to qb}^{\text{Collins}} ,$$

$$d\mathcal{P}.\mathcal{S}. = dy_1 dy_2 dP_\perp^2 dz d^2 P_{hT}$$

δq_T --- quark transversity

$\delta\hat{q}$ --- Collins fragmentation function

P_J --- Jet's momentum

P_{hT} --- hadron's momentum relative to the jet

$H_{qb->qb}^{Collins}$ --- Hard partonic cross sections

Azimuthal dependence

$$\epsilon^{\alpha\beta} S_\perp^\alpha \left[P_{hT}^\beta - \frac{P_B \cdot P_{hT}}{P_B \cdot P_J} P_J^\beta \right] = |S_\perp||P_{hT}| \sin(\phi_h - \phi_S)$$

ϕ_S: azimuthal angle of $S_?$ relative to the reaction plane
ϕ_h: azimuthal angle of hadron's transverse momentum

$$\frac{d\sigma}{d\mathcal{P}.\mathcal{S}.} = \frac{d\sigma_{UU}}{d\mathcal{P}.\mathcal{S}.} + |S_\perp| \frac{|P_{hT}|}{M_h} \sin(\phi_h - \phi_s) \frac{d\sigma_{TU}}{d\mathcal{P}.\mathcal{S}.}$$

$$\frac{d\sigma_{UU}}{d\mathcal{P}.\mathcal{S}.} = \sum_{a,b,c} x' f_b(x') x f_a(x) D_c^h(z, P_{hT}) H_{ab\to cd}^{uu} \Longrightarrow d\hat{\sigma}^{uu}/d\hat{t}$$

$$\frac{d\sigma_{TU}}{d\mathcal{P}.\mathcal{S}.} = \sum_{b,q} x' f_b(x') x \delta q_T(x) \delta\hat{q}(z, P_{hT}) H_{qb\to qb}^{\text{Collins}} \Longrightarrow$$

Stratmann-Vogelsang, 92
Collins-Heppelmann-Ladinsky, 94

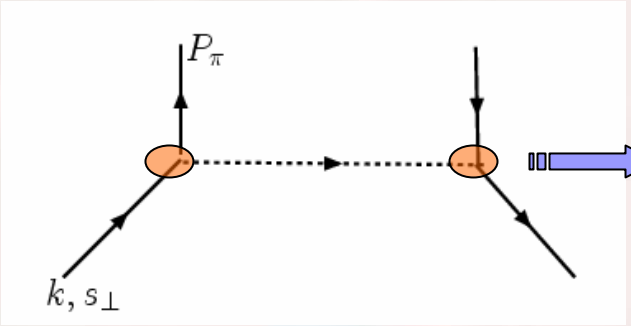
Predictions for RHIC

- Quark transversity distribution
  - Martin-Schafer-Stratmann-Vogelsang, 98
  - Anselmino et al., 07
- Collins fragmentation function
  - HERMES measurements
  - Vogelsang-Yuan extraction

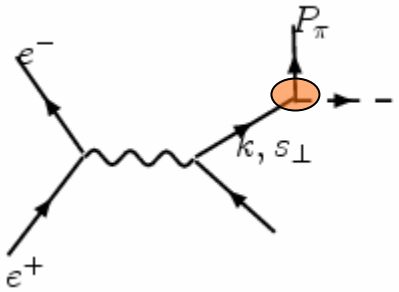
One more thing …

- Universality of the Collins fragmentation function
  - Metz, 02
  - Boer-Mulders-Pijlman, 03
  - Collins-Metz, 04
  - Gamberg-Goldstein, 02-05
  - …

