News on Spin

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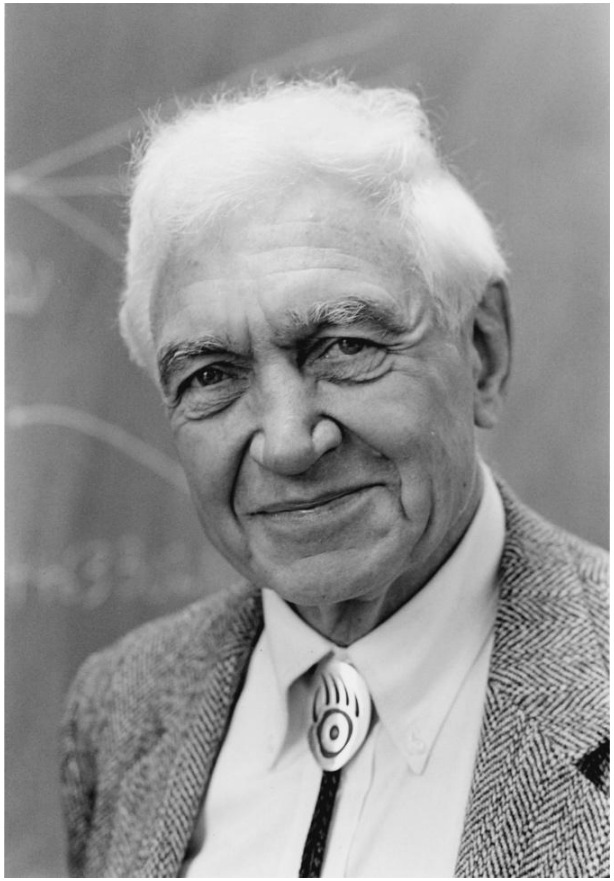
RIKEN-BNL Research Center / BNL Nuclear Theory

DIS 03, April 23, 2003

Purposes of this talk :

- summarize latest status and main new developments in the field
- introduction to (some of) the talks in WG E

parallel session organizers Anselmino / van der Steenhoven



Vernon W. Hughes (1921-2003)

Outline :

Part I : Nucleon Helicity Structure

- What we know, and what we'd like to know
- Today's facilities & experiments in Spin Physics
- Recent results & future prospects

Part II : Transverse-Spin Phenomena

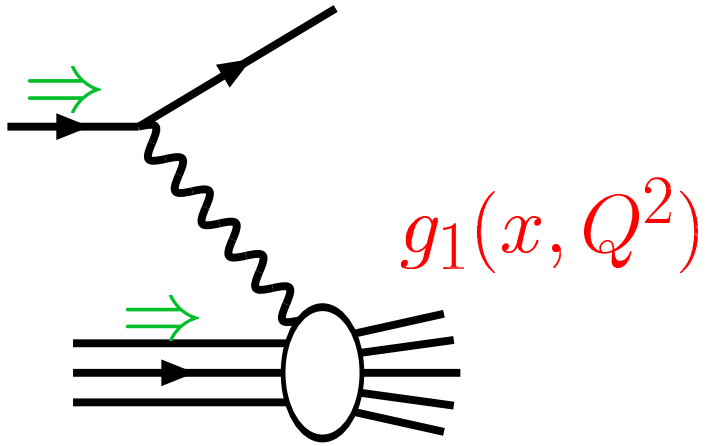
- Transversity
- Single-spin asymmetries
- Developments in $\sim$ past year

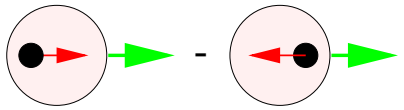
Part I : Nucleon Helicity Structure

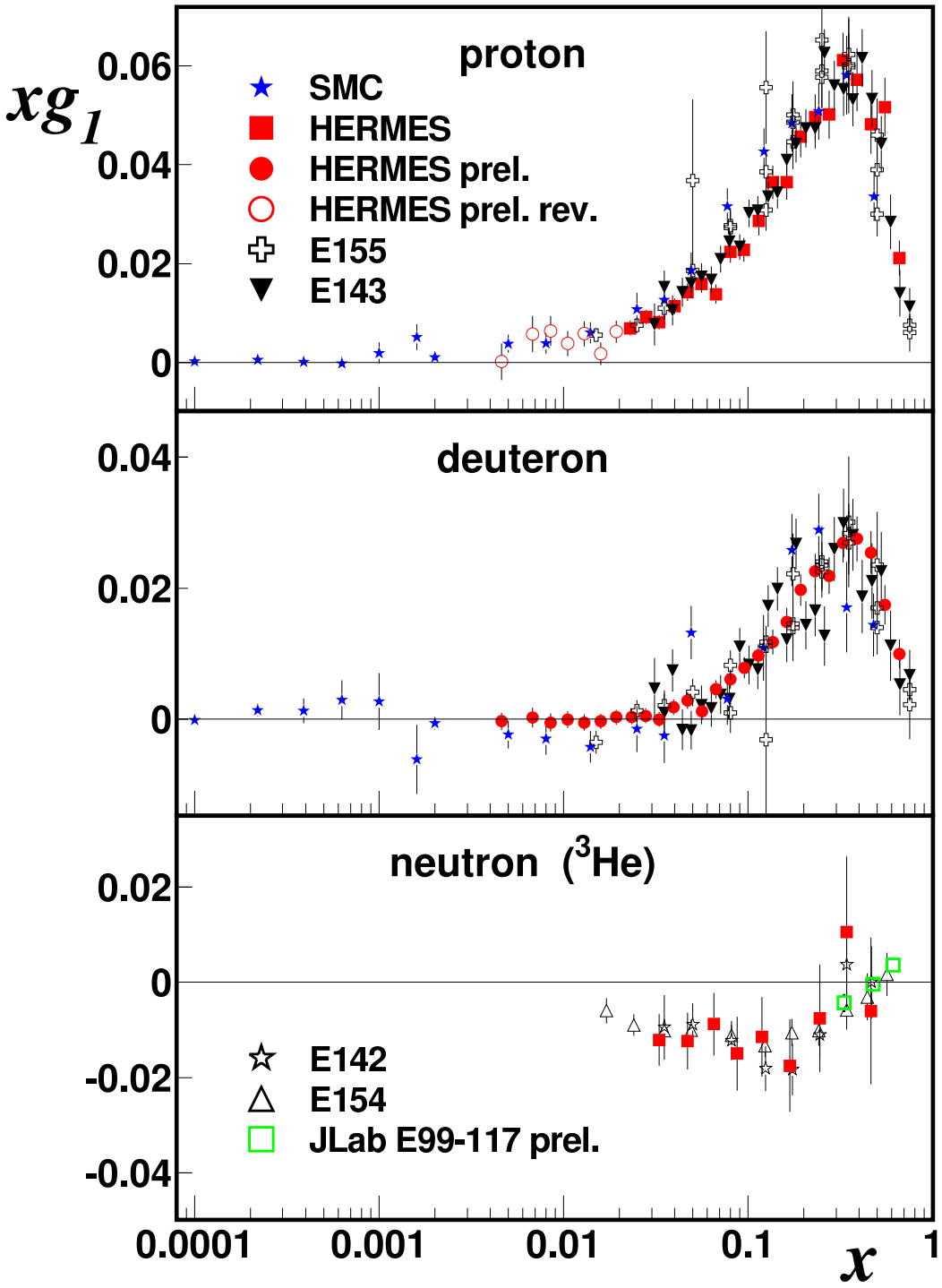
1. What we know, and what we'd like to know

Spin physics $\lesssim$ 2000 :

- dominated by *inclusive DIS*
  at SLAC,CERN,DESY



- learned about
  - $[\Delta q + \Delta\bar{q}]\,(x, Q^2)$ distributions 
  - small axial charge $\sim \langle P|\bar{\psi}\,\gamma^\mu\,\gamma^5\,\psi|P\rangle \approx 0.2$, axial anomaly
  - Bjorken sum rule $\int dx\ [g_1^p - g_1^n] \propto g_A$ confirmed



(U. Stösslein)

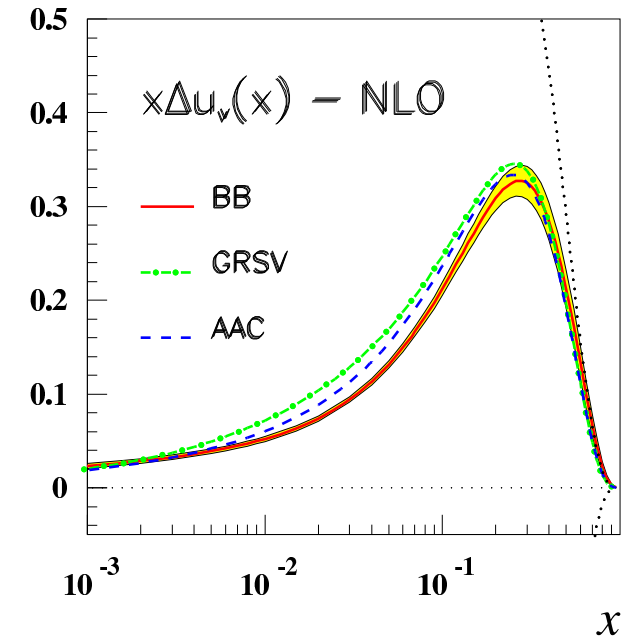
de Nardo, McCormick

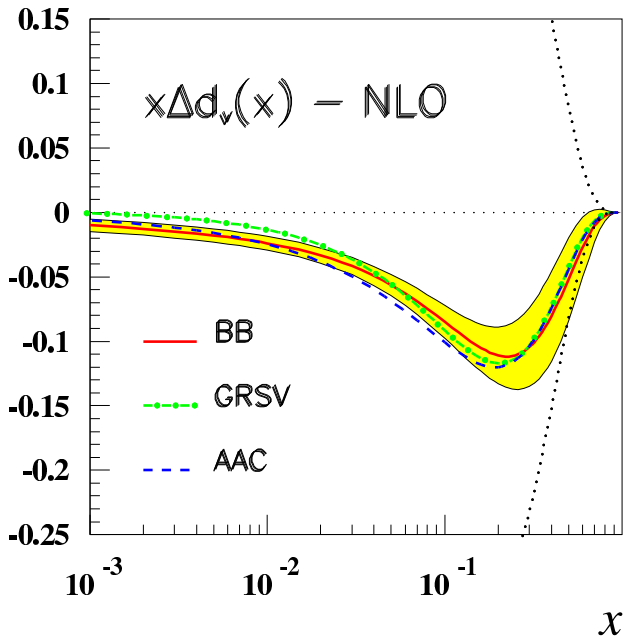
higher-twist studies Stamenov

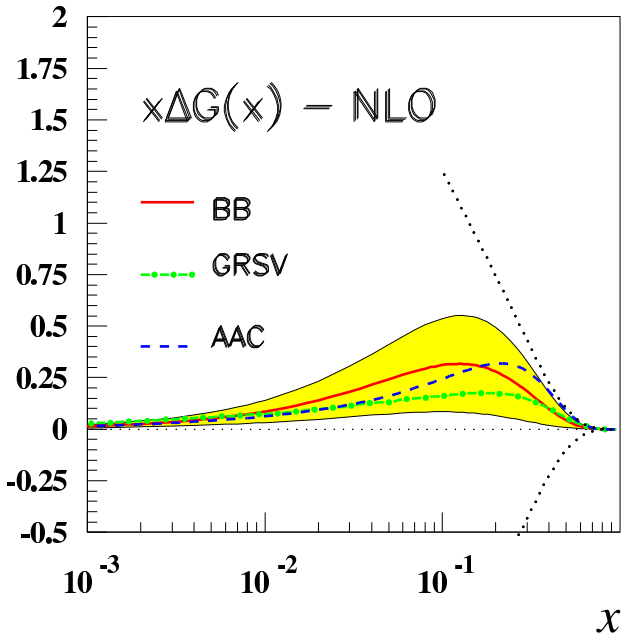
IR renormalon Kataev

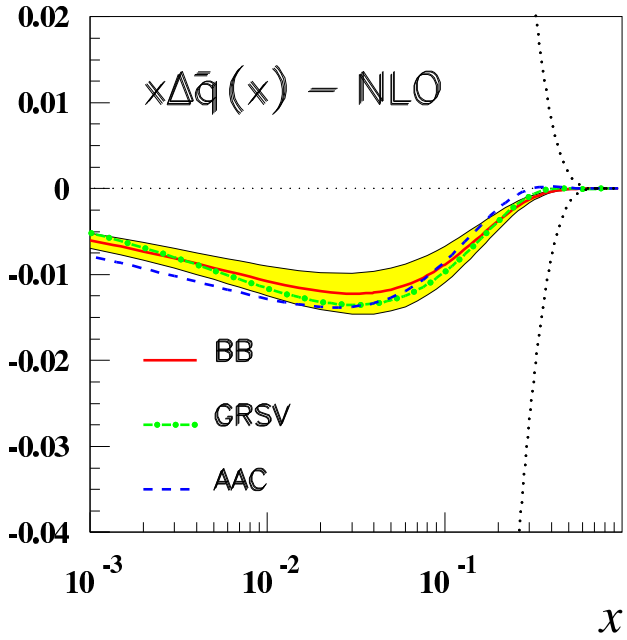
small-x Ermolaev

for $g_2^{c\bar{c}}$ see Blümlein









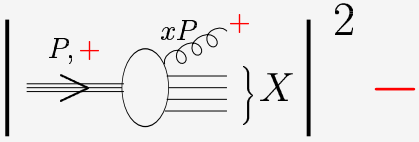
(Blümlein,Böttcher)

$\overline{\mathrm{MS}}$ scheme

← $SU(3)_f$ symm. sea

de Nardo

- identified goals for near future :

  * gluon polarization $\Delta g(x, Q^2) = \left| \; \right|^2 - \left| \; \right|^2$ 

    $\int_0^1 dx\, \Delta g$ – a likely major contributor to the nucleon spin !

    a main emphasis at most current experiments

  * more detailed information on quark distributions :

    – flavor separations : $\Delta\bar{u}$ vs. $\Delta\bar{d}$, Δs, Δs vs. $\Delta\bar{s}$ etc.
    (models, Pauli blocking, . . . , relation to baryon β decays)

