W Physics at RHIC

Werner Vogelsang

BNL Nuclear Theory

2007 RHIC/AGS Users Meeting

Outline:

- Introduction
- Basics of W production at RHIC
- Theory aspects
- Future opportunities
- Conclusions

Workshop On:
Parity-Violating Spin Asymmetries at RHIC

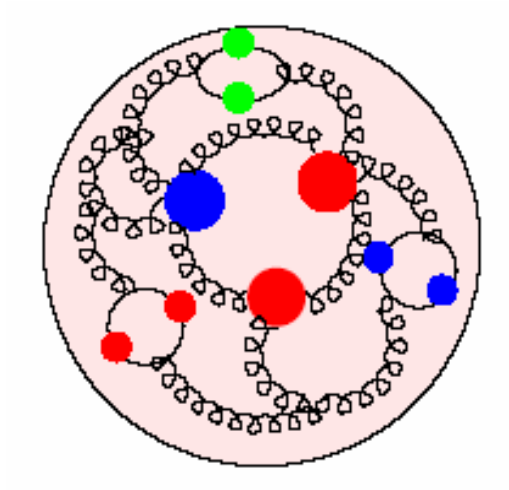
Date:	April 26-27, 2007
Location:	Brookhaven National Laboratory (BNL) Physics Department, Bldg 510, Large Seminar Room
Organizers:	Werner Vogelsang (BNL), Matthias Perdekamp (RIKEN-BNL and University of Illinois), Bernd Surrow (Massachusetts Institute of Technology)
Sponsors:	Brookhaven National Laboratory

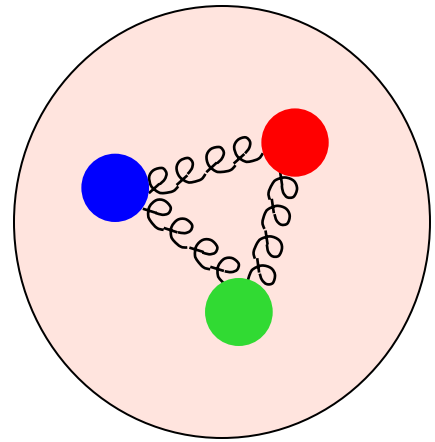
Material from talks by

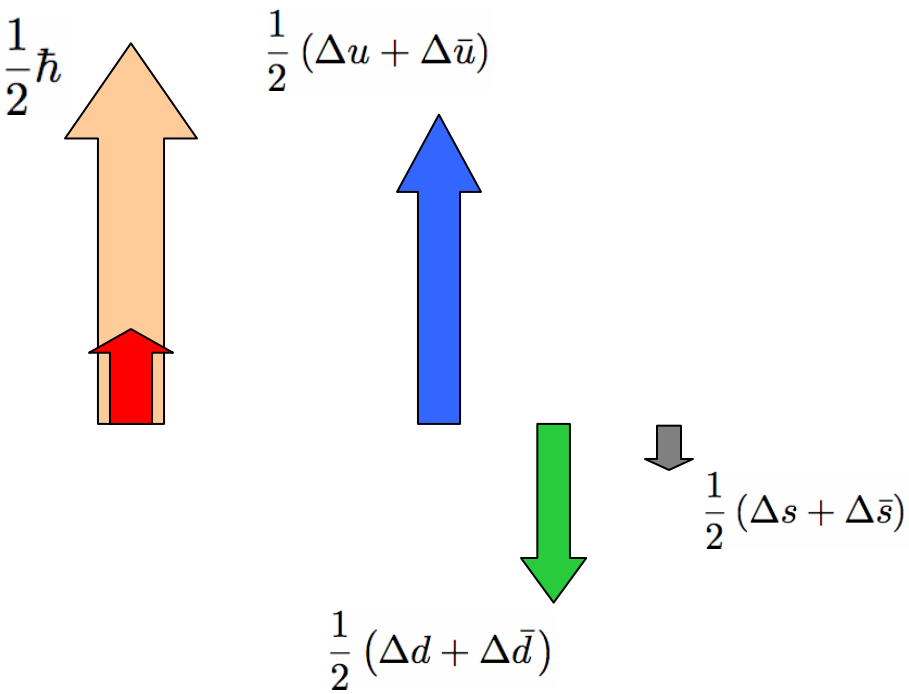
- C. Weiss
- P. Nadolsky
- S. Arnold
- A. Mukherjee
- H. Yokoya