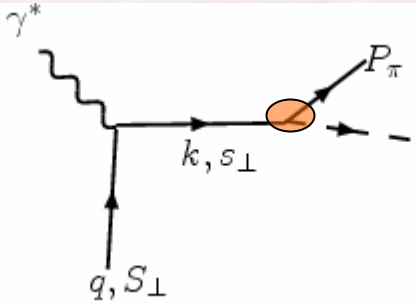
Simple model a la Collins 93



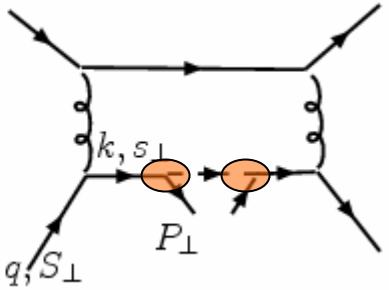
Phase information in the vertex
Collins-93



e⁺e⁻ annihilation



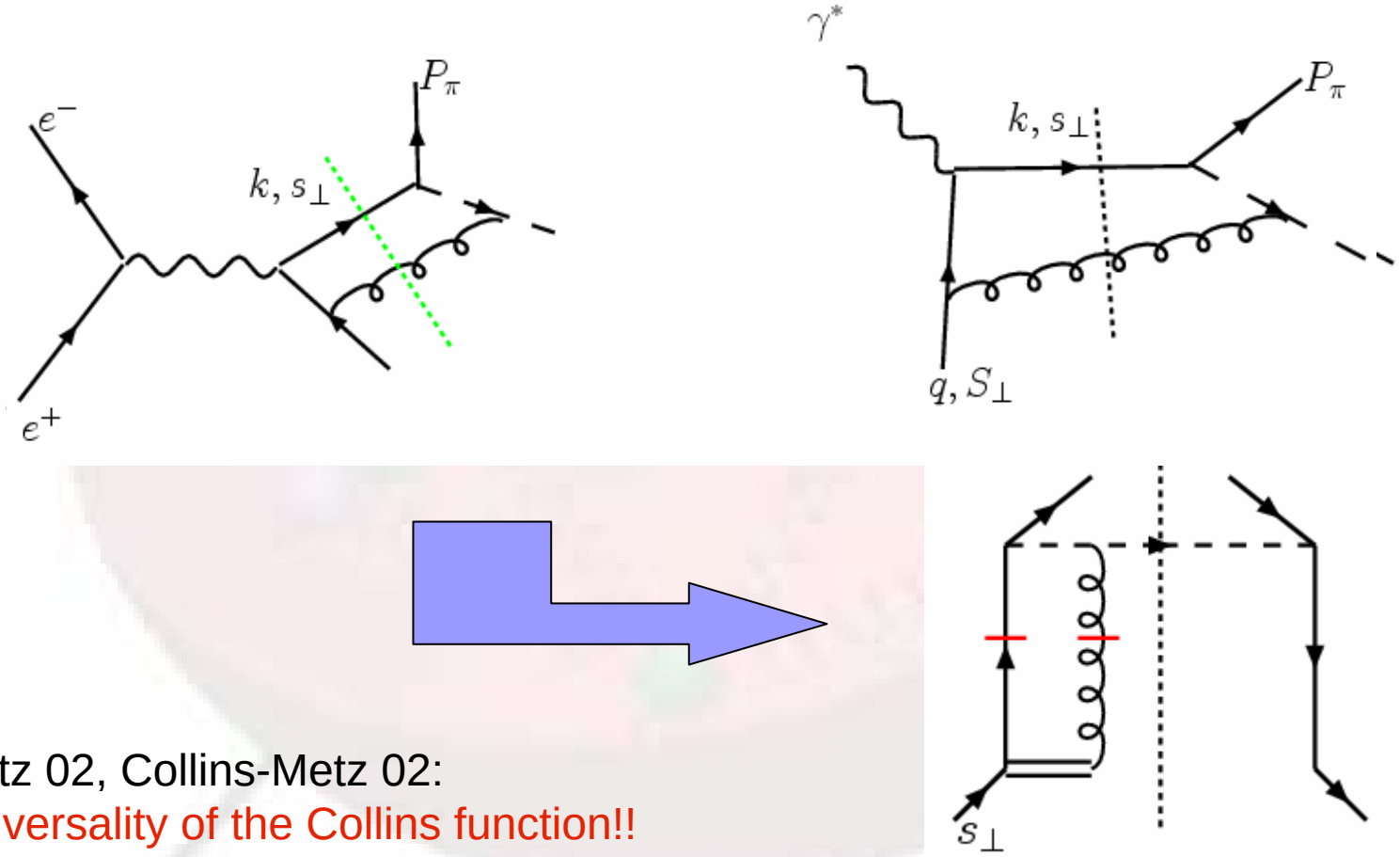
Semi-inclusive DIS