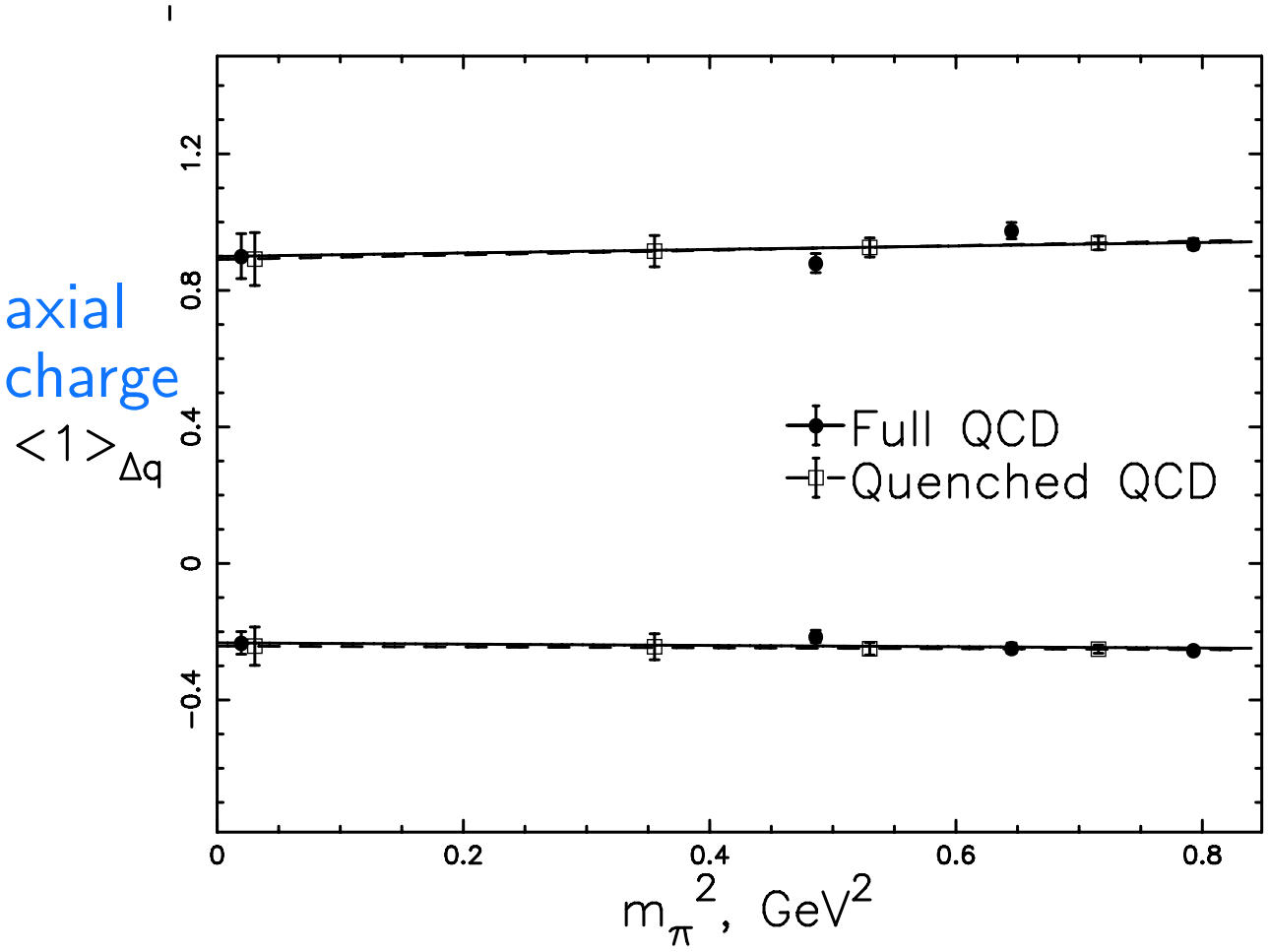
    – small-x / large-x behavior

  * orbital angular momentum of quarks and gluons :

    – $\left(\vec{x} \times \vec{T}_{q,g}\right)_z$ matrix elements can be measured in DVCS & Co.

(Ji)

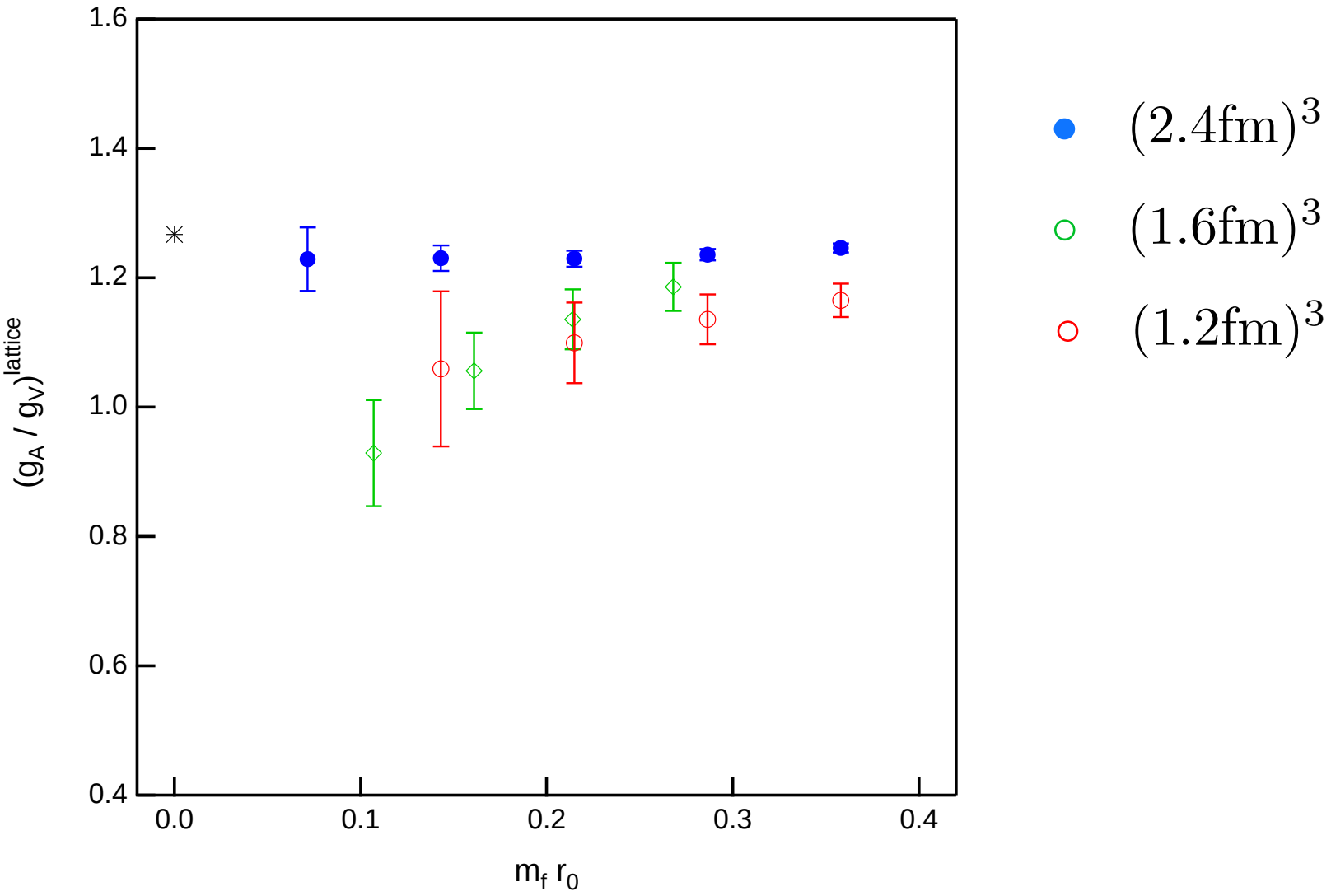
- spin structure on the lattice :
  - ∗ can calculate low moments of pdfs
  - ∗ agreement w/ phenomenological values at 20% level (or worse)
  - ∗ chiral extrapolations? Arndt,Savage; Chen,Ji; Detmold,Melnitchouk,Negele,Renner,Thomas
  - ∗ continuum extrapolations ? QCDSF



- ∗ quenched vs. full ?

LHPC/SESAM | Negele

- $g_A = \int dx\ (\Delta u - \Delta d)$ RBC : Sasaki,Orginos,Ohta,Blum

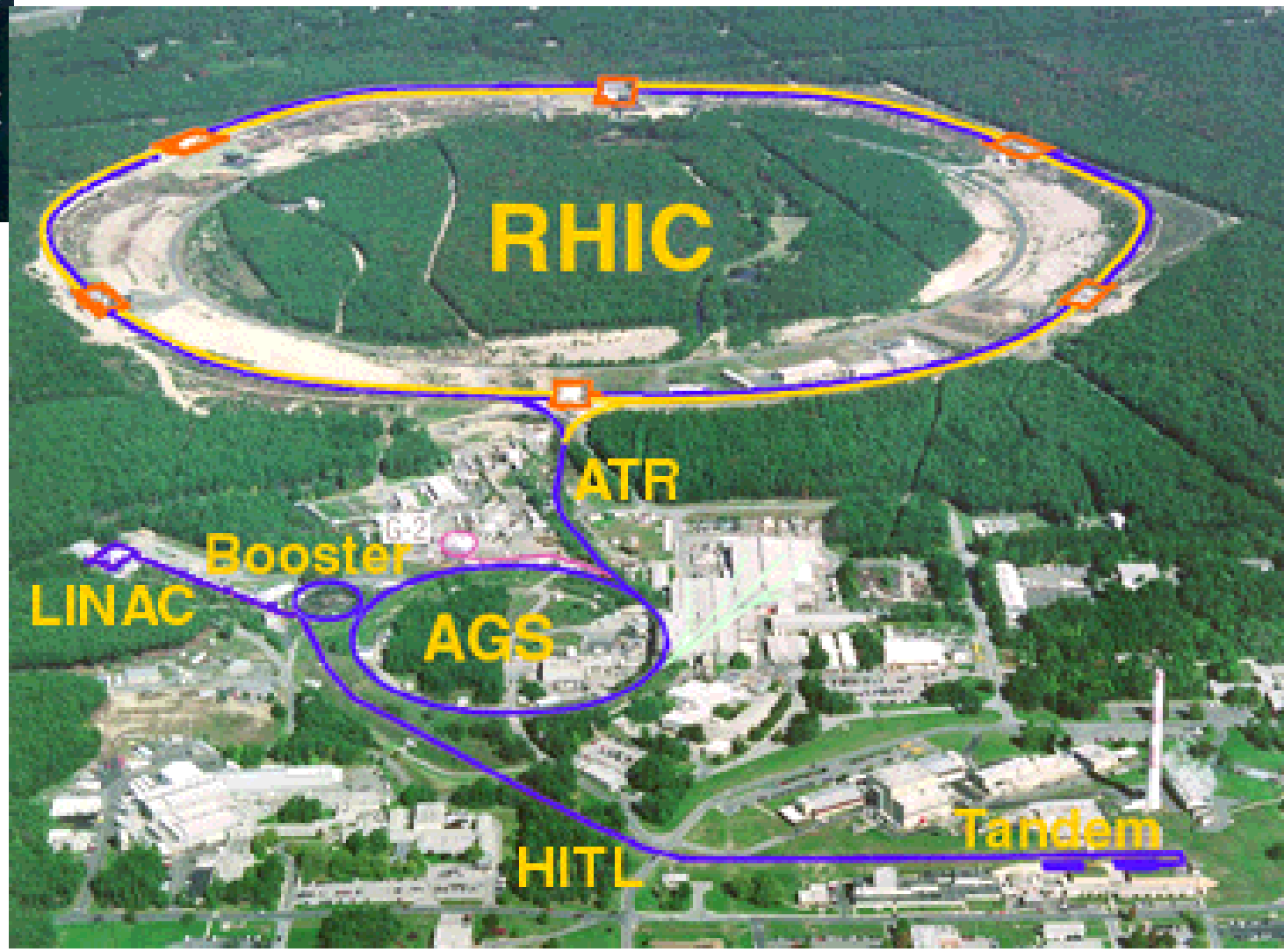


2. Today's facilities & experiments in HE Spin Physics

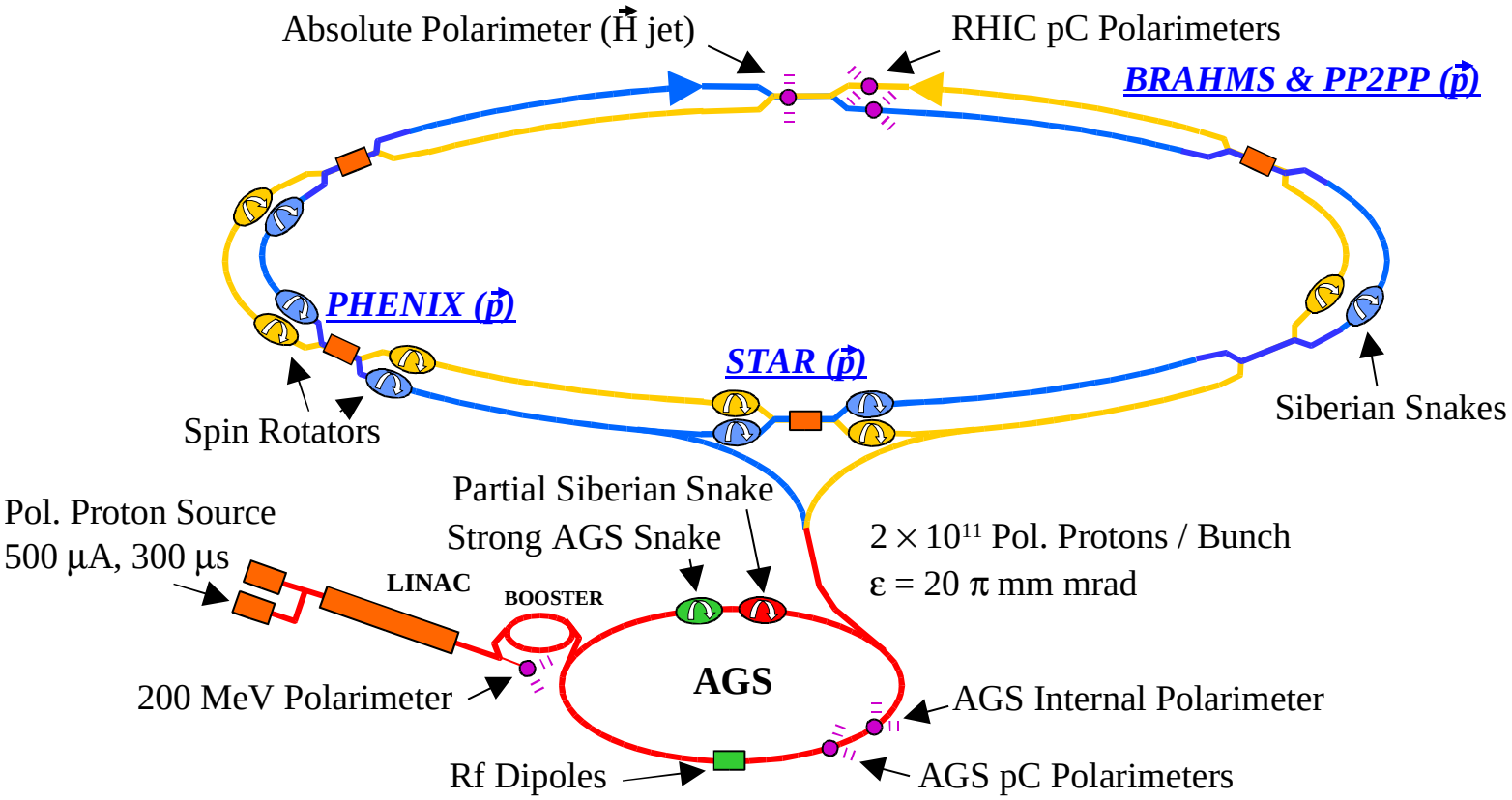
Lepton-Nucleon :