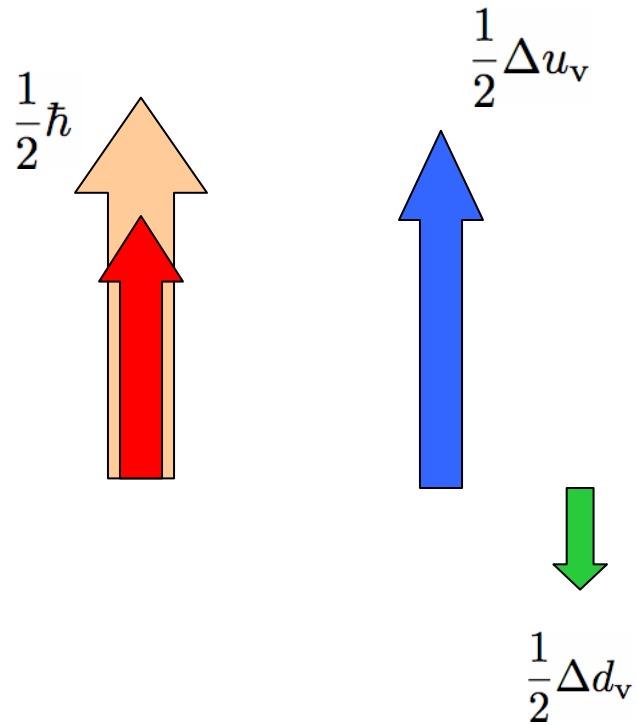
I. Introduction

Current "spin budget" of the nucleon:





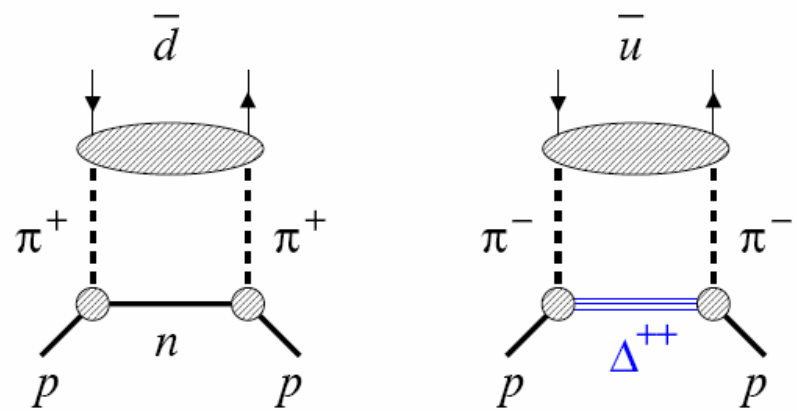




- correct picture? (relies on symmetries, F,D)
- important role played by sea ?
- would like to know more: $\Delta\bar{u}$ vs. $\Delta\bar{d}$ vs. $\Delta\bar{s}$ etc.
- Nucleon models make predictions, for example:

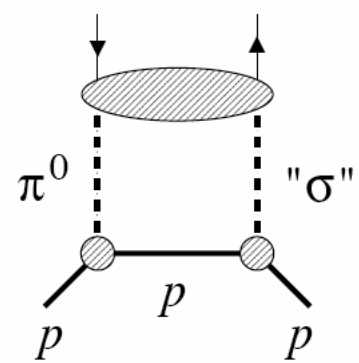
Pion cloud

Sullivan; Thomas



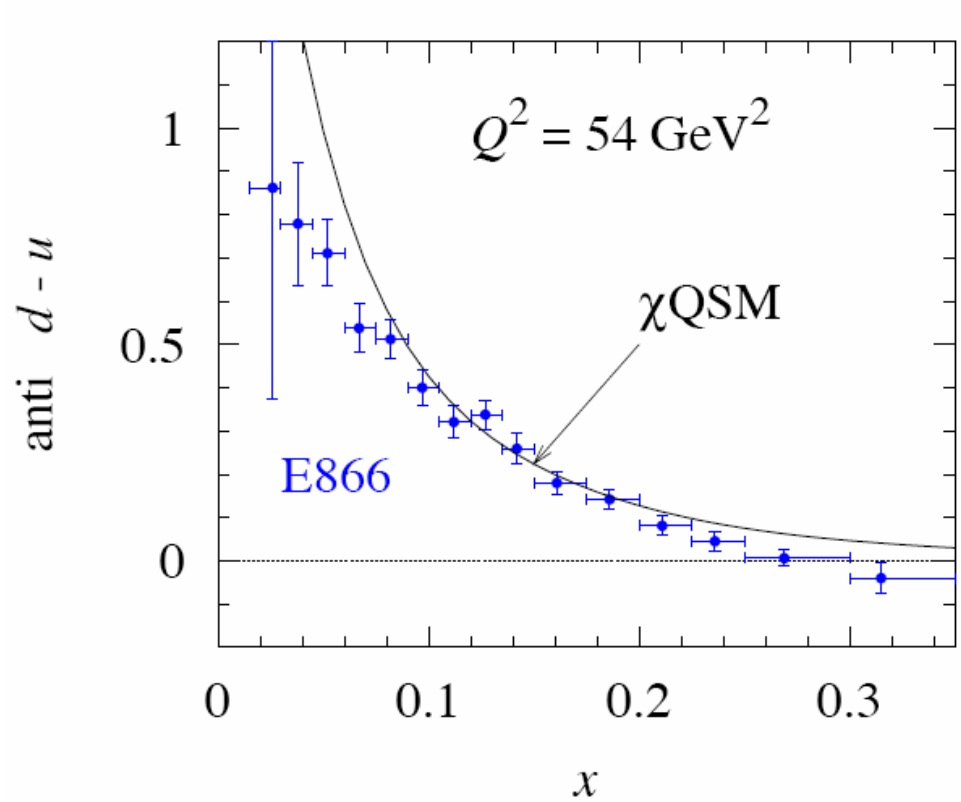
$$\bar{d} > \bar{u}$$

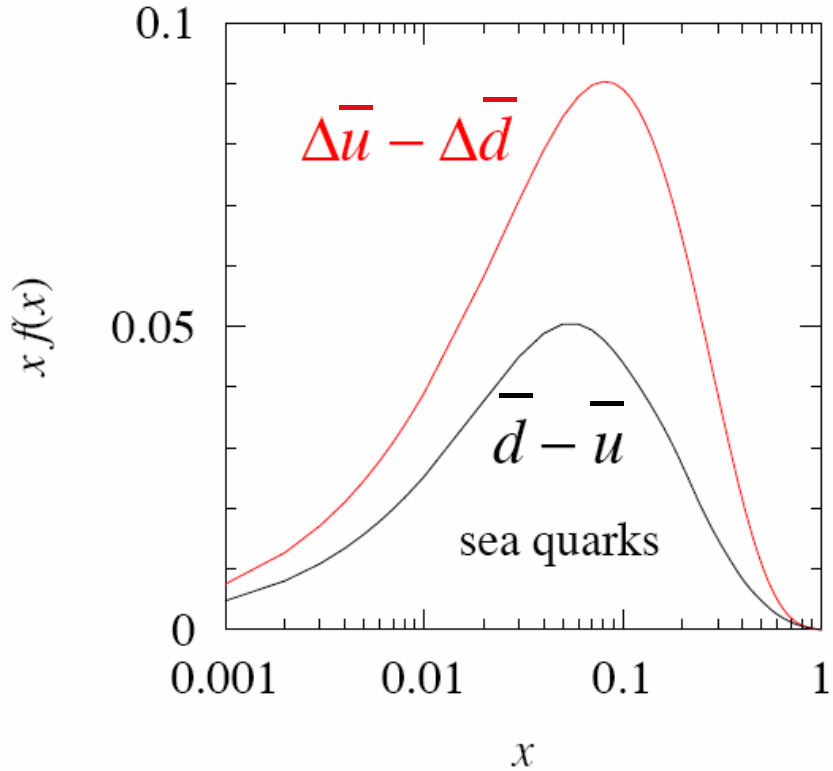
Dressler;
Fries, Schäfer, Weiss



$$\Delta\bar{u} - \Delta\bar{d} > 0$$