Hadron in a jet in pp

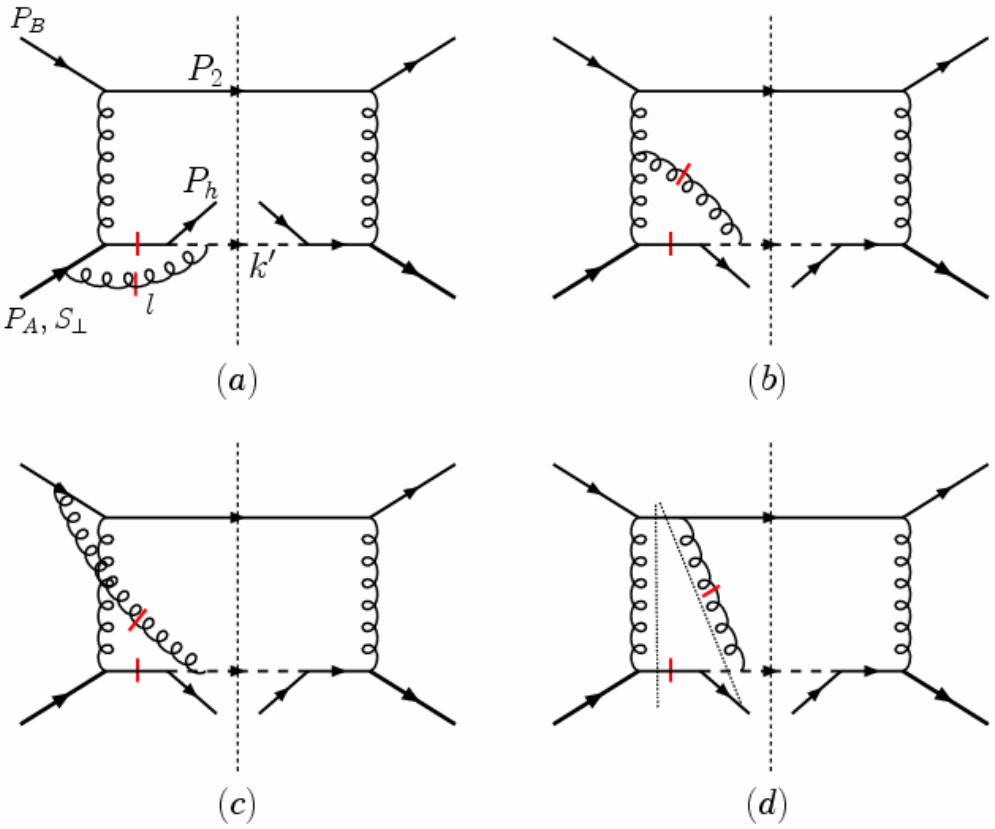
Universality of the Collins Function!!

One-gluon exchange (gauge link)?

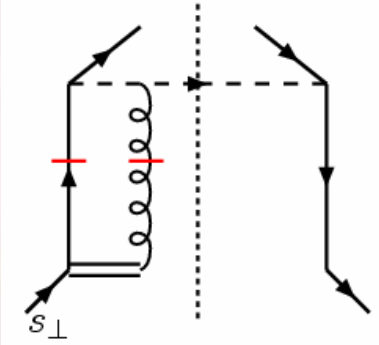


Metz 02, Collins-Metz 02:
Universality of the Collins function!!