- HERMES $(E_e \leq 27.5$ GeV)
  - DIS structure functions, semi-inclusive, transversity, DVCS/excl., . . .
  - recent run with transversely polarized target
- JLab $(E_e \leq 6$ GeV)
  - structure functions in valence region, GDH sum rule E99-117
  - $+$ DVCS, beam-spin az. asymmetry in $\vec{e}p \to e\pi^{\pm}X$ CLAS
- COMPASS $(E_\mu = 160$ GeV)
  - gluon polarization, transversity, DVCS
- E161 $(E_\gamma = 35 - 45$ GeV)
  - gluon polarization
  - currently on hold

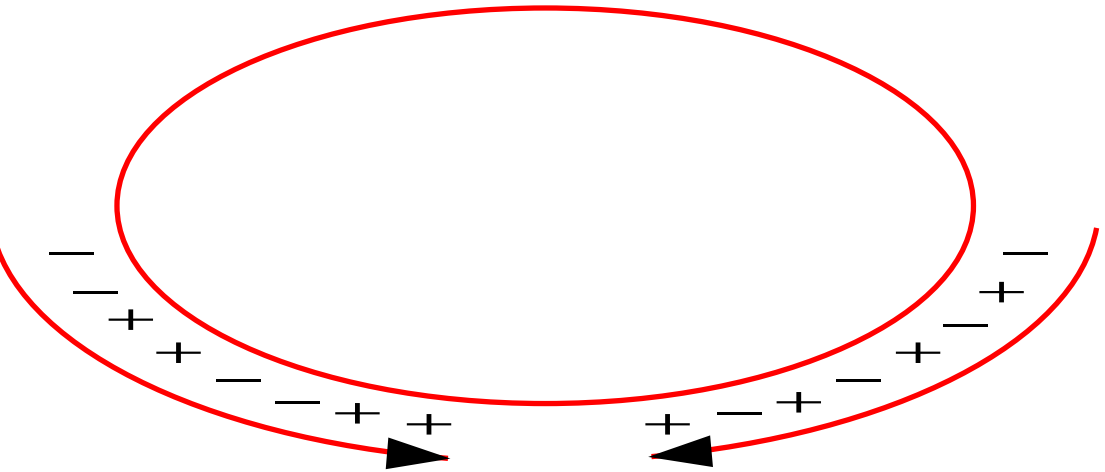
A new milestone : polarized pp collider RHIC



Polarized Proton Collisions in RHIC



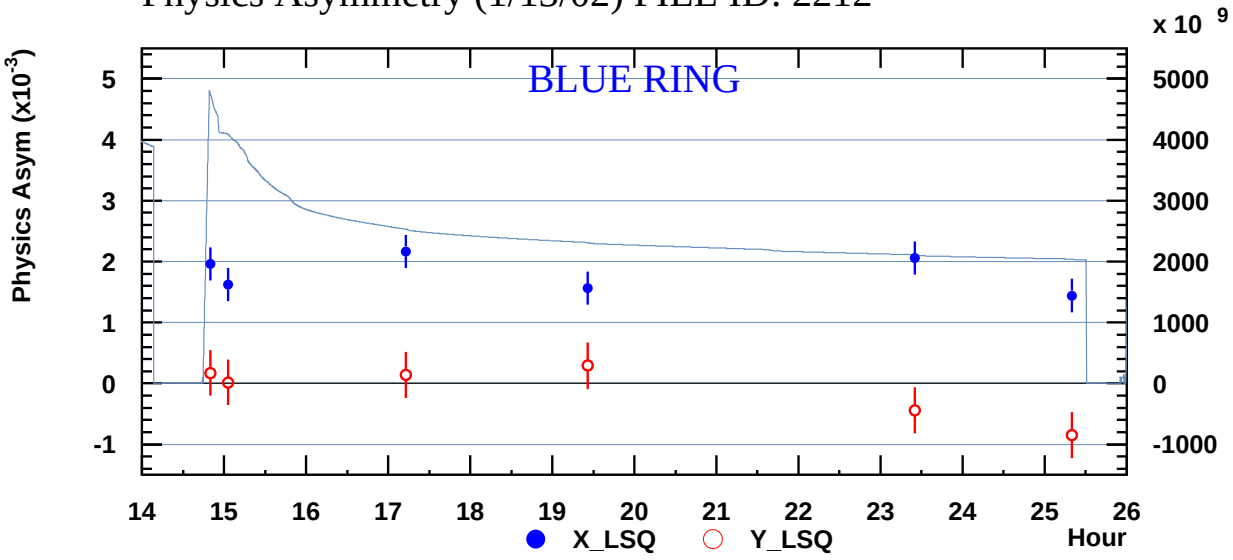
BROOKHAVEN NATIONAL LABORATORY

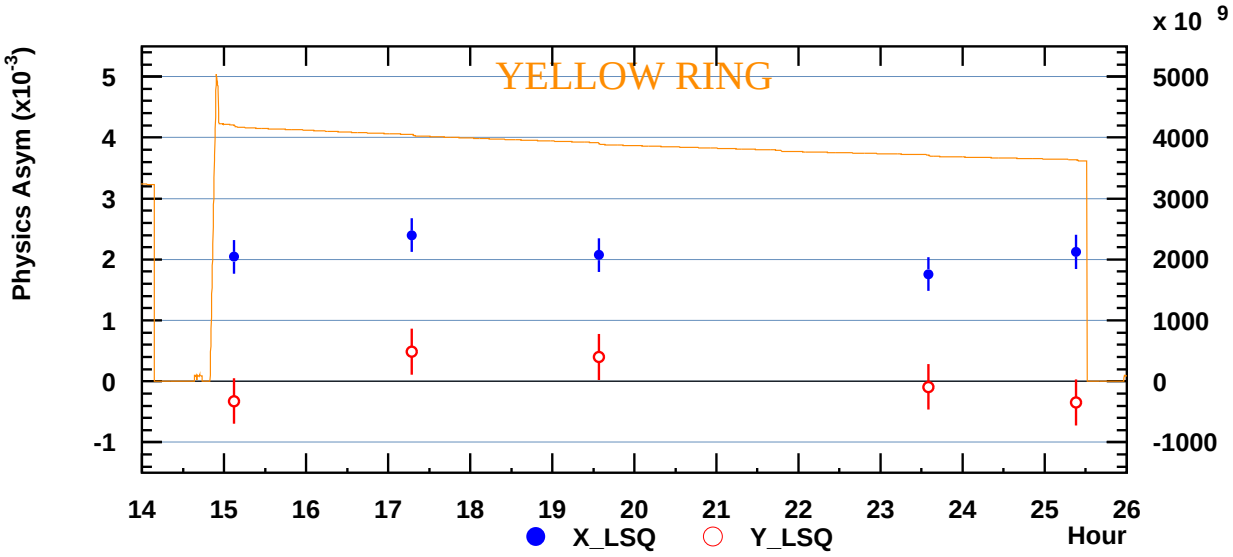


- 55 bunches
- different spin comb. every 212 nsec.
- maintain pol. for 10 hrs.

- '02 run : $P \lesssim 0.2$
- currently $P \gtrsim 0.4$
- ultimately $P \approx 0.7$
- currently $\sqrt{S} = 200$ GeV (500 GeV later)
- '02 run : $L \sim 1.5 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- current goal : $L \sim \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- ultimately $L \sim 2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Physics Asymmetry (1/13/02) FILL ID: 2212



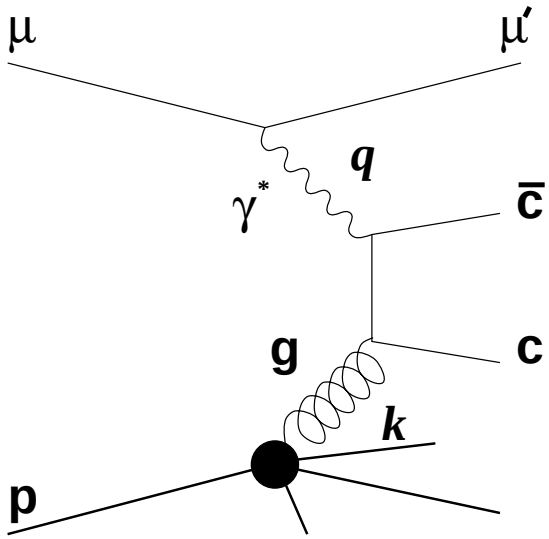


3. Recent results & future prospects

- gluon polarization $\Delta g(x, Q^2)$
- more detailed information on quark distributions :
  - flavor separations
  - large-x behavior / valence region

Probing gluon polarization Δg

- lepton-nucleon : for direct measurement, may use $\gamma p \to c\bar{c}X$



COMPASS, E161, HERMES

Marchand v.d.Steenhoven

(NLO corr. Stratmann,Bojak; Contogouris et al.)

- can also use high-p_T hadrons HERMES, COMPASS
  (idea Bravar,Kotzinian,v.Harrach) Marchand

Excellent prospects for RHIC :

- several different reactions with sensitivity to Δg can be studied :

  $pp \to \gamma X$, $\boxed{pp \to \mathrm{jet} X}$, $\boxed{pp \to \pi X}$, $pp \to (c\bar{c})X$, $\ldots$

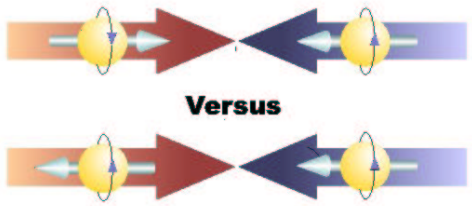
- can check consistency of Δg determinations
  (universality / factorization theorems)

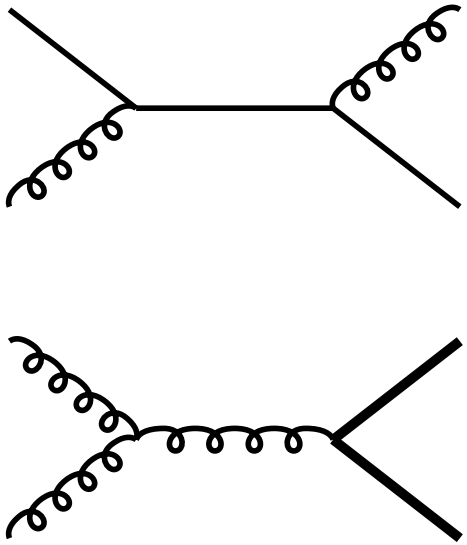
- theory framework under control :
  - experience from unpolarized case (Tevatron,SpS)
  - NLO corrections now known for all relevant reactions

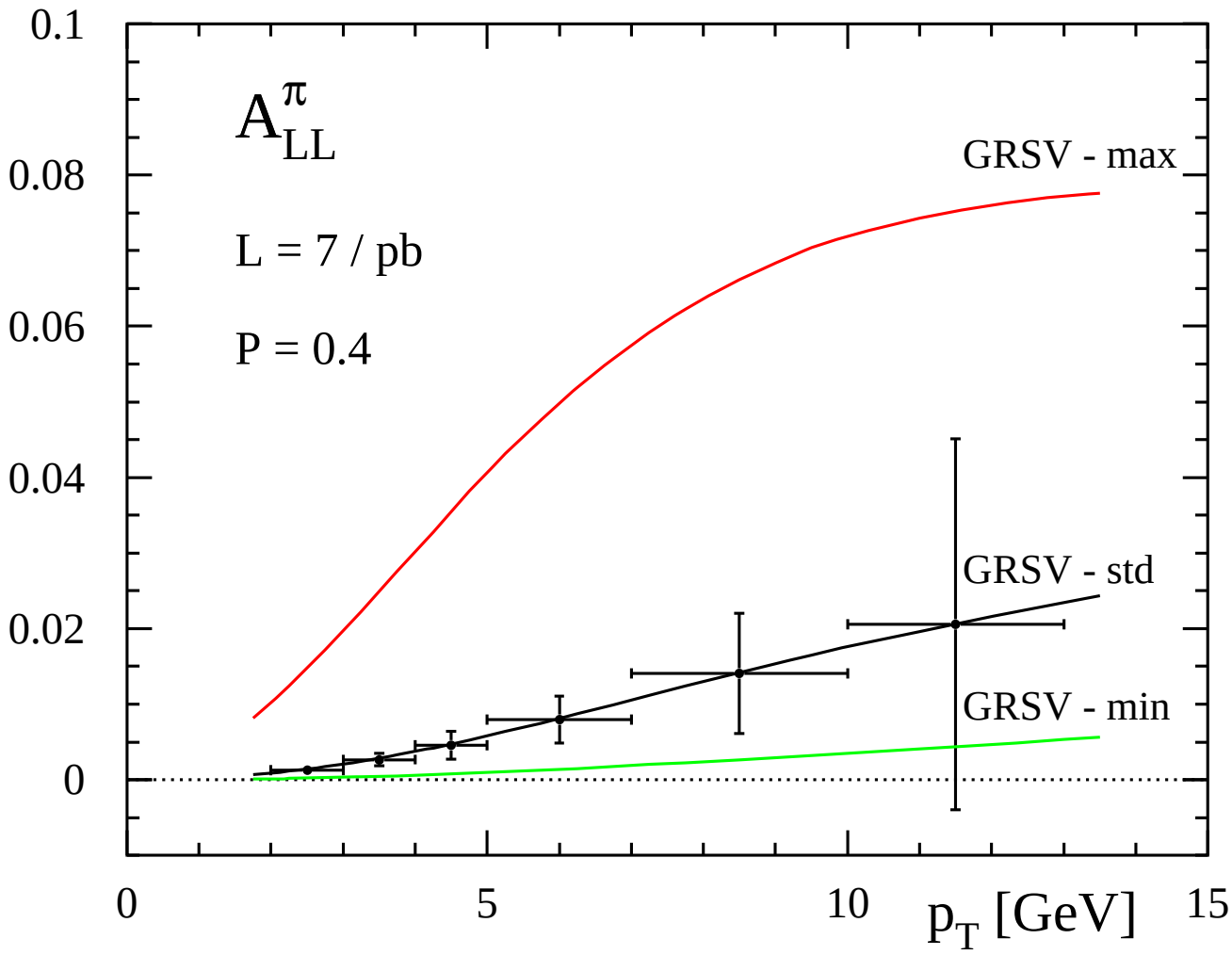
    Gordon,WV; Contogouris et al.; de Florian,Frixione, Signer,WV; Stratmann,Bojak;
    de Florian; Jäger,Stratmann,WV; . . .

