Spin Physics Requiring Upgraded STAR Tracking

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Two basic measurement programs from STAR Decadal Plan:

1) ***$W^{\pm}$ Production in $\vec{p} + \vec{p}$ Collisions***

- *Physics Goal:* **What is the mechanism for producing the $q\bar{q}$ sea?**
- *Measure:* **$\Delta\bar{u}(x)$ vs. $\Delta\bar{d}(x)$ via parity-violating helicity asymmetries**
- *Endcap region important for clean Δq vs. $\Delta\bar{q}$ distinction*
- ***Improved forward tracking essential to distinguish e^+ vs e^-, hence flavor-dependence, important for improved e/h discrimination***

2) ***Transverse Single Spin Asymmetries for Heavy Quark Jets***

- *Physics Goal:* **Can effect of explicit χSB m_q-dependent terms in L_{QCD} be seen in transverse spin asymmetries at high p_T?**
- *Measure:* **transverse analyzing power (sensitivity to incident p spin) for open c,b hadron prod'n; transverse pol'n of outgoing Λ_c^+ or Λ_b (averaging over p spins), via self-analyzing decays**
- ***Microvertex + improved inner tracking needed to identify c,b displaced vertices***

What is the Physical Origin of the $q\bar{q}$ Sea in a Nucleon?

Perturbative: $g \rightarrow q\,\bar{q} \Rightarrow$ **expect:**

$u\bar{u}$ and $d\bar{d}$ in $\approx$ proportions;
$\approx$ contributions to proton spin from $\bar{u}$, $\bar{d}$, $\bar{s}$, s, u_{sea}, d_{sea}

Non-perturbative:

$u \rightarrow d\underbrace{\pi^{+}}_{\sim |u\,\bar{d}\rangle_{0^-}}$

$u \rightarrow s\underbrace{K^{+}}_{\sim |u\,\bar{s}\rangle_{0^-}}$

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Emission and reabsorption of Goldstone bosons $\Rightarrow$ naively expect:

More $\bar{d}$ than $\bar{u}$ in p; ✓

$\Delta\bar{d}/\bar{d} \approx \Delta\bar{s}/\bar{s} \approx 0$, but $\Delta s/s < 0$; ✓ (dotted)

$\langle L_z(\bar{q})\rangle \neq 0$. ?

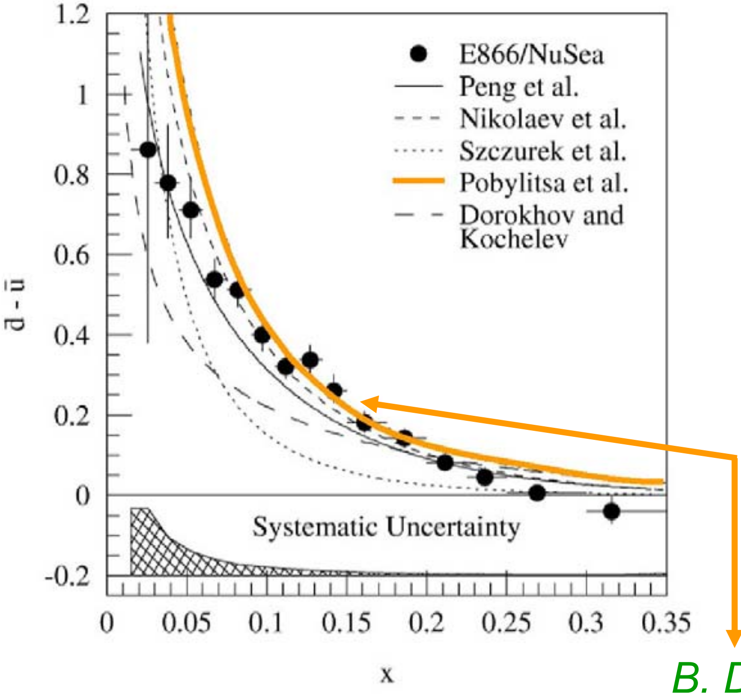
But, $1/N_c$ expansion $\Rightarrow \Delta\bar{u} - \Delta\bar{d} \sim N_c(\bar{d} - \bar{u}) \Rightarrow$ LARGE!

Conclude: would be nice to measure $\bar{q}$ polarization, flavor-dependence directly! Best Method:

$$u + \bar{d} \rightarrow W^{+} + X \rightarrow l^{+} + (\nu) + X$$
$$d + \bar{u} \rightarrow W^{-} + X \rightarrow l^{-} + (\bar{\nu}) + X$$

Weak interaction $\Rightarrow$
parity-violating $\Rightarrow$
$A_L \neq 0$, given by Standard Model