Similar arguments for pp collisions



By using the Ward Identity:

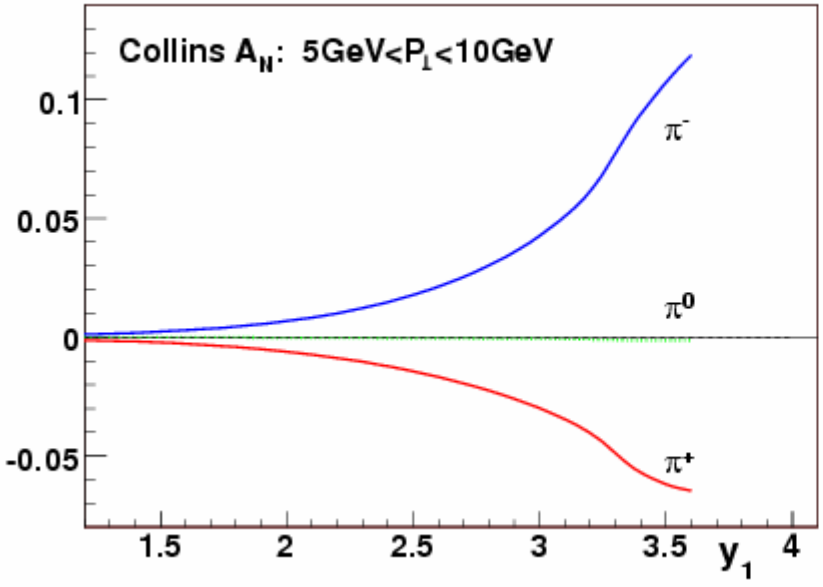


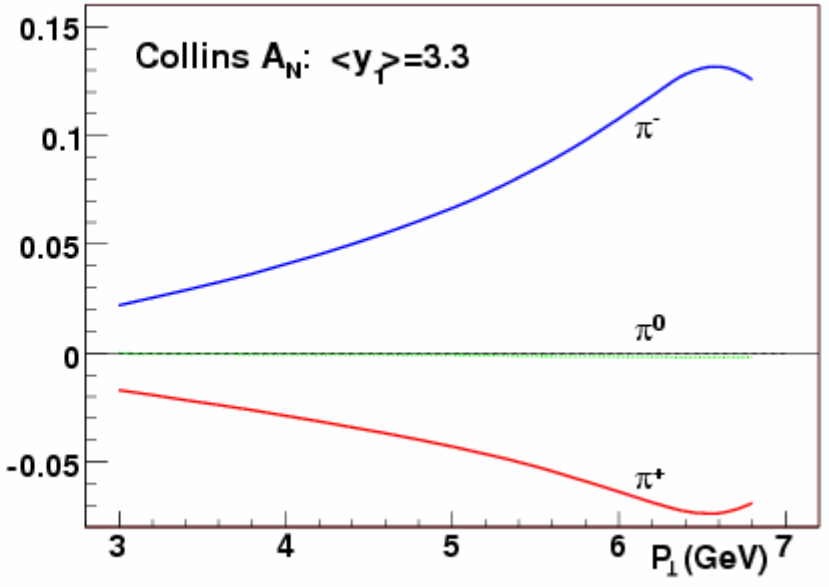
same Collins fun.