Already in present run : $\vec{p}\vec{p} \to \pi^0 X$ **Jäger,Stratmann,WV**

$\sqrt{S} = 200\,\mathrm{GeV}$, PHENIX Sato Makdisi NLO



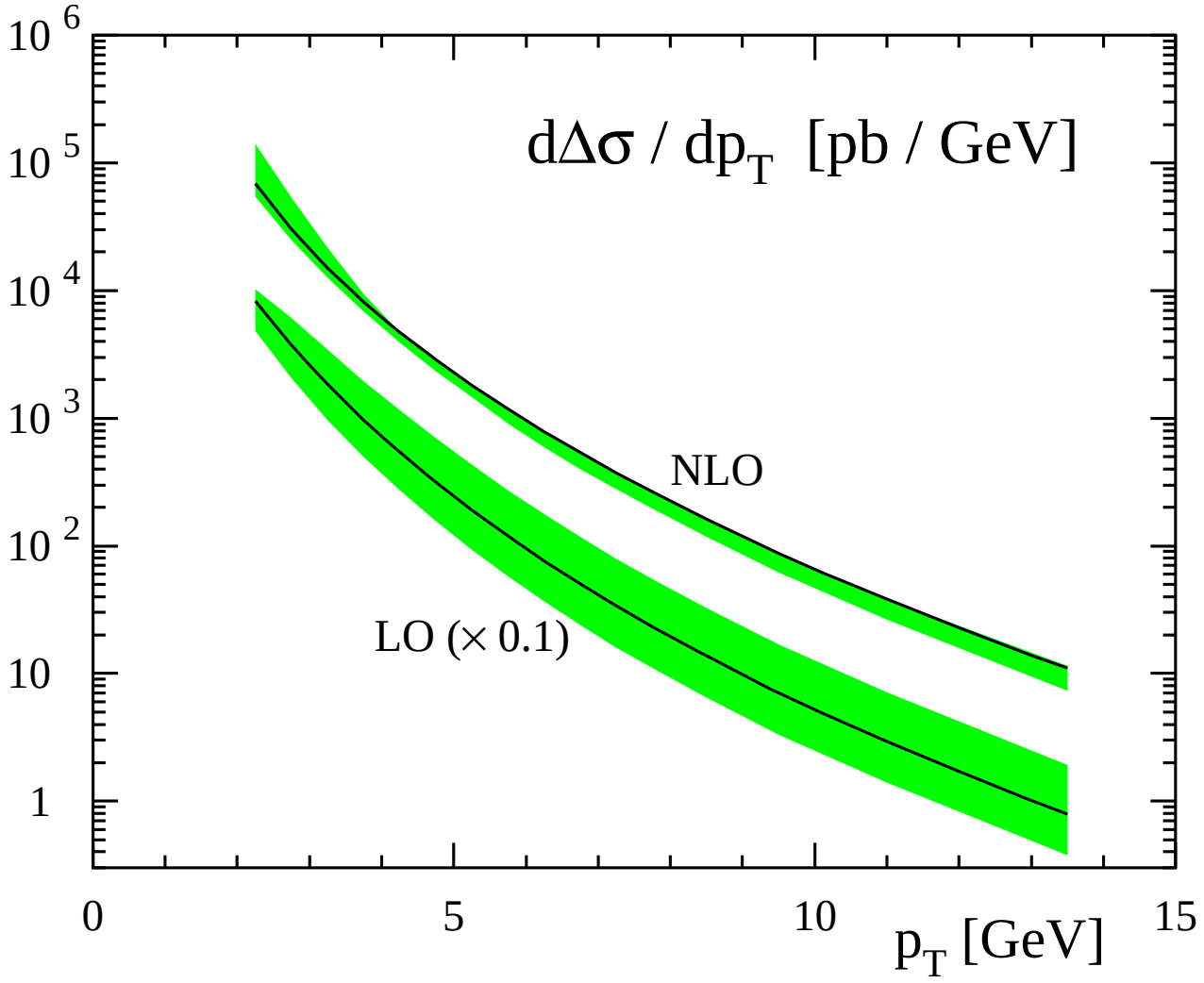




unpol. NLO calculation : Aversa,Chiappetta,Greco,Guillet

CTEQ 5M (unpol. pdf), Kniehl et al. (fragm. fcts)

improvement in scale dependence:



variation of scales: $\mu = p_T/2 \ldots 2p_T$ Jäger,Stratmann,WV

$pp \rightarrow \pi^0 X$ **by**

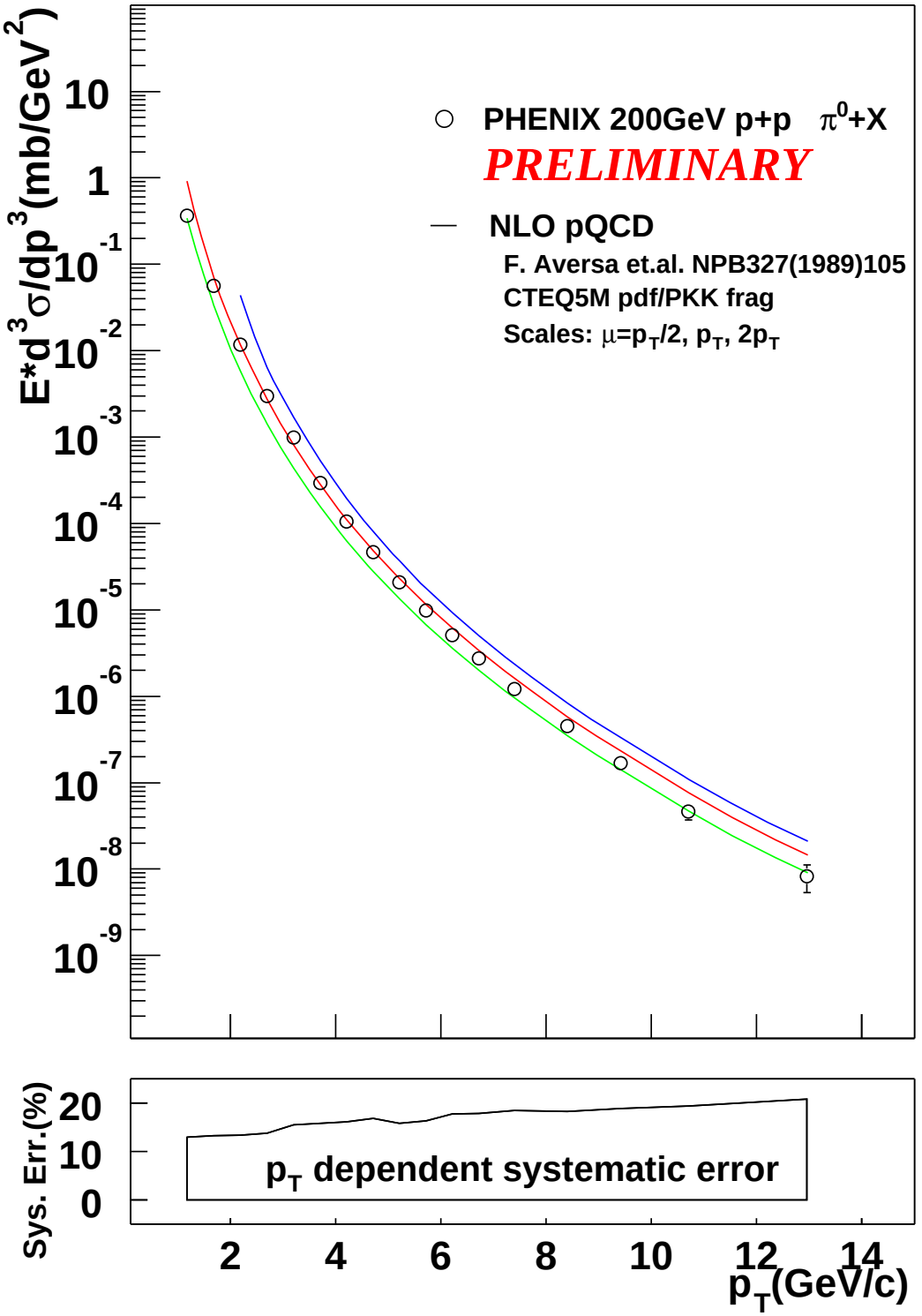
PHENIX

(±30% normalization unc.)

Sato

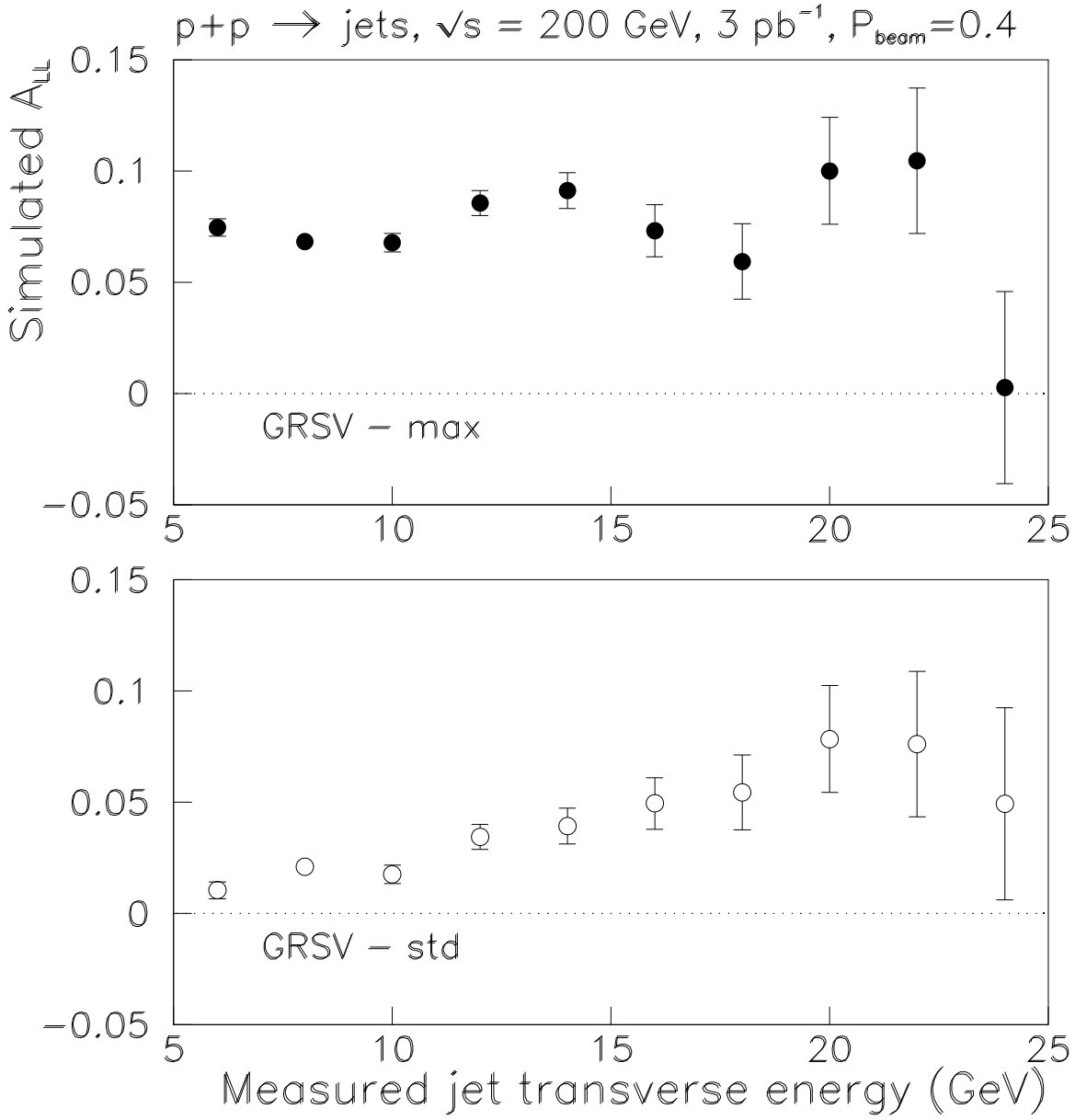
STAR to come

Rakness



- jet physics at STAR

Rakness



cone alogrithm, $R = 0.7$

Further information

on quark distributions

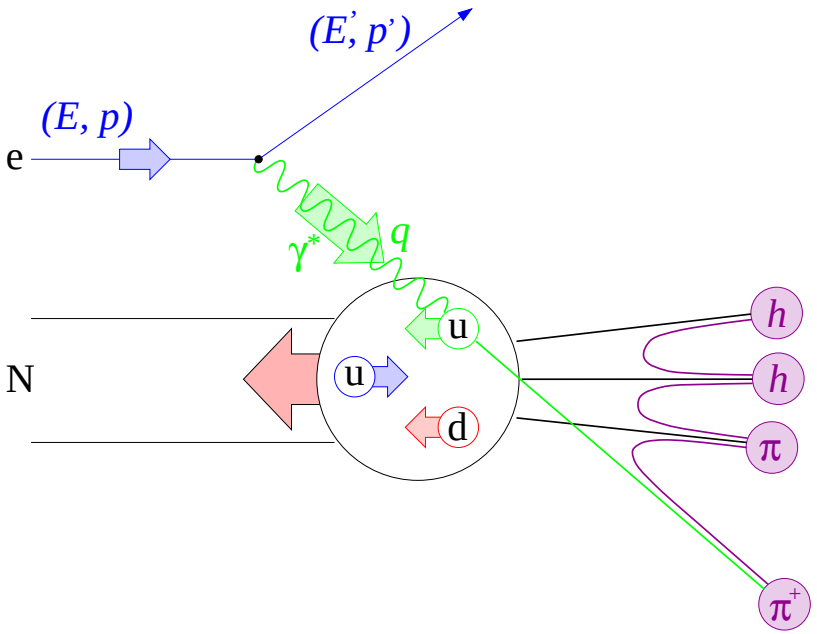
- inclusive DIS cannot distinguish between q and $\bar{q}$
- considerable interest :
  - SU(2) breaking in sea (meson cloud models, Pauli exclusion, . . .)

(Thomas,Signal,Cao; Diakonov,Goeke,Polyakov,Weiss; Glück,Reya; Schäfer,Fries; Kumano; Wakamatsu)

  - strange quark polarization

(Ellis,Karliner et al.; Brodsky,Ma Bo-Qiang et al; . . .)