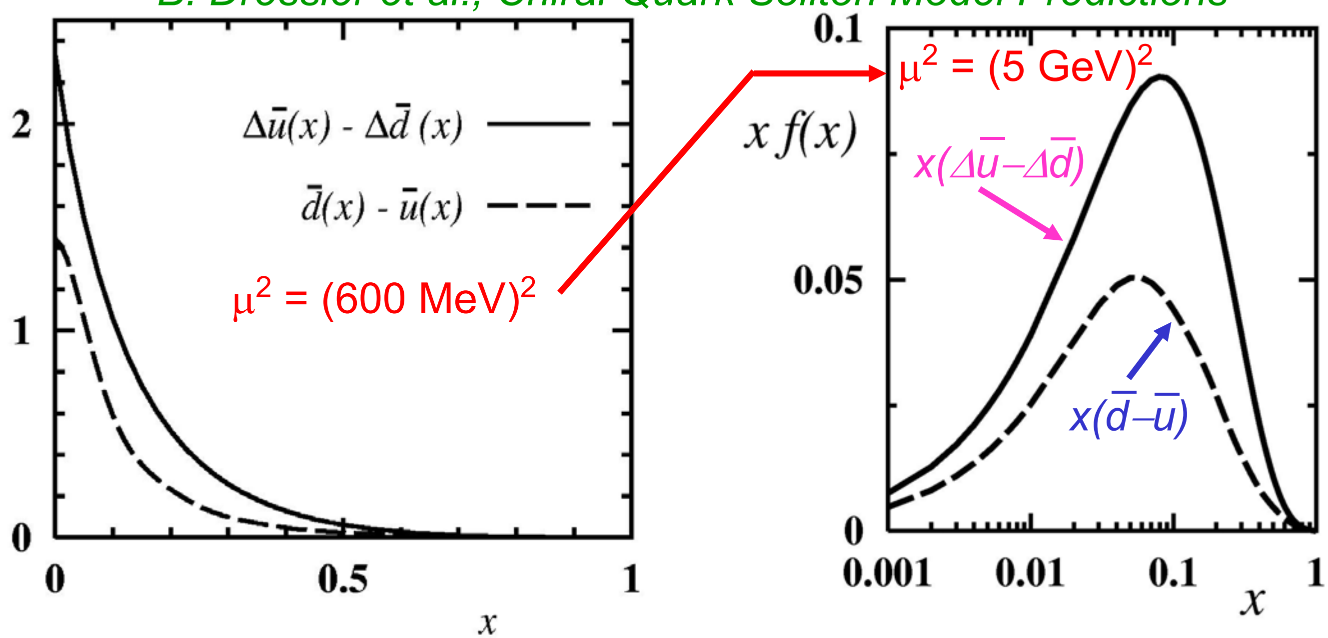
Flavor Asymmetry in the Nucleon Sea



- ➢ ***FNAL E866 compared Drell-Yan for p+d to p+p, to reveal sizable unpolarized flavor asymmetry $\bar{d}(x)-\bar{u}(x)$.***
- ➢ ***Results are qualitatively consistent with pion cloud models, instanton models, chiral quark soliton models, etc.***
- ➢ ***Chiral quark soliton model is appropriate in large-N_c limit of QCD: Dirac quarks bound in collective pion field to model χSB.***

- ➢ ***Is there a large flavor-dependence of $\bar{q}$ polarizations in the proton?***
- ➢ ***Most quark-based models predict $\int_0^1[\Delta\bar{u}(x)-\Delta\bar{d}(x)]dx \geq \int_0^1[\bar{d}(x)-\bar{u}(x)]dx$ most meson-based models disagree***

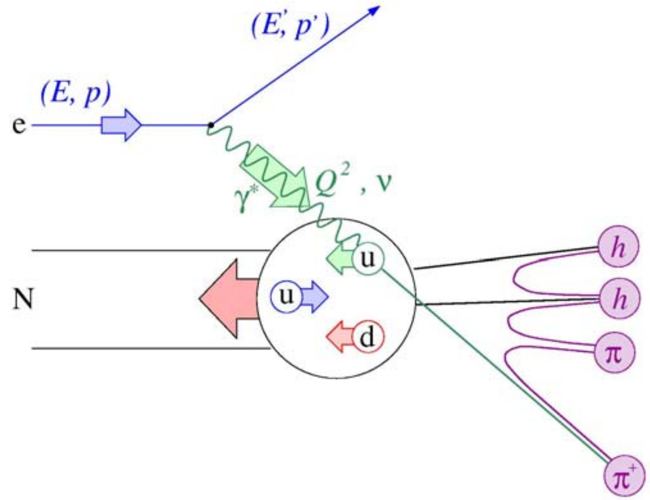
B. Dressler et al., Chiral Quark Soliton Model Predictions