Conjecture: the Collins function will be the same as e^+e^- and SIDIS

Predictions at RHIC

$$d\sigma \propto 1 + A_N \sin(\phi_h - \phi_S)$$





Quark transversity: Martin-Schafer-Stratmann-Vogelsang, 98
Collins function: fit to the HERMES data, Vogelsang-Yuan, 05

Conclusion

- We propose to study quark transversity from the hadron azimuthal distribution in a jet in pp collisions
- We argue that the Collins function is the same as that in e^+e^- and DIS processes
- Measurements at RHIC will provide a crucial test for this Universality

Model for Collins Functions

- Two sets of parameterizations

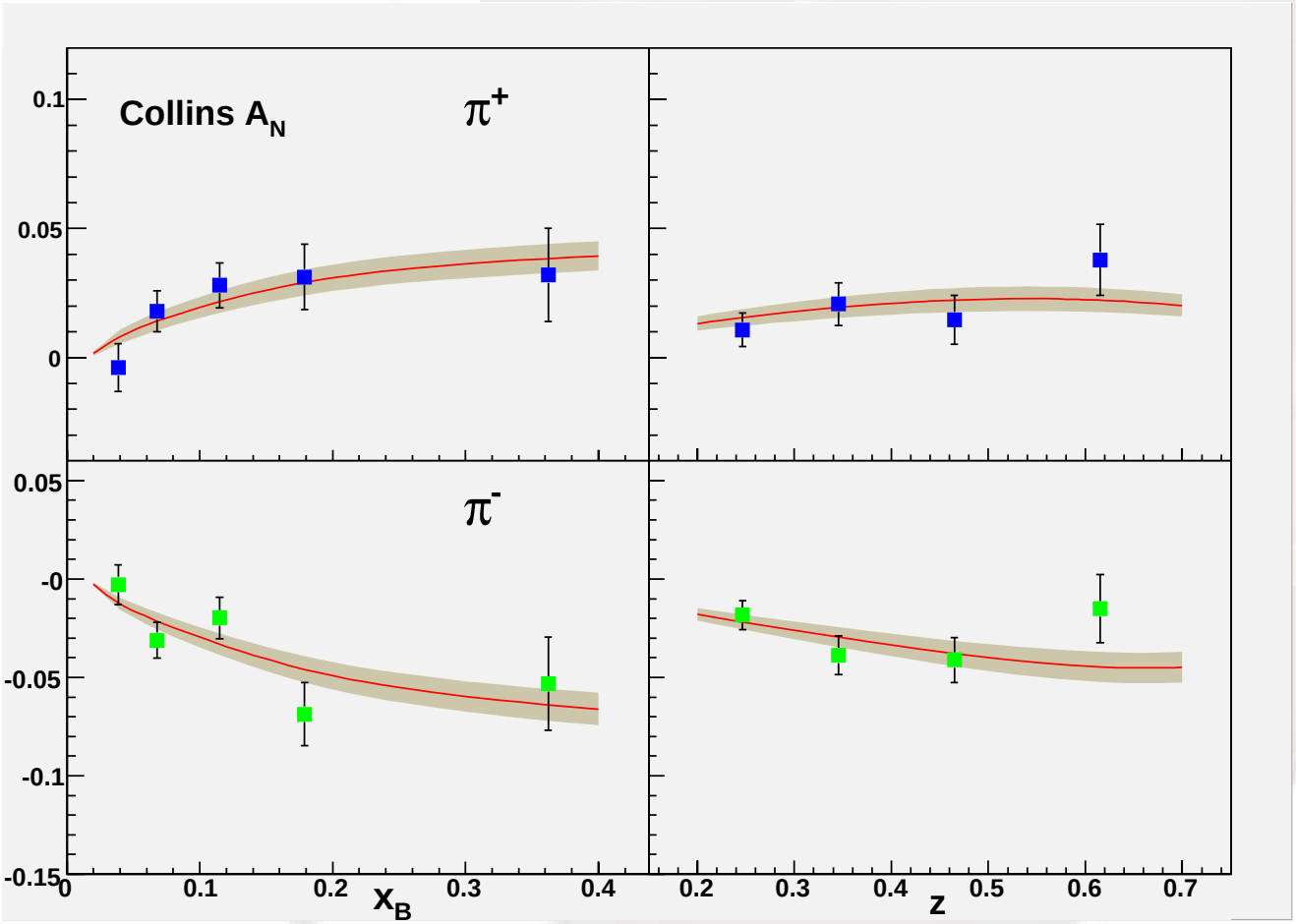
$$\begin{aligned}
\text{Set I}: \quad \delta\widehat{q}^{\pi(1/2)}_{favor}(z) &= C_f z(1-z)\widehat{u}^{\pi^+}(z) \\
\delta\widehat{q}^{\pi(1/2)}_{unfavor}(z) &= C_d z(1-z)\widehat{u}^{\pi^+}(z) \\
\text{Set II}: \quad \delta\widehat{q}^{\pi(1/2)}_{favor}(z) &= C_f z(1-z)\widehat{u}^{\pi^+}(z) \\
\delta\widehat{q}^{\pi(1/2)}_{unfavor}(z) &= C_d z(1-z)\widehat{d}^{\pi^+}(z)
\end{aligned}$$