- one option : semi-inclusive DIS. Detect a hadron $h = \pi^{\pm}, K^{\pm}, \ldots$



LO :

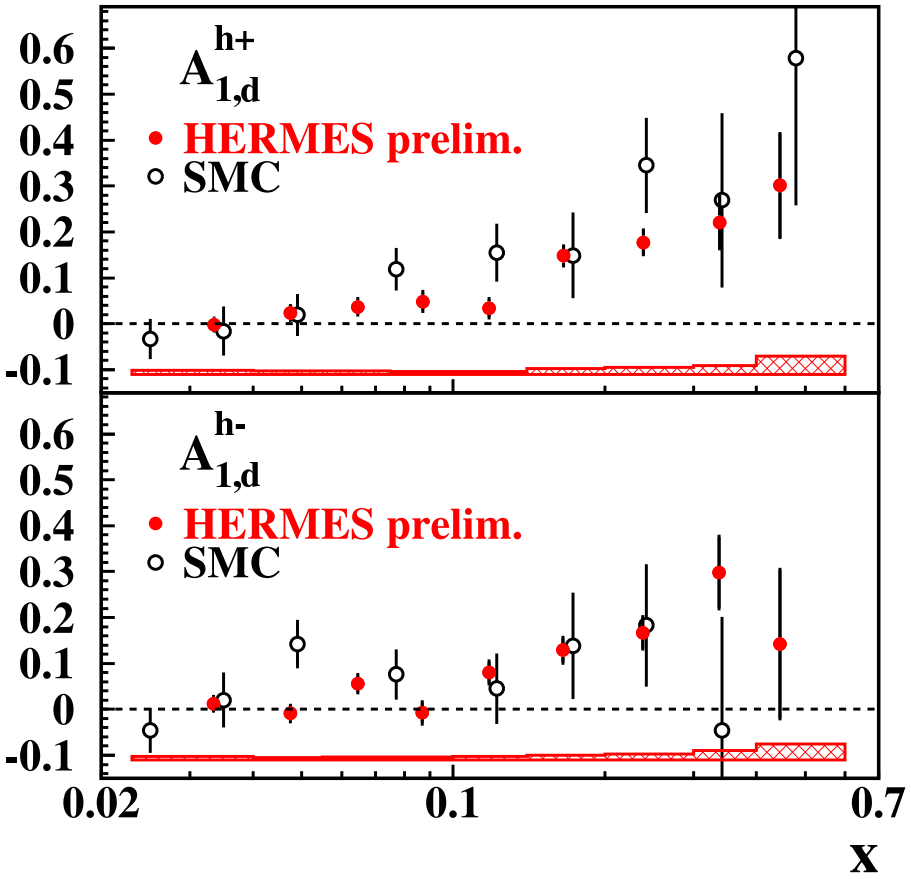
$$z = E^h/\nu$$

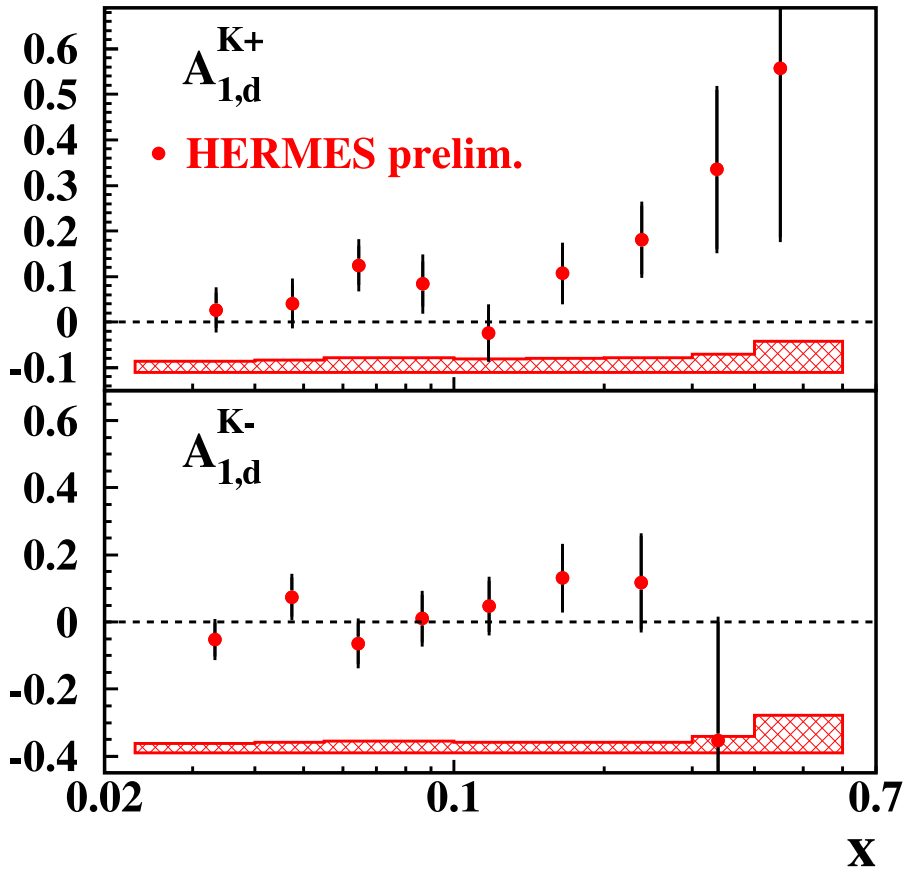
$$\rightsquigarrow \quad A_1^h(x,z) = \frac{\sum_q e_q^2\left[\Delta q(x)\ D_q^h(z) + \Delta\bar{q}(x)\ D_{\bar{q}}^h(z)\right]}{\sum_q e_q^2\left[q(x)\ D_q^h(z) + \bar{q}(x)\ D_{\bar{q}}^h(z)\right]}$$

$$= \sum_{q,\bar{q}} P_f^h(x,z)\,\frac{\Delta f(x)}{f(x)}$$

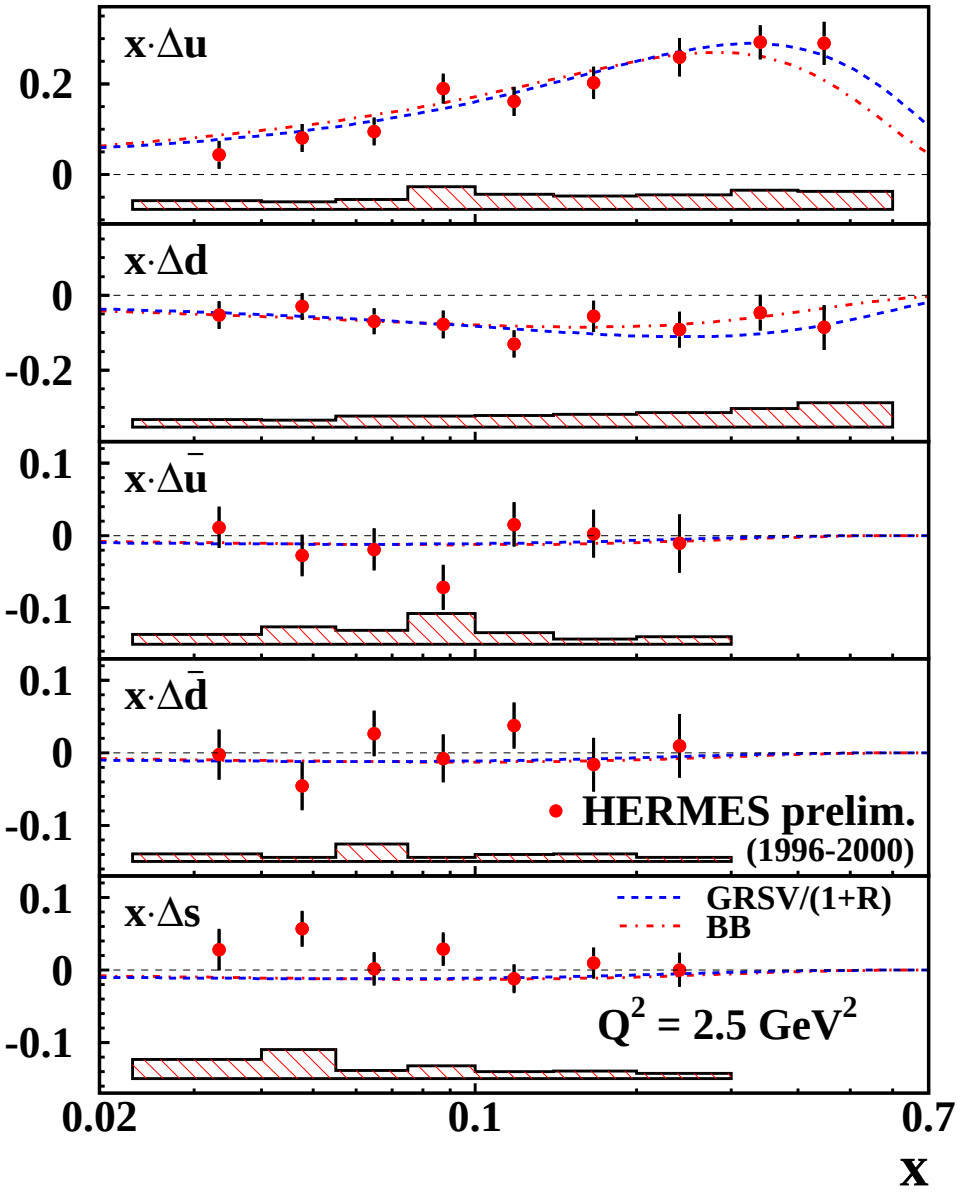
Last year's HERMES results :

Beckmann | Hillenbrand





HERMES analysis :



current points of discussion :

- small sea polarization ?
- positive strange polarization ?

  Bass; Leader,Stamenov
- validity of MC 'purity' approach?

  Christova,Kretzer,Leader; Kotzinian
- and/or higher twist ?

A neat way at RHIC : W production

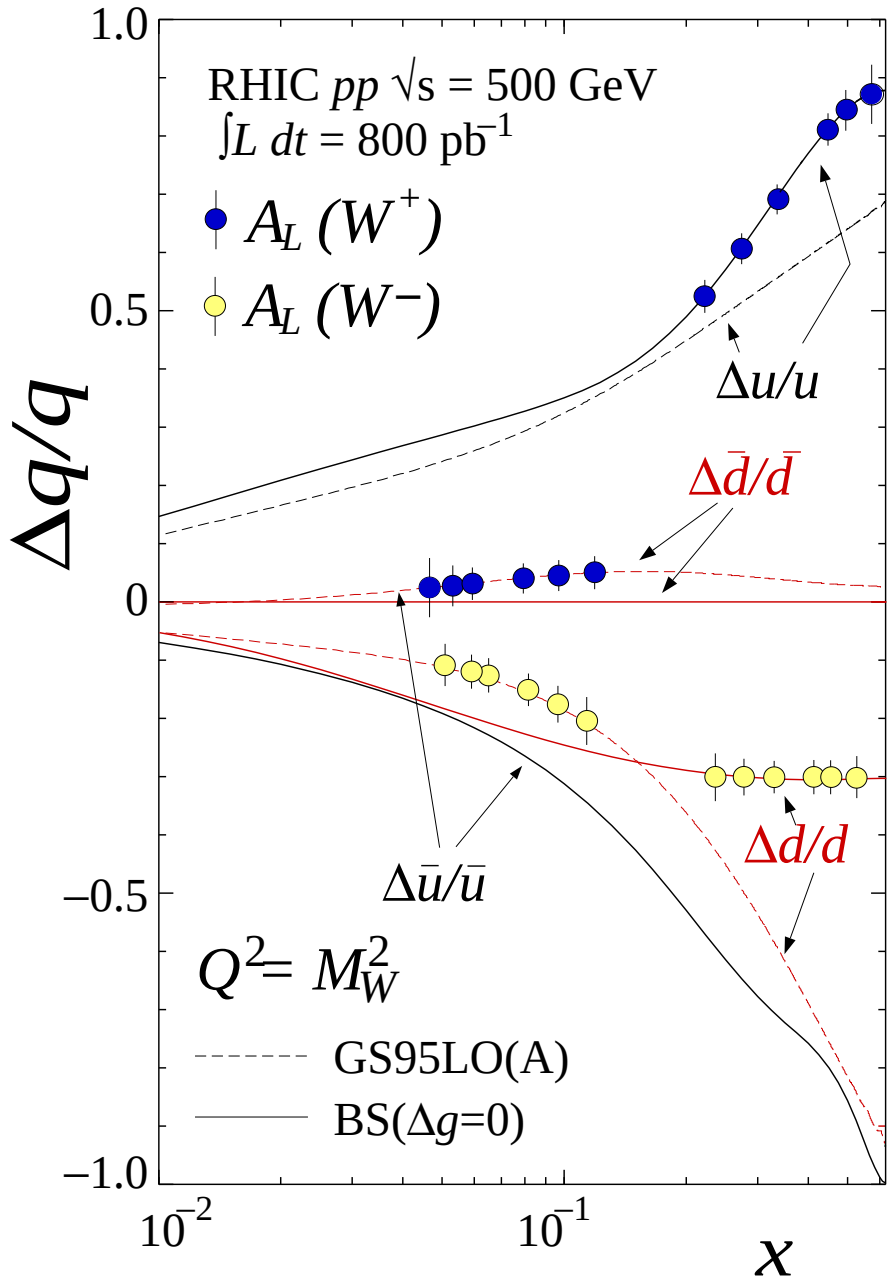
Bourrely,Soffer

$$A_L^{W^+} \approx \frac{\Delta u(x_1)\,\bar{d}(x_2) - \Delta\bar{d}(x_1)\,u(x_2)}{u(x_1)\,\bar{d}(x_2) + \bar{d}(x_1)\,u(x_2)}$$

HO corrections, lepton level :