Large-N_c , χ Quark Soliton

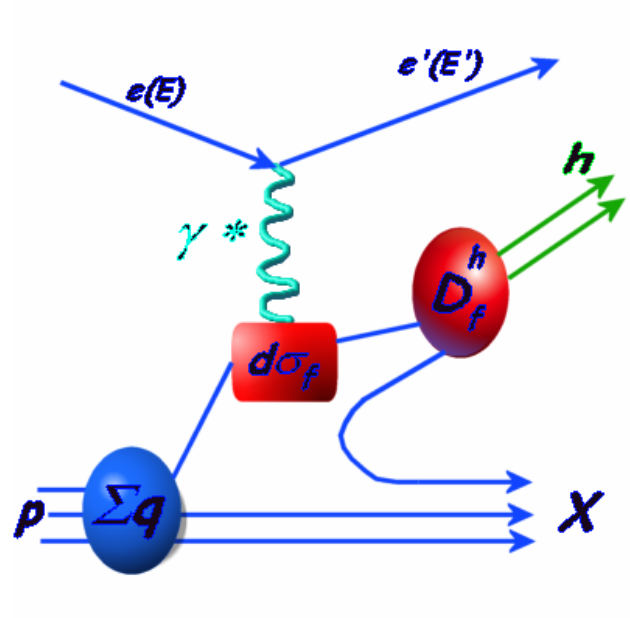




$$|\Delta\bar{u} - \Delta\bar{d}| > |\bar{u} - \bar{d}|$$

Diakonov et al.; Dressler et al.; …

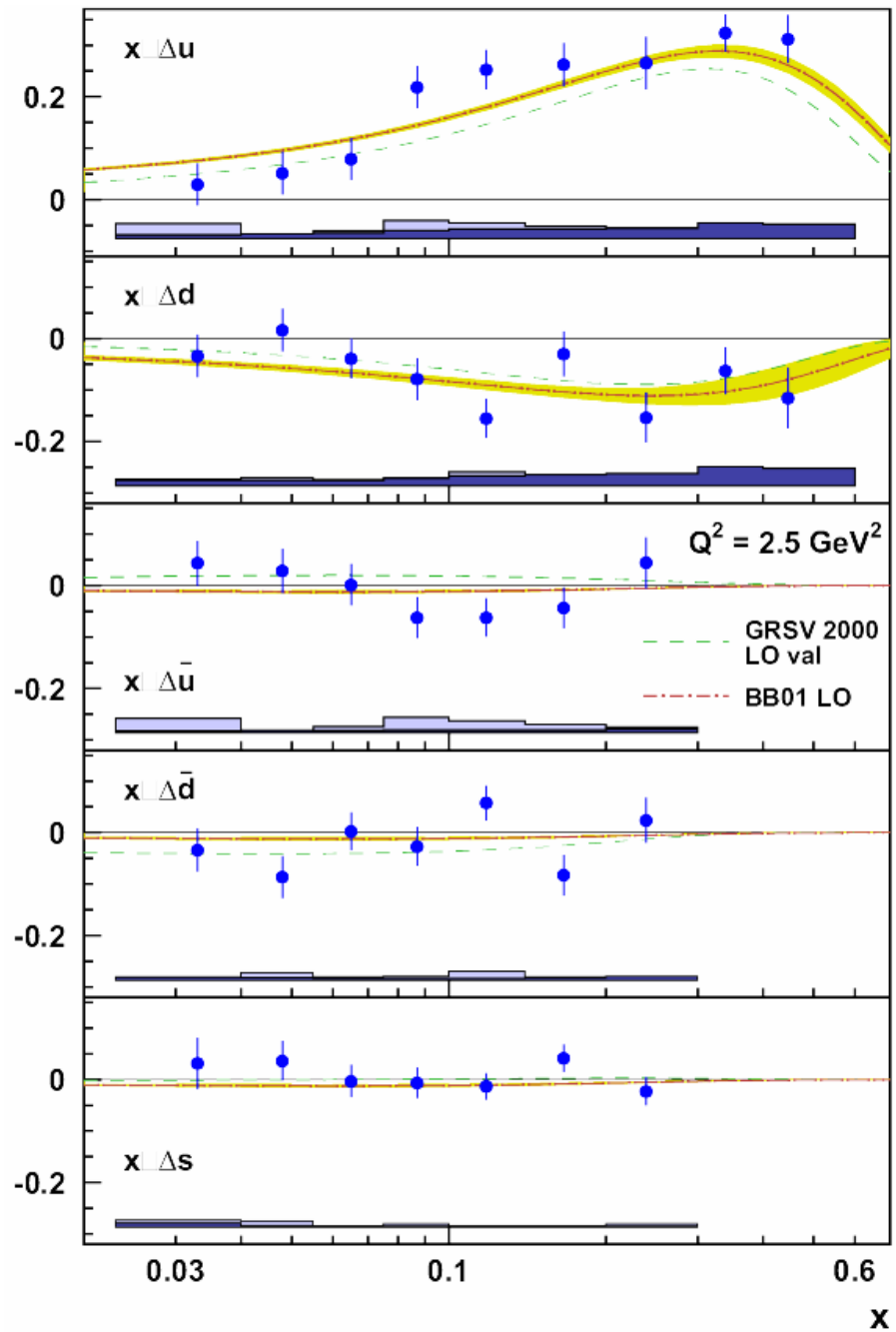
Little is known so far: "SIDIS"