Collins function vanishes at z→0

(1-z) comes from Collins 93'

- Transversity functions use the parameterization of Martin, Schafer, Stratmann, and Vogelsang, PRD 57(1998)

Set I Fit to HERMES

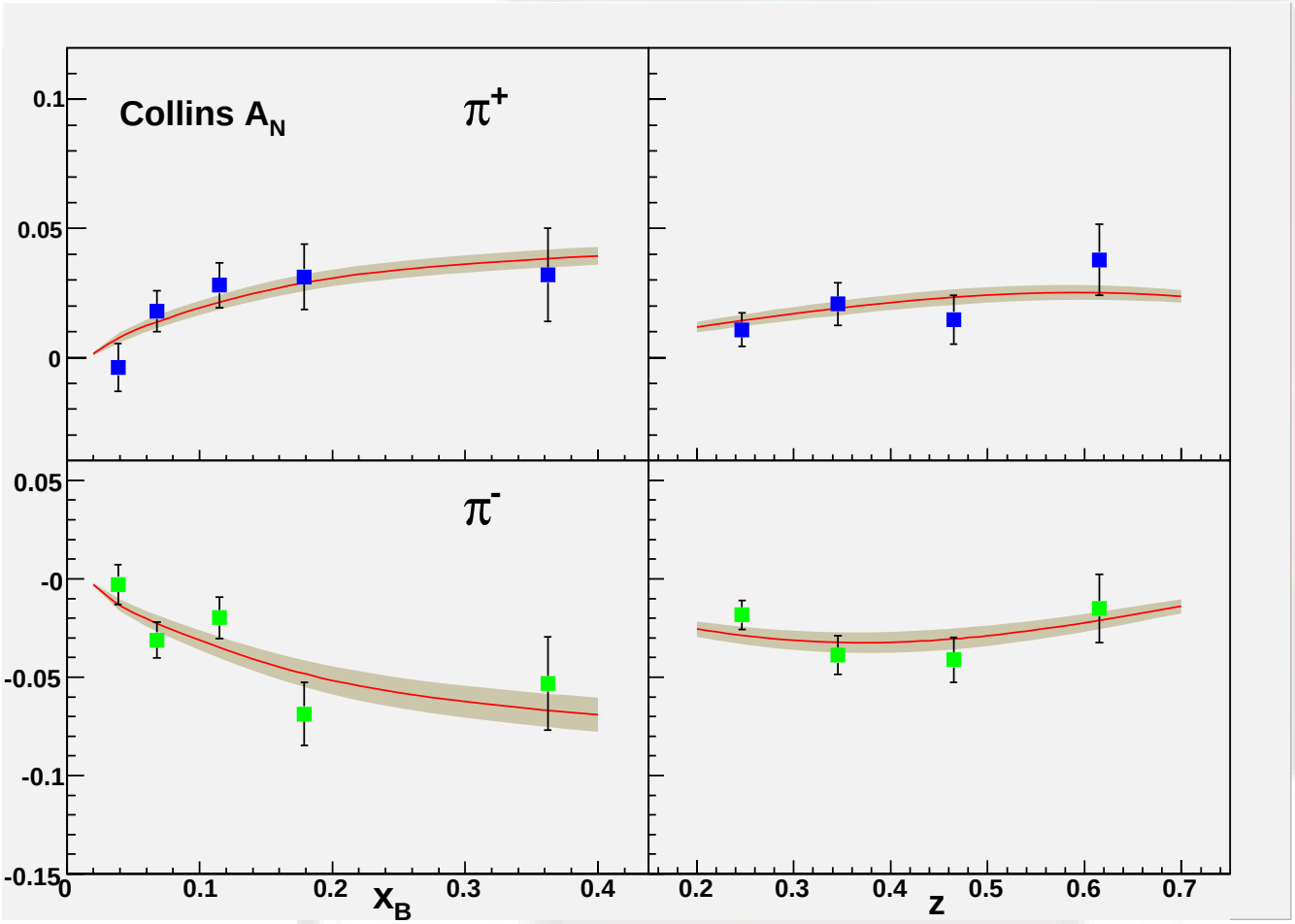


$C_f = 0.29 \pm 0.04$