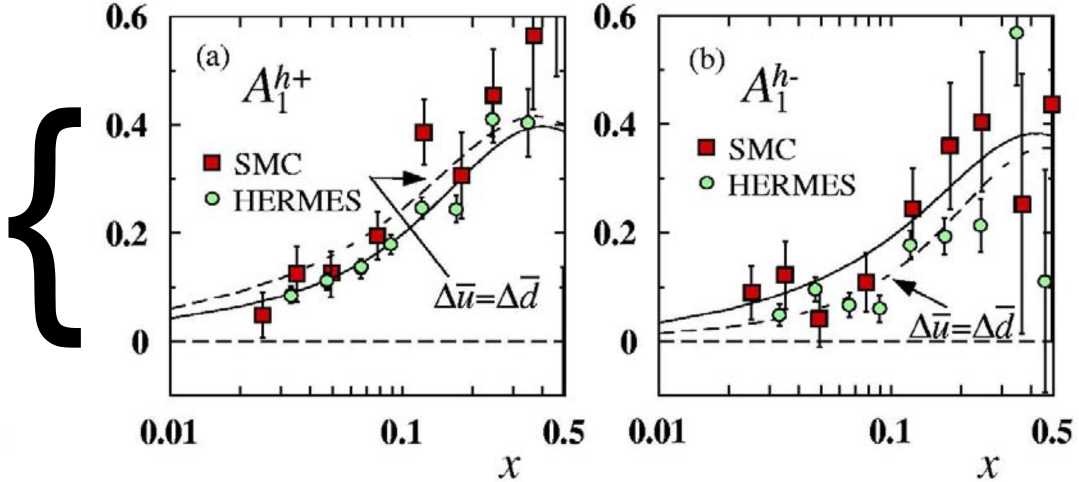
Two Proposed Methods for Probing Polarized Flavor Asymmetry Have Quite Different Sensitivities

SIDIS sensitivity reduced by fragmentation functions and e_q^2 weighting

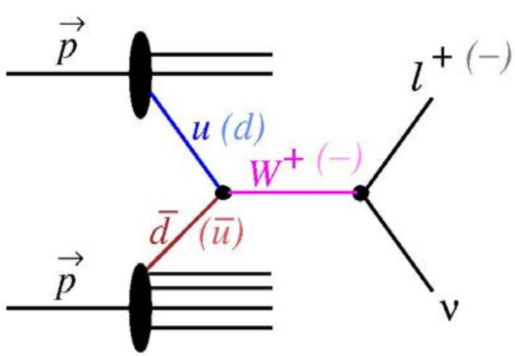
Semi-Inclusive DIS: $\vec{e} + \vec{N} \rightarrow e' + h + X$