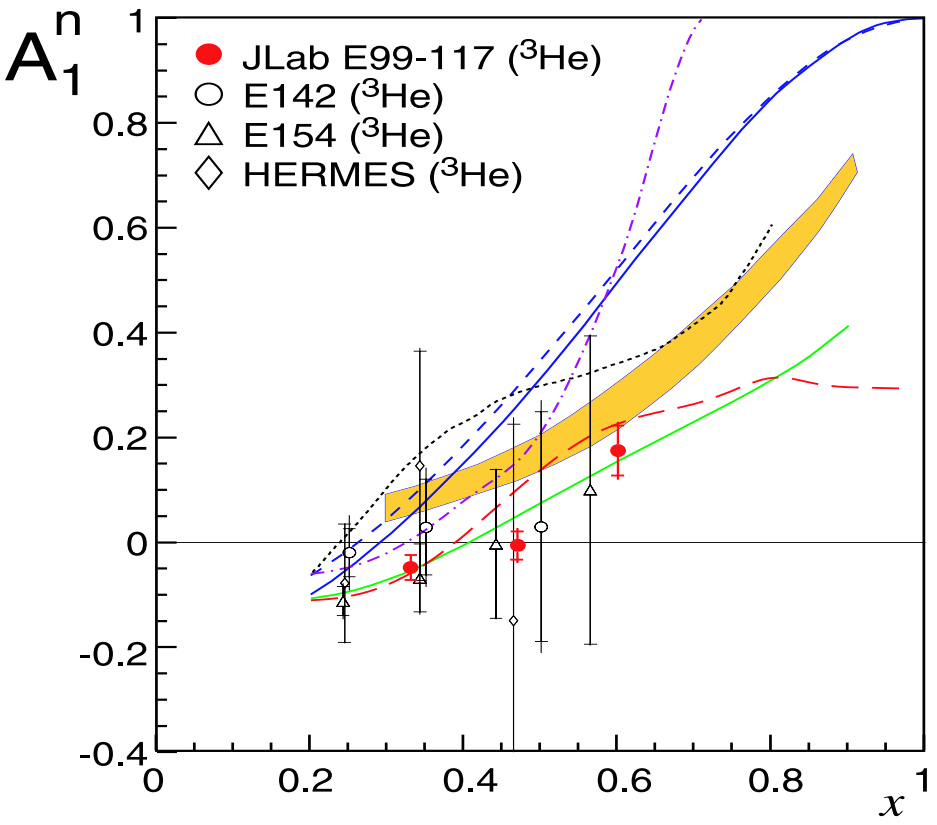
Nadolsky,Yuan

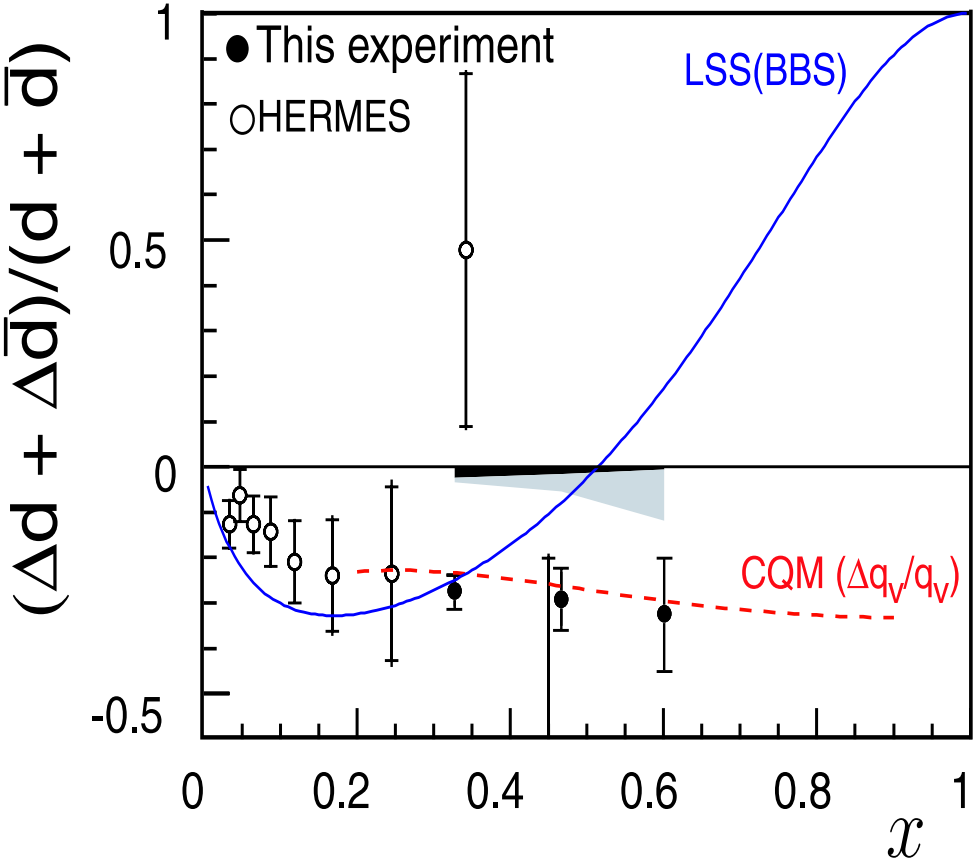
Isenhower



New JLab neutron results at large-x : E99-117

McCormick



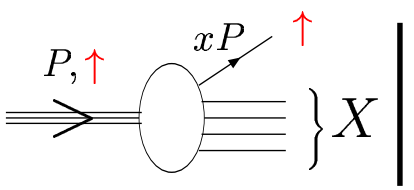


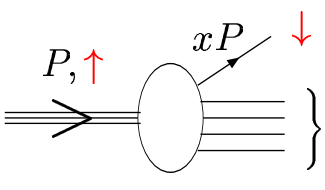
- testing ground for models at $x \to 1$:
  - constituent quark models : $\Delta d/d \to -1/3$ (Close,Thomas; Isgur)
  - pQCD models with hadron helicity retention : $\Delta d/d \to 1$
    (Farrar,Jackson; Brodsky,Burkardt,Schmidt → Leader,Sidorov,Stamenov,Boglione)
  - "statistical" pdf approach Soffer , duality phenom. Fantoni . . .

Part II : Transverse-Spin Phenomena

- Ralston,Soper '79 : Parton density of transversity

$$\delta q(x) \;=\; \Big|\; \}X \Big|^2 \;-\; \Big|\; \}X \Big|^2$$



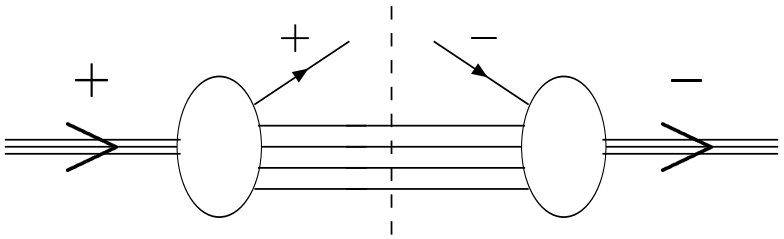


- in helicity basis :

$$|\uparrow\rangle \;=\; \frac{1}{\sqrt{2}}\Big(|+\rangle \;+\; i\,|-\rangle\Big) \qquad |\downarrow\rangle \;=\; \frac{1}{\sqrt{2}}\Big(|+\rangle \;-\; i\,|-\rangle\Big)$$

- then :

$$\delta q(x) \;\propto$$

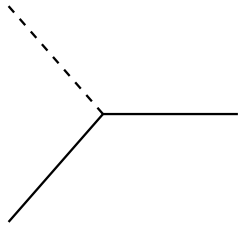


"Helicity flip" !

- $\rightsquigarrow$ not for gluons at leading twist

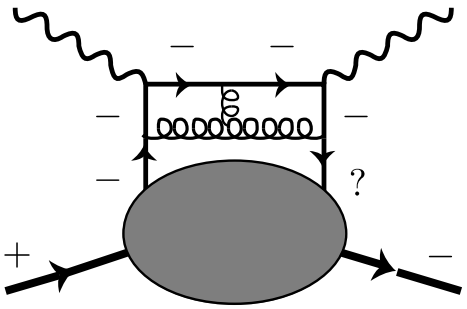
  Jaffe,Ji; Ji; Artru,Mekhfi; Soffer,Teryaev

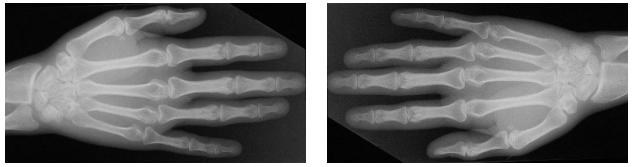
- Standard Model probes preserve chirality ($\approx$ helicity)



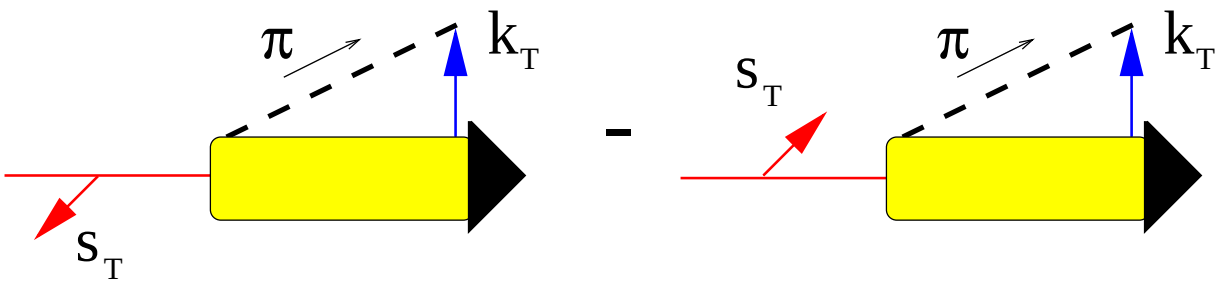
$$\gamma,\, W^{\pm},\, Z^0,\, g: \quad \begin{cases} \bar{\psi}\gamma^\mu\psi = \bar{L}\gamma^\mu L + \bar{R}\gamma^\mu R \\ \bar{\psi}\gamma^\mu\gamma^5\psi = \bar{L}\gamma^\mu L - \bar{R}\gamma^\mu R \end{cases}$$

- however, spontaneous χSB, $m_q \neq 0$, . . . Collins,Diehl; Jaffe; Polyakov,Weiss . . .
- transversity not accessible in inclusive DIS :



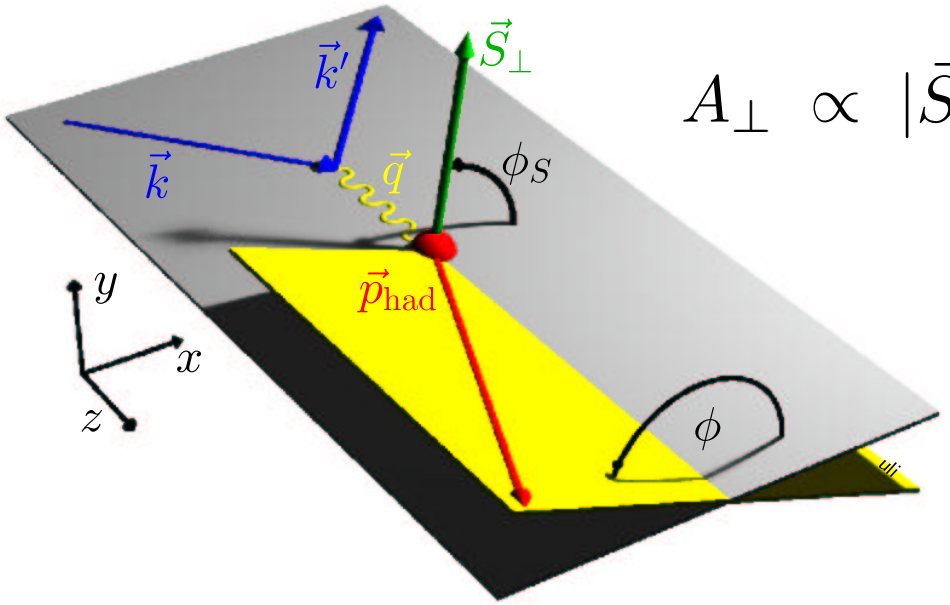


- Collins '93 : use fragmentation as "transversity polarimeter"

$H_1^\perp =$ 

$$i\,\vec{S}_T \cdot (\vec{P}_\pi \times \vec{k}_T)$$

- contributes to *leading power* single-spin asymmetry in $ep^\uparrow \to e\pi X$



$$A_\perp \;\propto\; |\vec{S}_T| \sin(\phi + \phi_S) \sum_q e_q^2\, \delta q(x)\, H_1^{\perp,q}(z)$$

SMC

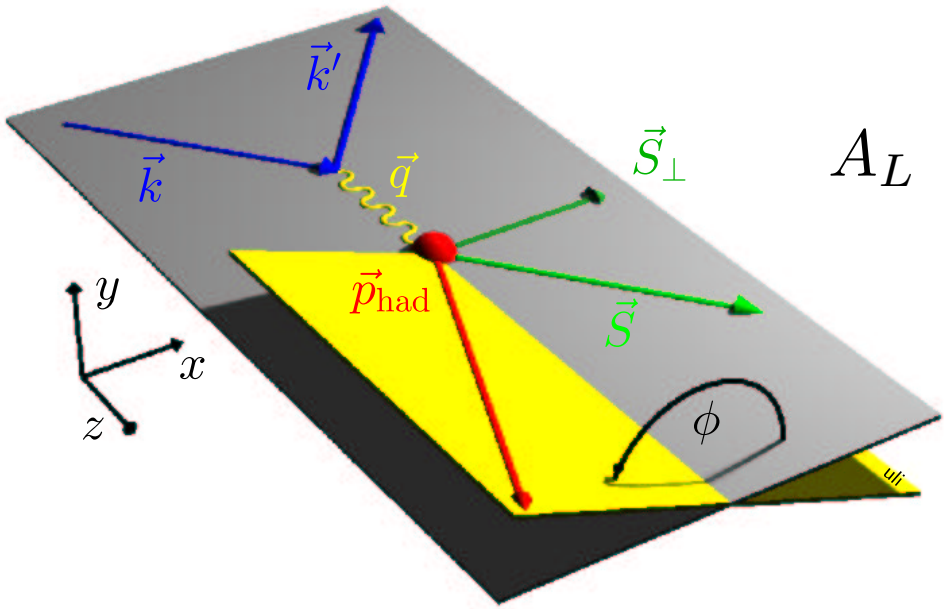
HERMES – soon ! Schnell

COMPASS Pagano

- (at small measured k_T a special factorization theorem applies)

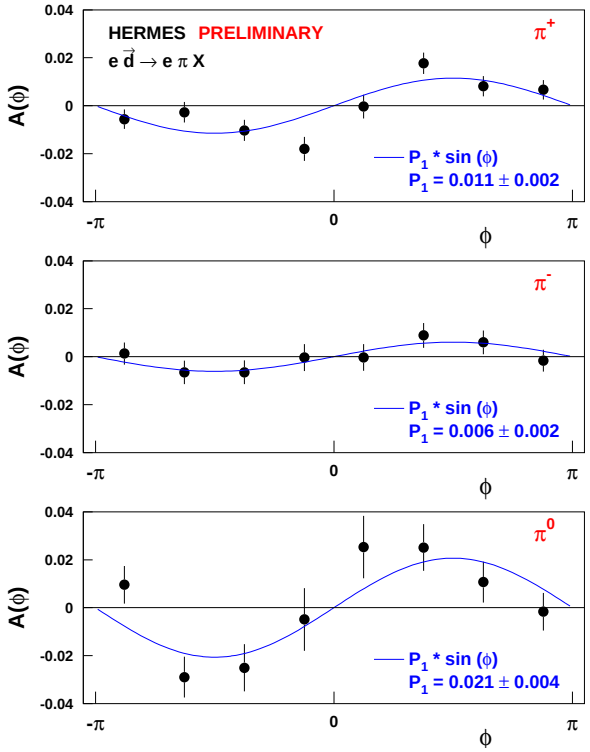
- recall, HERMES measurement of $e\vec{p} \to e\pi X$

Schill



$$A_L \propto \underbrace{|\vec{S}_T|}_{M/Q} \sin(\phi) \sum_q e_q^2 \, \delta q(x) \, H_1^{\perp,q}(z)$$

$+$ other power suppressed

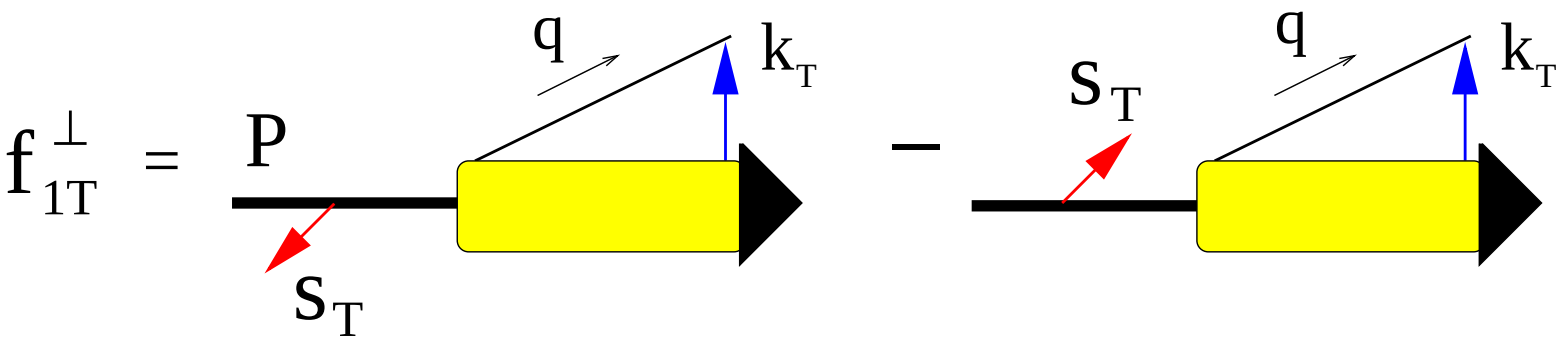


Oganessyan,Avakian,Bianchi,Kotzinian;
Mulders,Tangerman; Boer,Jakob,Mulders;
Efremov,Goeke, Schweitzer ;
Oganessyan,Bianchi,De Sanctis,Nowak

- (QCD corrections ? Sudakov effects . . .)

- however, intrinsic k_T of quarks in proton ?