$C_d = -0.33 \pm 0.04$

$\chi^2/\text{d.o.f} \approx 0.8$

Set II Fit

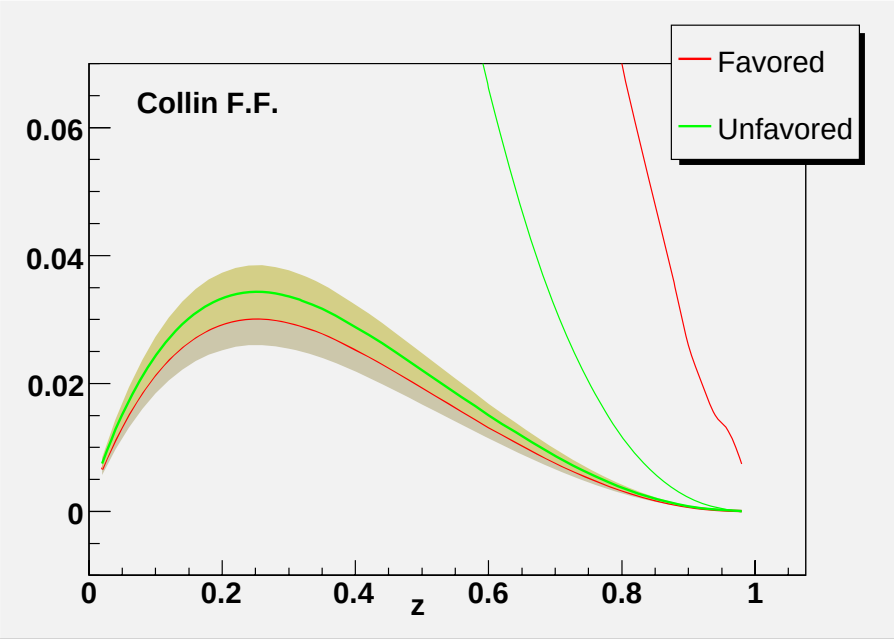


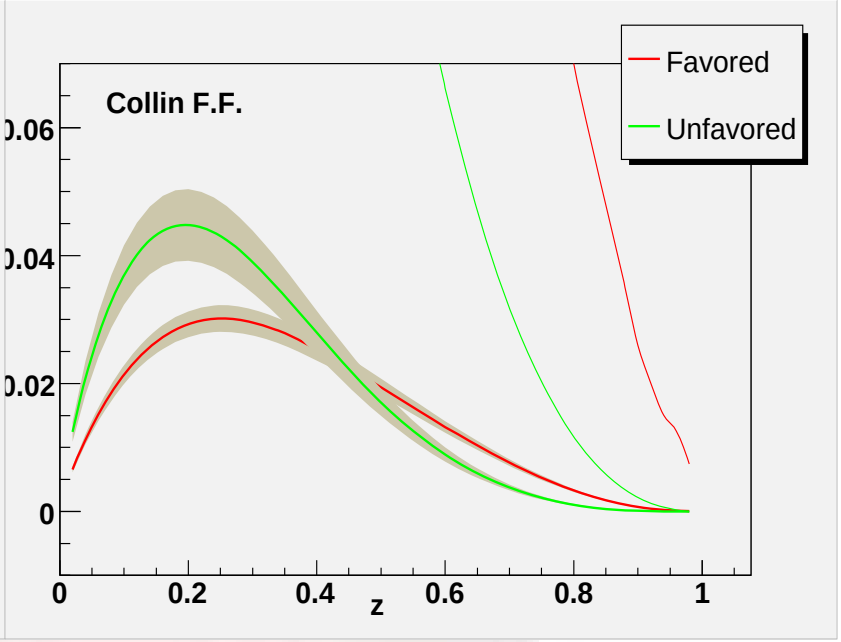
$C_f = 0.29 \pm 0.02$

$C_d = -0.56 \pm 0.07$

$\chi^2/\text{d.o.f} \approx 0.7$