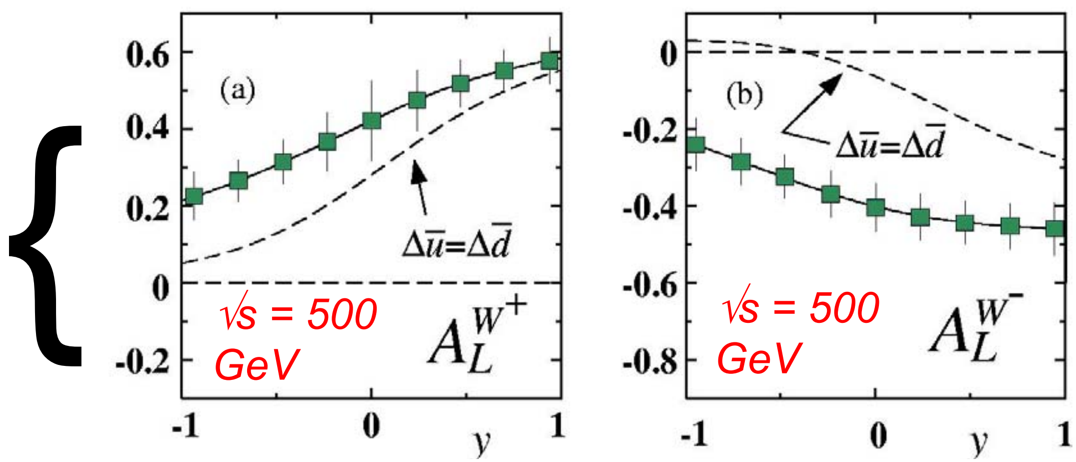


B. Dressler et al. Predictions



$W^{\pm}$ Production at RHIC





New HERMES SIDIS Results…

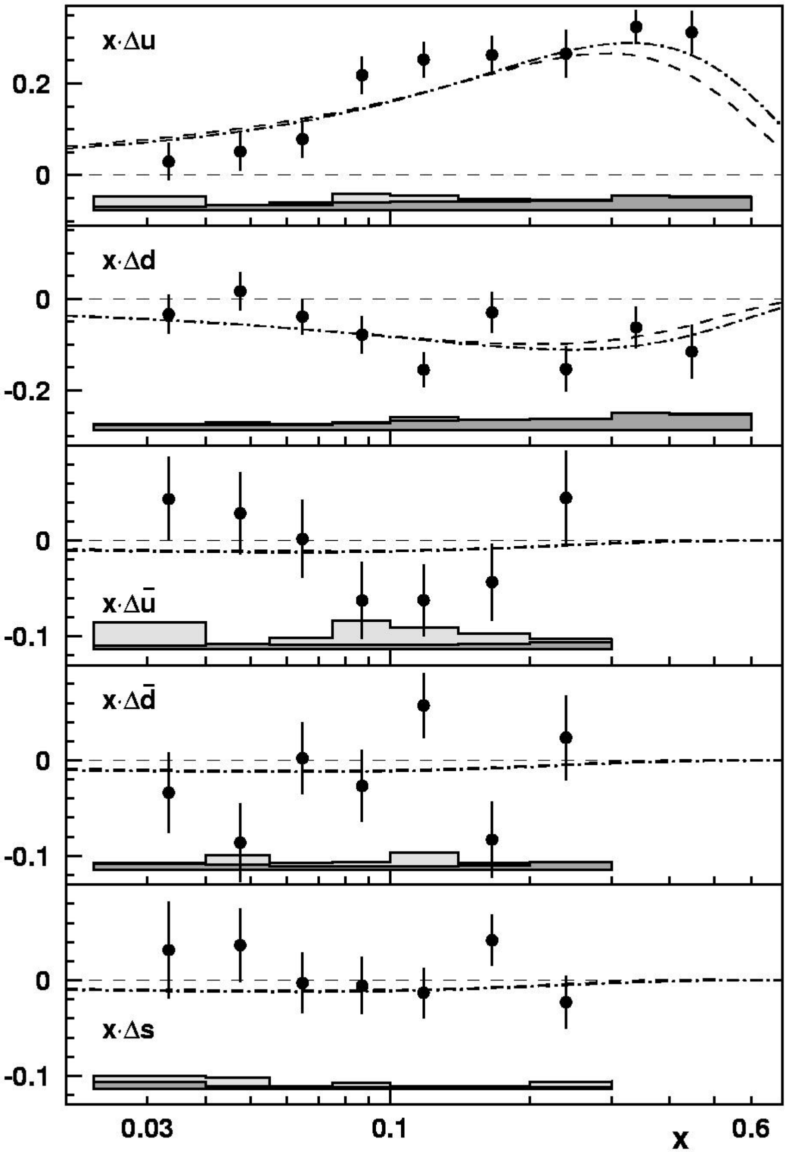
…do not appear to support either large positive $\Delta\bar{u}-\Delta\bar{d}$ or negative Δs

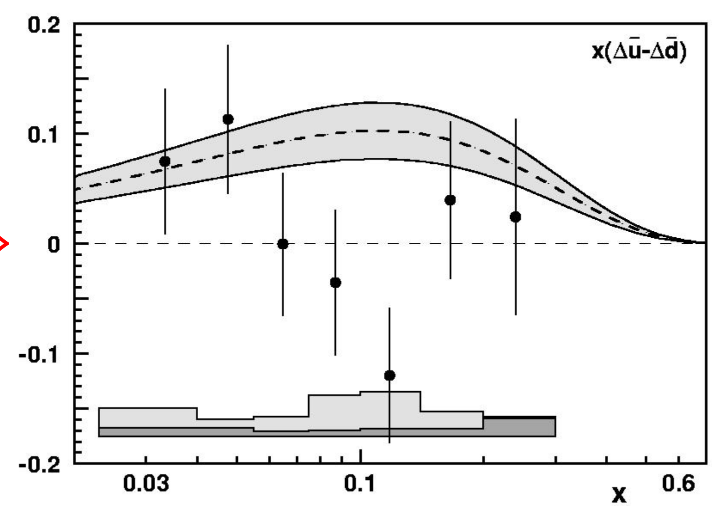
But, error bars are large and questions have been raised regarding analysis details.

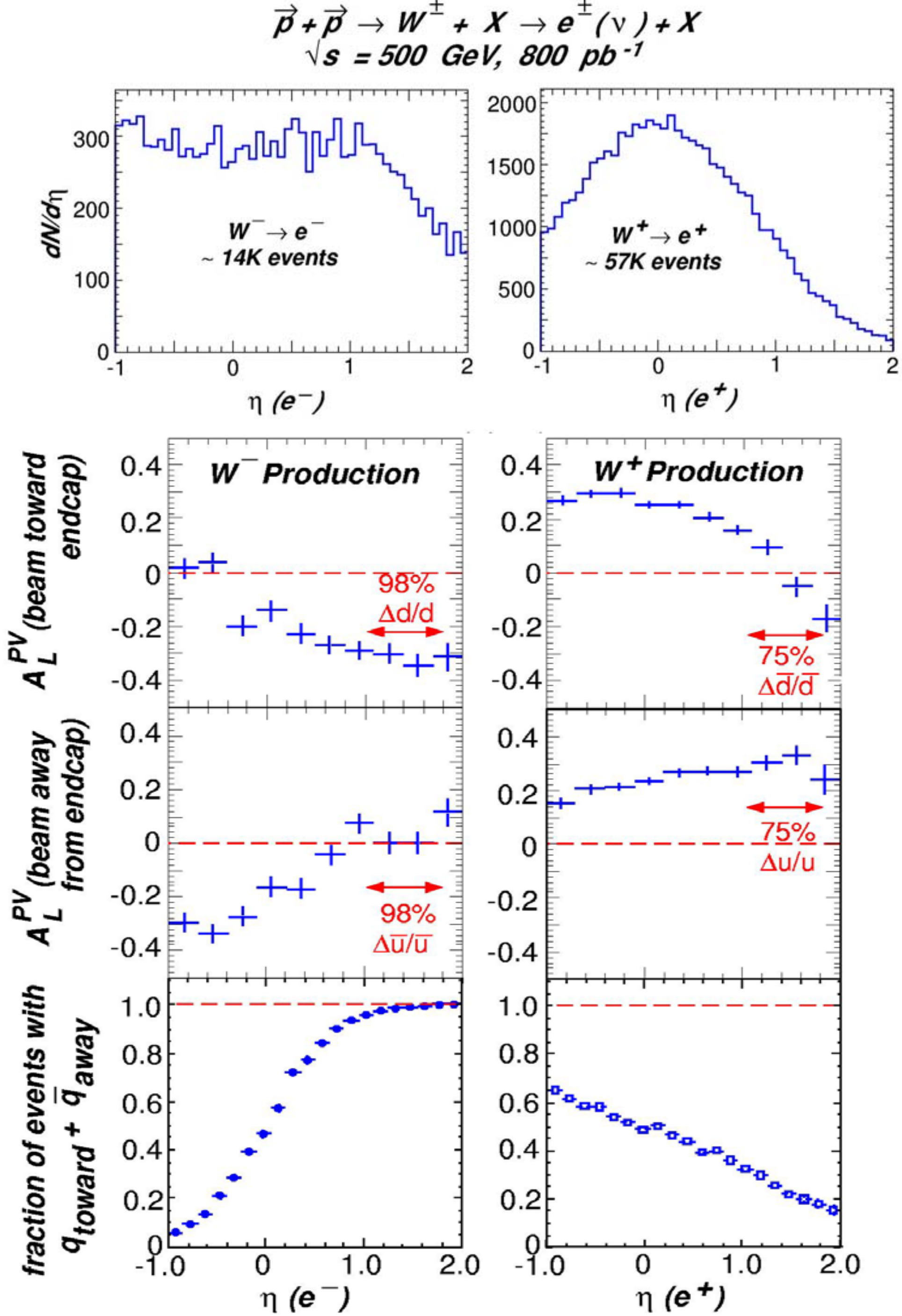
See:

A. Airapetian et al., hep-ex/0307064

A.N. Sissakian et al., hep-ph/0307189





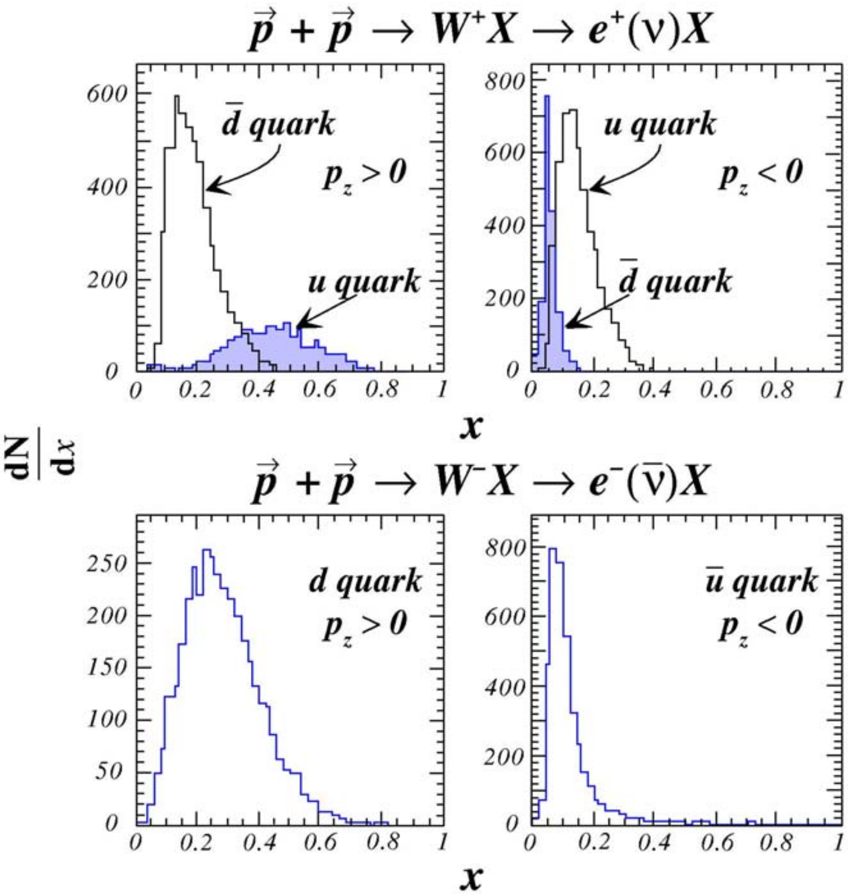


STAR Simulations of W Prod'n

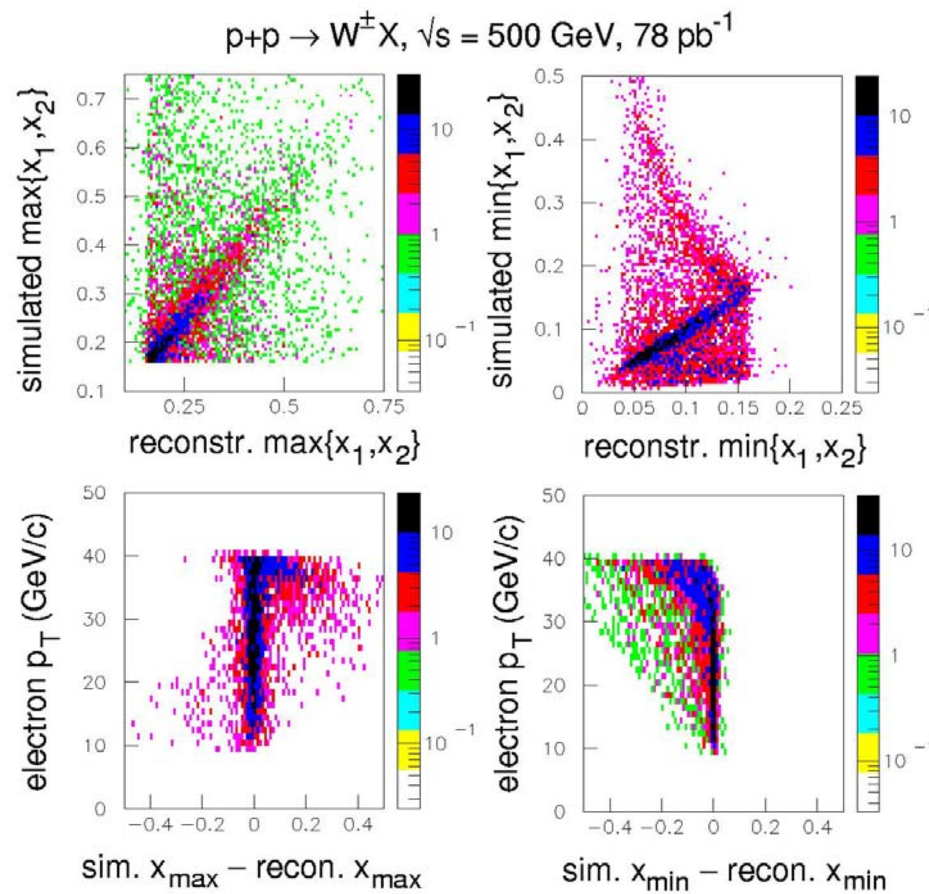
L.C. Bland

- ➢ LO only (NLO doesn't alter qualitative conclusions): $u\bar{d} \to W^+$; $d\bar{u} \to W^-$
- ➢ Detect via $e^{\pm} \Rightarrow$ kinematic differences in acceptance:
  - ❖ W momentum in dir'n of higher-x parton (usually q)
  - ❖ PV decay of L-handed $W^{\pm} \oplus$ CP $\Rightarrow$ in W rest frame: e^+ (e^-) emitted pref'ly along (opposite) W^+ (W^-) spin
  - ❖ $\Rightarrow e^-$ focused in q dir'n; e^+ more spread out
  - ❖ for W^- prod'n, e^- in endcap pref'ly probes $d_{toward}\,\bar{u}_{away}$ collisions
- ➢ 2 charges $\otimes$ 2 single-spin PV asyms. constrain Δu, Δd, $\Delta\bar{u}$, $\Delta\bar{d}(x)$
- ➢ Separation of antiquark and quark polarizations is kinematically cleanest in endcap region (opposite for W^+,W^-)

Bjorken x Sensitivity of STAR W Prod'n



- $1 \leq \eta_e \leq 2$ probes either asymmetric $q_{toward}\ \bar{q}_{away}$ or $\approx$ symmetric $\bar{d}_{toward}\ u_{away}$ collisions.
- Sensitivity generally good for $x_{\bar{q}} \approx 0.1$, where chiral soliton model predicts largest flavor dep. of $\Delta\bar{q}/\bar{q}$



- One may approximately reconstruct $x_{1,2}$ from $\eta(e)$, $p_T(e)$ event-by-event from 2-body fusion + 2-body decay, i.e., neglecting W width + transverse mom.

$\sqrt{x_1 x_2} = M_W / \sqrt{s} = 0.16$ @ $\sqrt{s} = 500$ GeV;

$(x_1 - x_2)/(x_1 + x_2) = \tanh[\eta_e^{meas} - \eta_e^{rest}] = \tanh[\eta_e^{meas} - \cosh^{-1}(M_W / 2p_T^{meas})]$

Experimental Issues for W Detection in STAR

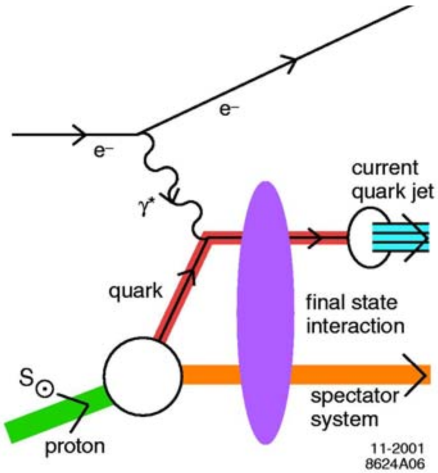
- **Triggering:** easy – very large p_T in single EMC tower (B or E)
- **e/h Discrimination:** ~ 1 order of magnitude apiece from:
  - *Isolation of detected particle from other jet fragments*
  - *Absence of accompanying jet at opposite azimuth (dijet rejection cut serves as "poor man's" missing energy cut)*
  - *EMC response: $E_{preshower}$, E_{SMD}, $E_{postshower}$ (for EEMC) vs. E_{shower} ; E_T (EMC) vs. p_T (TPC + fwd. Tracking)*

should ⇒ W signal/hadron bkgd > 1 for $p_T^e > 20$ GeV/c (most of W decay phase space), but improved p_T determination very useful!