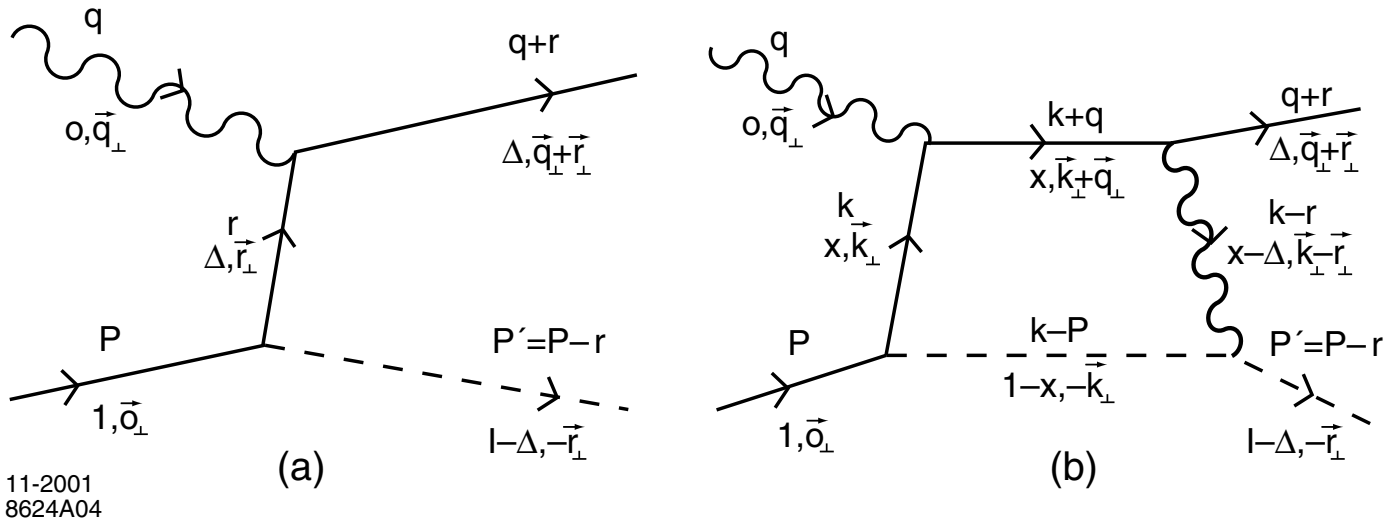
  Sivers '90 :



asymmetry $\boxed{q_{p\uparrow}(x,\vec{k}_T) \neq q_{p\uparrow}(x,-\vec{k}_T)}$

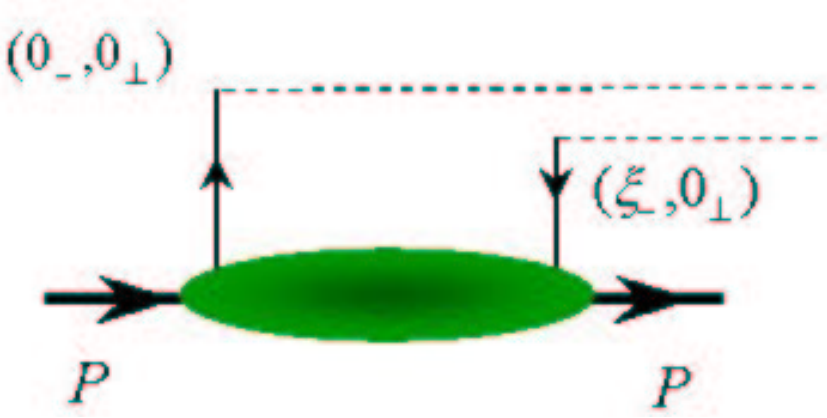
- however Collins '93 : for distribution functions correlation $\vec{S}_T \cdot (\vec{P} \times \vec{k}_T)$ ruled out by T invariance

- Brodsky,Hwang,Schmidt '02 : find *leading-power* asymmetry from final-state interaction in model calculation



- assumes ordinary fragmentation function !
- then realized : gauge links that make pdfs *gauge invariant* allow the Sivers "T-odd" structure Collins; Belitsky,Ji,Yuan; Boer,Mulders,Pijlman; Metz
- non-standard time-reversal discussed also by Anselmino,Barone,Drago,Murgia

- gauge-invariant parton distributions :



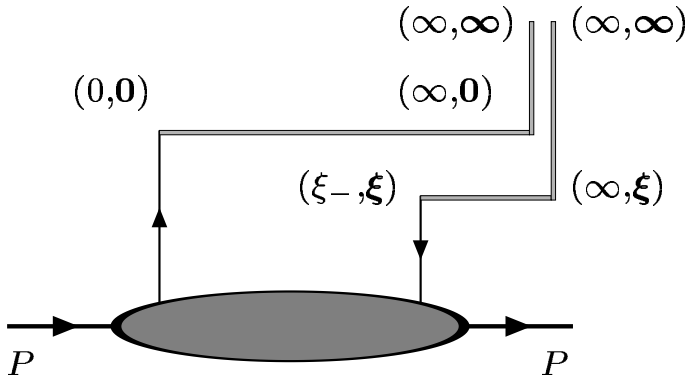
$$q(x) \sim \int d\xi^- \, \mathrm{e}^{i\xi^- x} \, \langle P \,|\, \overline{\psi}_+(\xi^-) \, U_{[\infty,\xi^-]} \, U_{[0,\infty]} \, \psi_+(0) \,|\, P \rangle$$

$$U_{[a,\xi^-]} \equiv \mathcal{P} \exp\left(-ig \int_a^{\xi^-} d\lambda \, A^+(\lambda) \right)$$

- with k_T dependence

$$q(x,\vec{k}_T) \sim \int d\xi^- \, d^2\xi_T \, \mathrm{e}^{i\xi^- x + i\vec{k}_T\cdot\vec{\xi}_T}$$

$$\times \, \langle P \,|\, \overline{\psi}_+(\xi^-,\vec{\xi}_T) \, \tilde{U}_{[\infty,\xi^-]} \, \tilde{U}_{[0,\infty]} \, \psi_+(0) \,|\, P \rangle$$

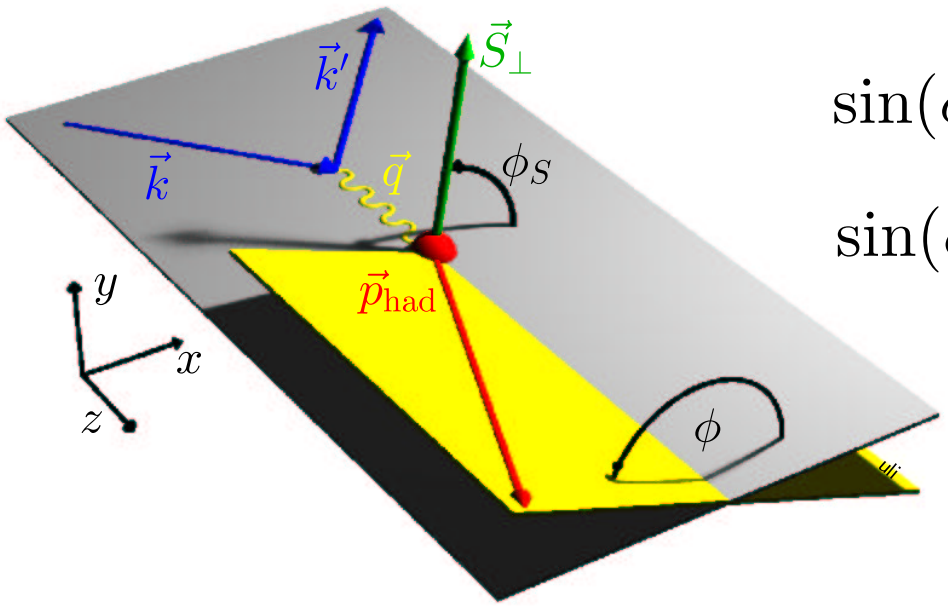


- gauge link survives even in $A^+ = 0$ gauge

(Belitsky,Ji,Yuan; Boer,Mulders,Pijlman)

Implications for phenomenology :

- two leading contributions to $ep^{\uparrow} \to e\pi X$



$$\sin(\phi+\phi_S)\ \sum_q e_q^2\ \delta q(x)\ H_1^{\perp,q}(z)$$

$$\sin(\phi-\phi_S)\ \sum_q e_q^2\ f_{1T}^{\perp,q}(x)\ D_q(z)$$

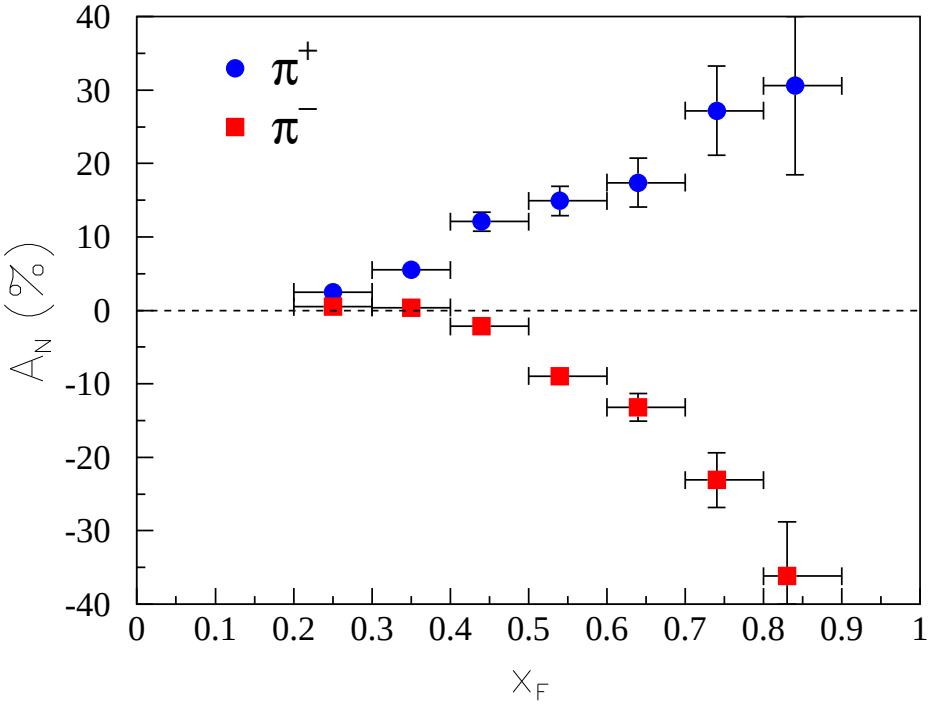
Teryaev | Gamberg

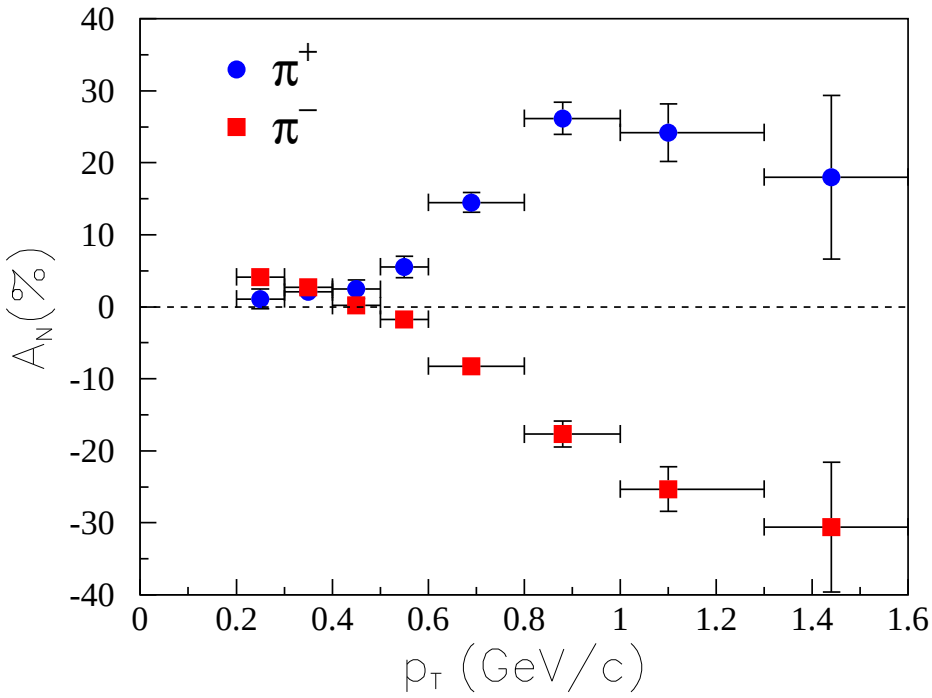
- hadronic single-spin asymmetries in $p^{\uparrow\downarrow}p \to \pi X$

$$A_{\rm N} \equiv \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$

- large $A_{\rm N}$ seen in fixed-target experiments at BNL,ANL,Fermilab,Serpukhov

- E704 ('96) :



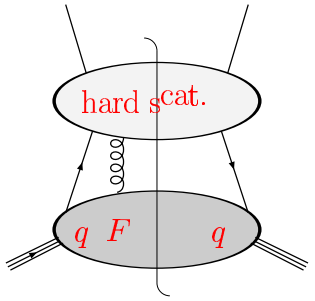


- in pQCD, A_N is power-suppressed as $1/p_T$
- intrinsic transverse momentum effects à la Sivers,Collins,Boer

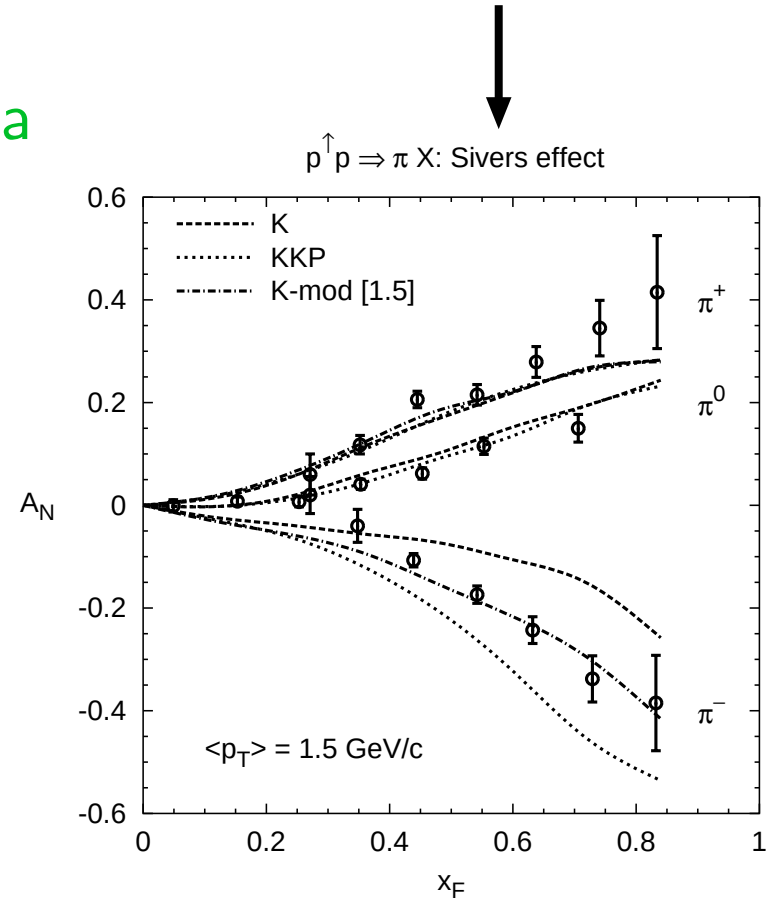
  Anselmino,Boer,D'Alesio,Murgia; Leader,Boglione; Boer,Mulders; . . .