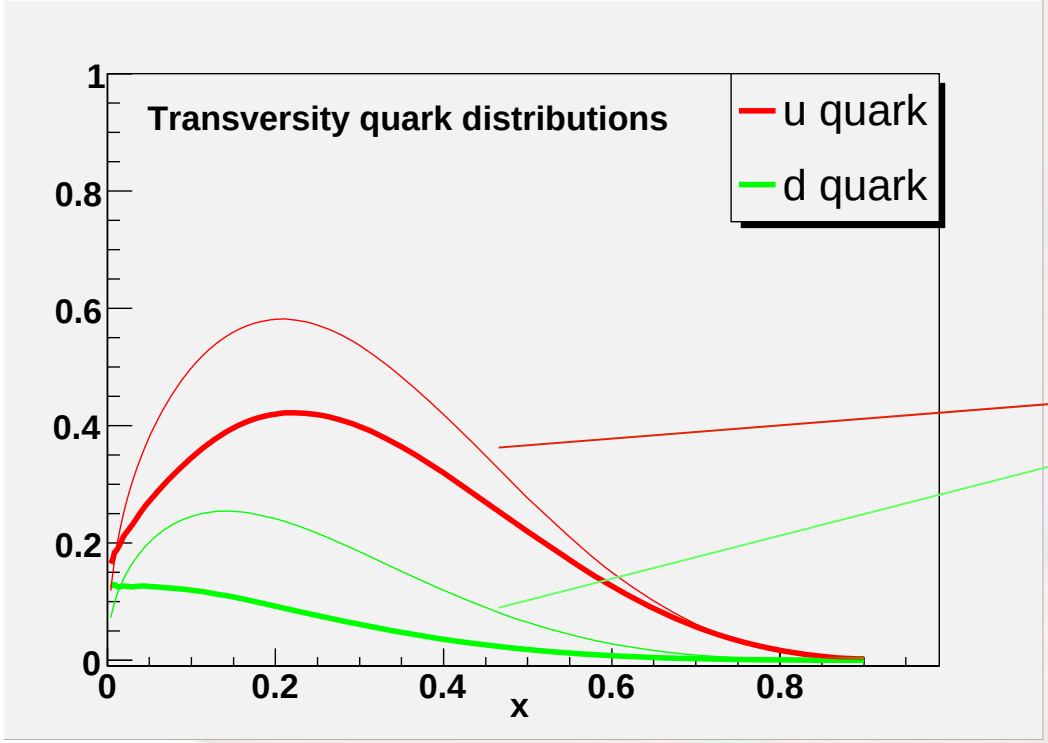
Fitted Collins Functions





Set I **Set II**

Transversity functions in the fit



Unpolarized quark distributions

If we get Collins functions from other processes, e.g., e^+e^-, we can constrain the transversity functions !!