- **e^+ vs. e^- Charge Sign Discrimination:** OK for BEMC, but needs improved forward tracking for EEMC! (see N. Smirnov simulations)

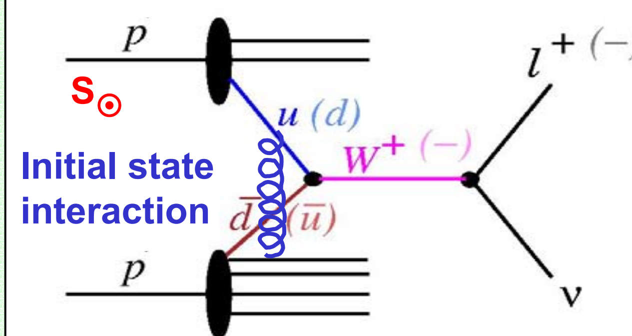
More Speculative Spin-Flavor Structure Determinations via W Production

- Single-spin transverse (non-PV) asymmetry A_N for $W^{\pm}$ production at $p_T(W) \neq 0$ can aid in distinguishing transverse motion of partons from transverse spin alignment in a transversely polarized proton: both contribute to A_N in hadronic processes, but W's do not couple to transverse quark spin, $\therefore$ can map flavor-dep. of $q,\bar{q}$ $\vec{k}_T$ preference.



Sivers-effect mechanisms for transverse single-spin asyms. in SIDIS and RHIC W prod'n:

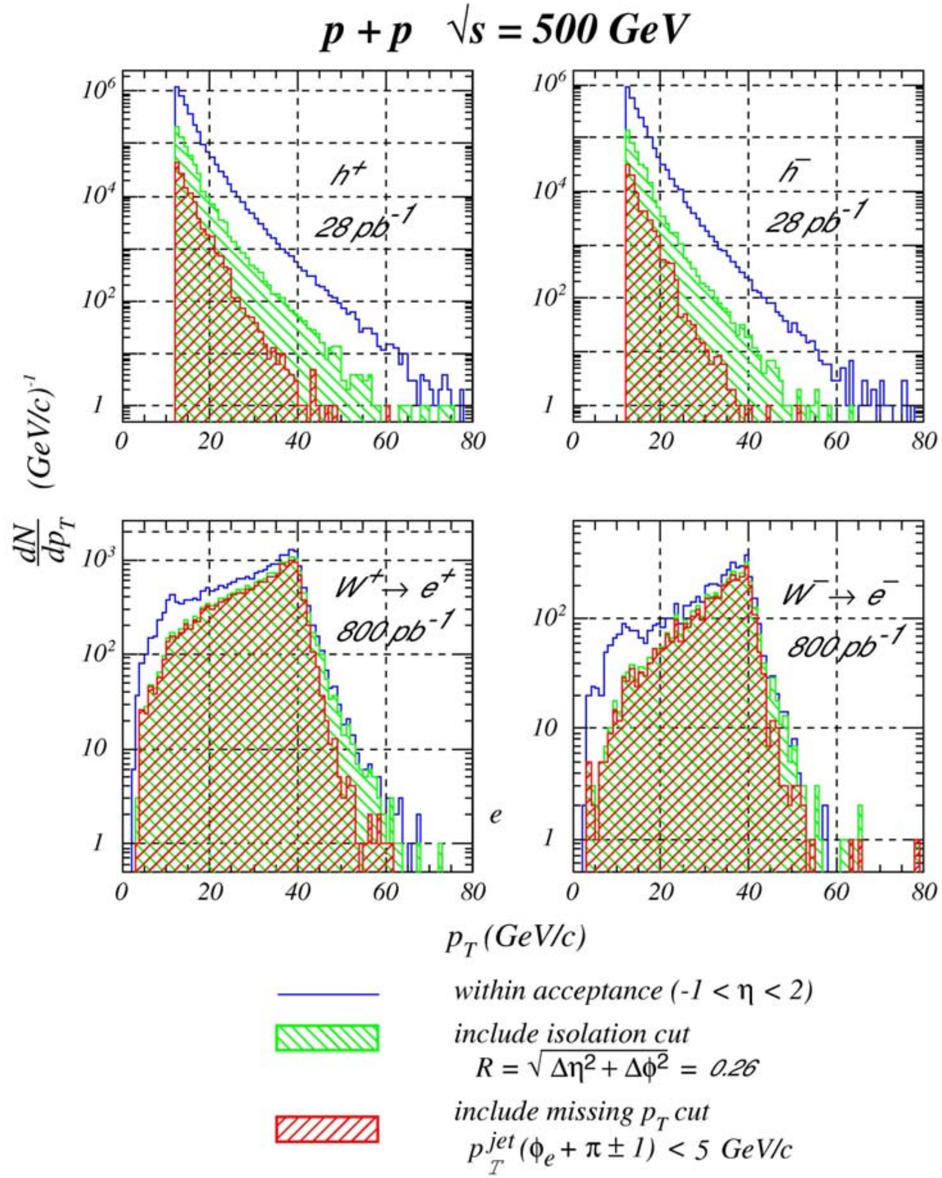
from T-odd $\langle \vec{S}_p \bullet (\vec{p}_p \times \vec{k}_T) \rangle \neq 0$, allowed by FSI or ISI phases – related to $\langle \vec{S} \bullet \vec{L} \rangle$, anomalous magnetic moment in proton