- "Twist-3 quark-gluon correlation functions"

  Efremov,Teryaev; Qiu,Sterman; Koike et al.; . . .



- D'Alesio,Murgia



- also : $\bar{p}^{\uparrow}p \to \pi X$, $pp \to \Lambda^{\uparrow}X$

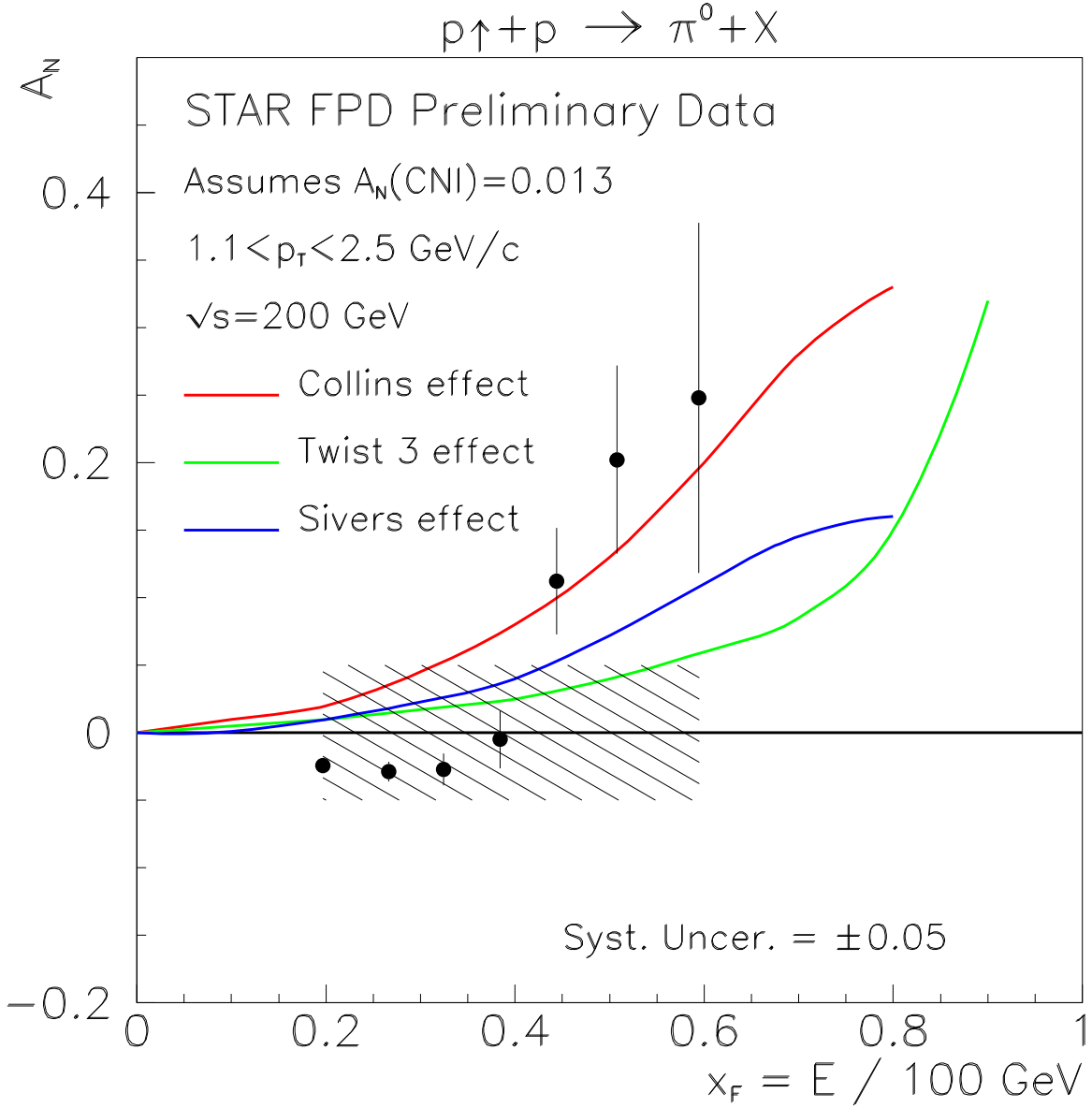
  Soffer; Anselmino,Boer,D'Alesio,Murgia; . . .

- also : $\cos(2\phi)$ dependence in unpolarized Drell-Yan

  NA10; Brandenburg,Nachtmann,Mirkes; Boer; Collins; Boer, Brodsky ,Hwang . . .

STAR

Rakness



- higher p_T . . .
- Drell-Yan $f_{1T}^{\perp}|_{\rm DY} = -f_{1T}^{\perp}|_{\rm DIS}$ Collins; Brodsky,Hwang,Schmidt; Belitsky,Ji,Yuan; Boer,Mulders,Pijlman; Anselmino,D'Alesio,Murgia

- another recent development :
  Fourier transforms of off-forward parton distributions give information on position space distribution of partons

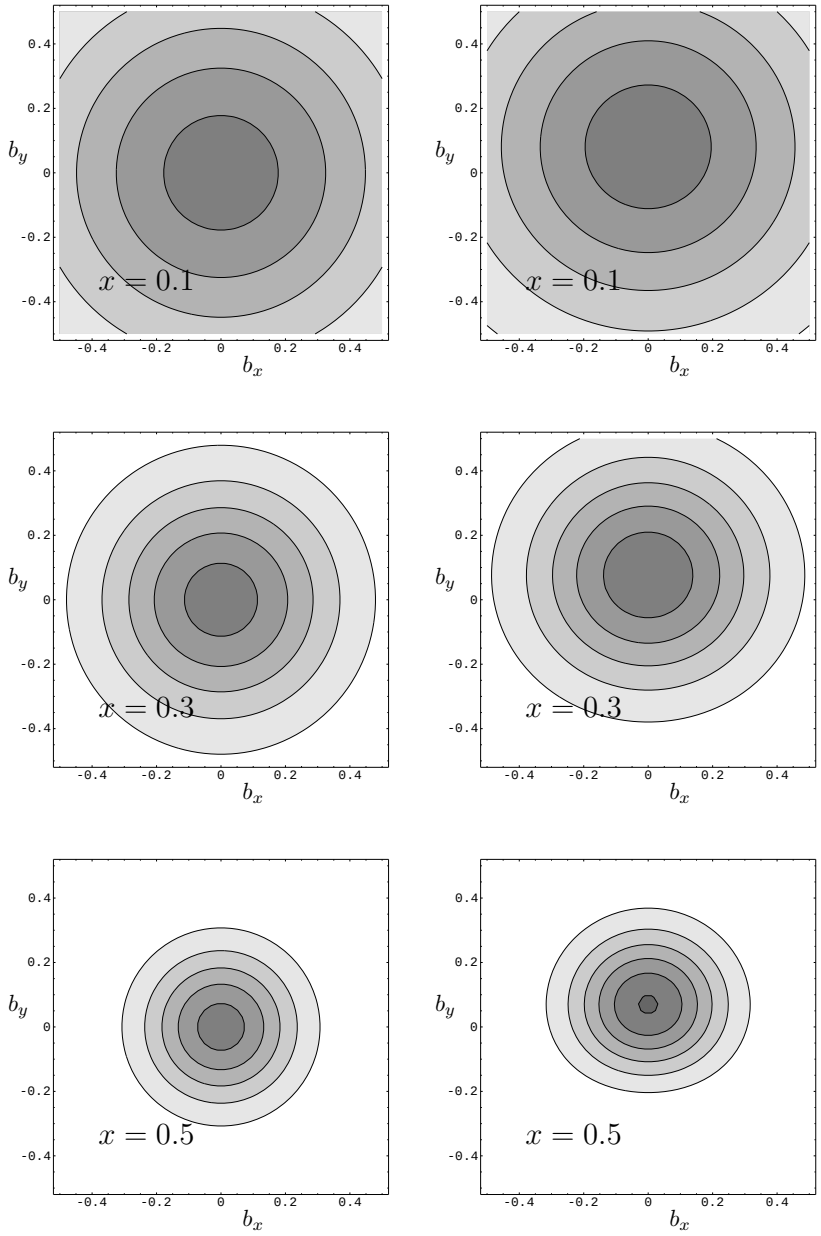
$$q(x, \vec{b}_T) \;=\; \int d^2\Delta_T \; \mathrm{e}^{-i\vec{\Delta}_T \cdot \vec{b}_T} \; H(x, 0, -\Delta_T^2)$$

Burkardt; Ralston,Pire; Diehl

- for transverse nucleon polarization : expect distortion Burkardt
  (Brodsky,Hwang,Schmidt; Ji,Ma,Yuan)
- may lead to A_{N} asymmetry
- connection between $q(x, \vec{k}_T)$ and $q(x, \vec{b}_T)$ Burkardt
- similar in spirit to early "rotating constituent" models
  Boros,Liang,Meng

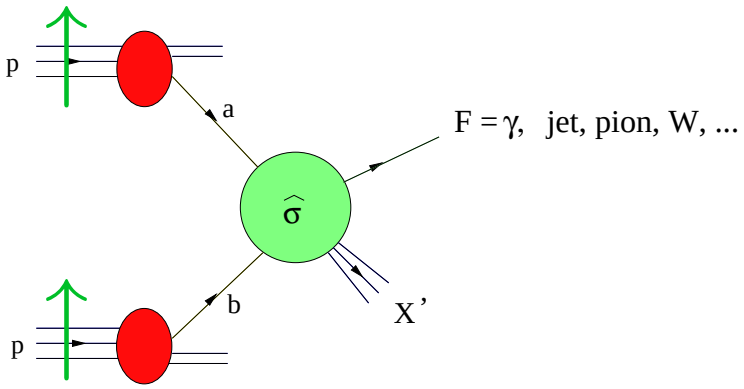
model by Burkardt

$u(x, \mathbf{b}_\perp)$ $u_X(x, \mathbf{b}_\perp)$ ← transverse pol.



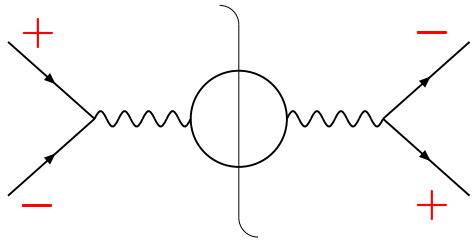
More possibilities for transverse-spin physics at RHIC :

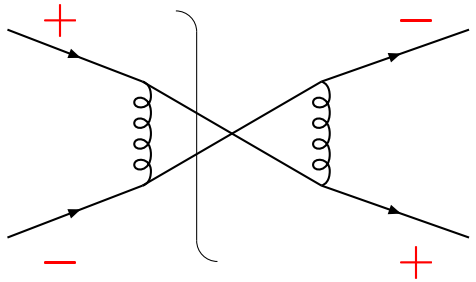
- transversity also from :



$$A_{\mathrm{TT}} = \frac{d\sigma^{p^{\uparrow}p^{\uparrow}} - d\sigma^{p^{\uparrow}p^{\downarrow}}}{d\sigma^{p^{\uparrow}p^{\uparrow}} + d\sigma^{p^{\uparrow}p^{\downarrow}}}$$

  - ∗ Drell-Yan, direct-photon, jets





Predictions : $A_{TT} \ll A_{LL}$

1-jet

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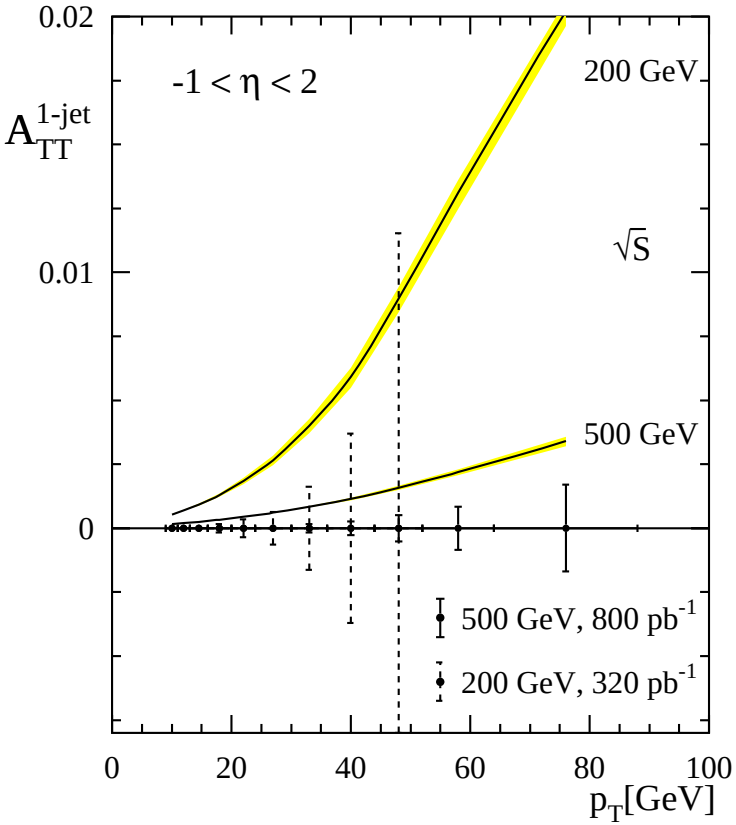
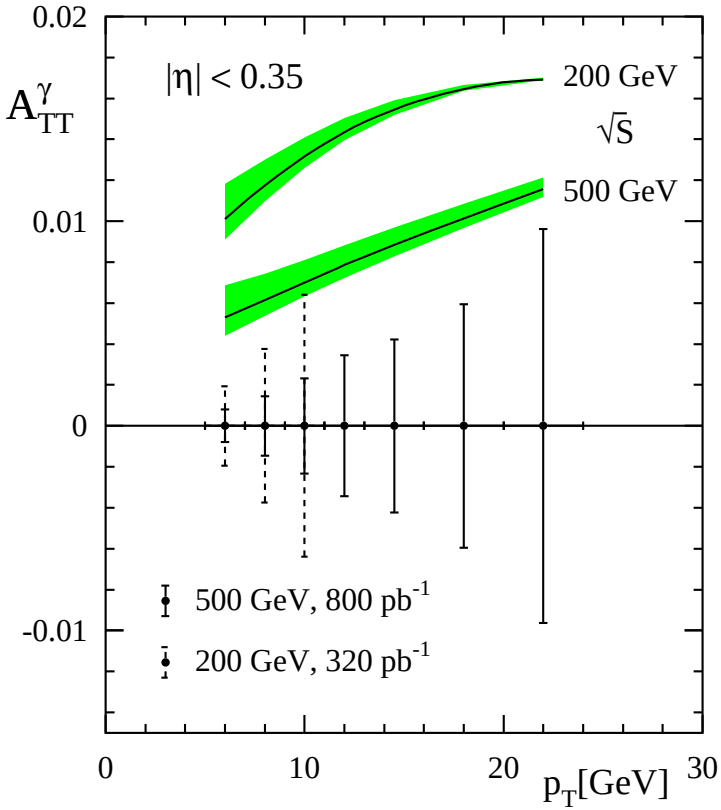


high-p_T photon

PHENIX



Jaffe,Saito; Soffer ,Stratmann,WV; NLO corr. Mukherjee,Stratmann,WV

Enjoy talks of WG "Spin Physics" !