- PV helicity asymmetry A_L for $W^+ \rightarrow e^+$ detected in coinc. with spectator n in ZDC can probe dominance of Goldstone bosons ($0^- \Rightarrow$ unpolarized d) in $|n\ \mathrm{meson}\rangle$ configurations of proton: this measurement requires well beyond "enhanced" pp design luminosity!

Table 2. Prediction of various theoretical models on the integral $I_\Delta = \int_0^1 [\Delta\bar{u}(x) - \Delta\bar{d}(x)]dx$. ***(from J.C. Peng)***

Model	I_Δ prediction	Ref
Meson cloud (π-meson)	0	[42,
Meson cloud (ρ-meson)	$\simeq -0.0007$ to -0.027	[34]
Meson cloud ($\pi - \rho$ interf.)	$= -6\int_0^1 g^p(x)dx$ $\simeq -0.7$	[35]
Meson cloud (ρ and $\pi - \rho$ interf.)	$\simeq -0.004$ to -0.033	[36]
Meson cloud (ρ-meson)	< 0	[37]
Meson cloud ($\pi - \sigma$ interf.)	$\simeq 0.12$	[44]
Pauli-blocking (bag-model)	$\simeq 0.09$	[36]
Pauli-blocking (ansatz)	$\simeq 0.3$	[45]
Pauli-blocking	$= \frac{5}{3}\int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ $\simeq 0.2$	[46]
Chiral-quark soliton	0.31	[47]
Chiral-quark soliton	$\simeq \int_0^1 2x^{0.12}[\bar{d}(x) - \bar{u}(x)]dx$	[48]
Instanton	$= \frac{5}{3}\int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ $\simeq 0.2$	[39]
Statistical	$\simeq \int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ $\simeq 0.12$	[49]
Statistical	$> \int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ > 0.12	[50]



Transverse Spin Asymmetries in Heavy Quark Production

Factorization:

Hard hadronic ampl. = PDF's $\otimes$ hard partonic ampl. $\otimes$ fragment'n fcn.

Non-pert. — pQCD — Non-pert.

Chiral symmetry of QCD (for $m_q \to 0$) $\Rightarrow$ no helicity flip $\Rightarrow$

$$\hat{a}_N^{partonic} \to 0 \text{ at leading twist}$$

Observed hadronic $A_N \neq 0$ (generally @ moderate p_T) usually attributed to T-odd spin-k_T correlation in the 1st [e.g., Sivers effect: $\vec{s}_{inc} \bullet (\vec{p}_{inc} \times \vec{k}_T^{parton})$] or 3rd [Collins effect: $\vec{s}_q \bullet (\vec{p}_{jet} \times \vec{k}_T^{fragment})$] non-perturbative factors above.

However, L_{QCD} contains (explicit chiral symmetry breaking) terms $\propto m_q q\bar{q}$ for $m_q \neq 0 \Rightarrow$ expect:

$$\hat{a}_N^{partonic} \sim (m_q / E_q)\, \alpha_{strong}$$

Negligible for hard processes and light quarks (u,d,s), but not necessarily for c or b quarks!

$\Rightarrow$ Measure 1-spin transverse spin asymmetries for prod'n of charmed or bottom hadrons, to look for m_q-dependent effects of perturbative origin.

Caveats & Rates

Dominant prod'n mechanism likely $gg \to c\bar{c}$, $b\bar{b}$. But g doesn't share p transverse spin, so unlikely to generate $A_N \neq 0$ of pQCD origin.

$\Rightarrow$Measure either P_N of outgoing Λ_c^+ or Λ_b^0, via their self-analyzing weak decay to lighter Λ's + leptons (polarized beams not necessary for this!), and compare to Λ^0 or measure A_N for kinematics chosen to emphasize $qq \to c\bar{c}$, $b\bar{b}$ (e.g., high p_T, asymmetric collisions: one jet in EEMC, one at mid-rapidity)

No simulations yet performed to flesh out these ideas!

Total cross section for $b\bar{b}$ prod'n within STAR, p_T = 10-20 GeV/c:

$\sigma_{b\bar{b}}$ ~ 10 nb (R. Vogt calcs.) $\Rightarrow$ ~ 2×10^6 pairs produced in 200 pb^{-1}

Interesting sensitivity level to $A_N = \pm 0.01 \Rightarrow$ need ~ 2×10^4 events analyzed $\Rightarrow$ need:

Trigger (high-p_T e in EMC) eff. $\times$ APS/inner tracker vertex acceptance $\times$ reconstruction eff. $\times$ relevant kinematic cut acceptance ~ 1%