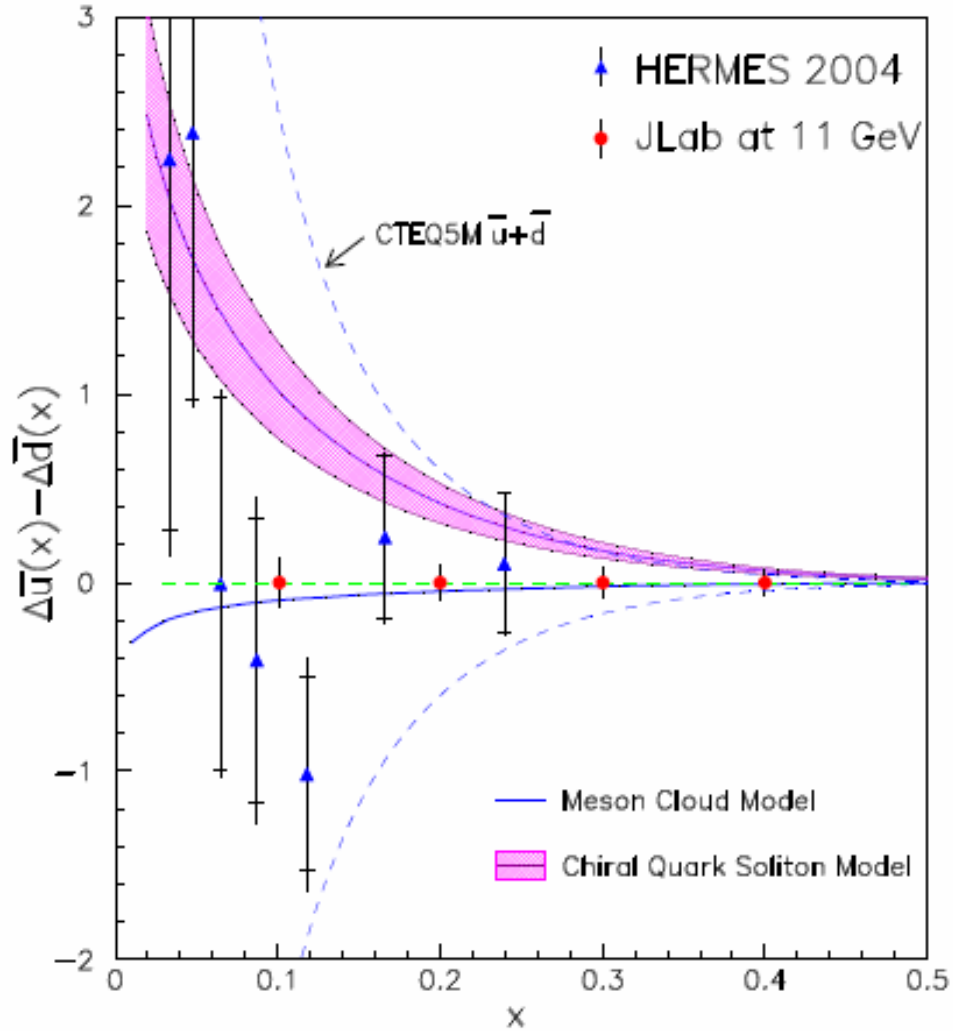


HERMES, COMPASS, JLab

- inconclusive
- large inherent uncertainties

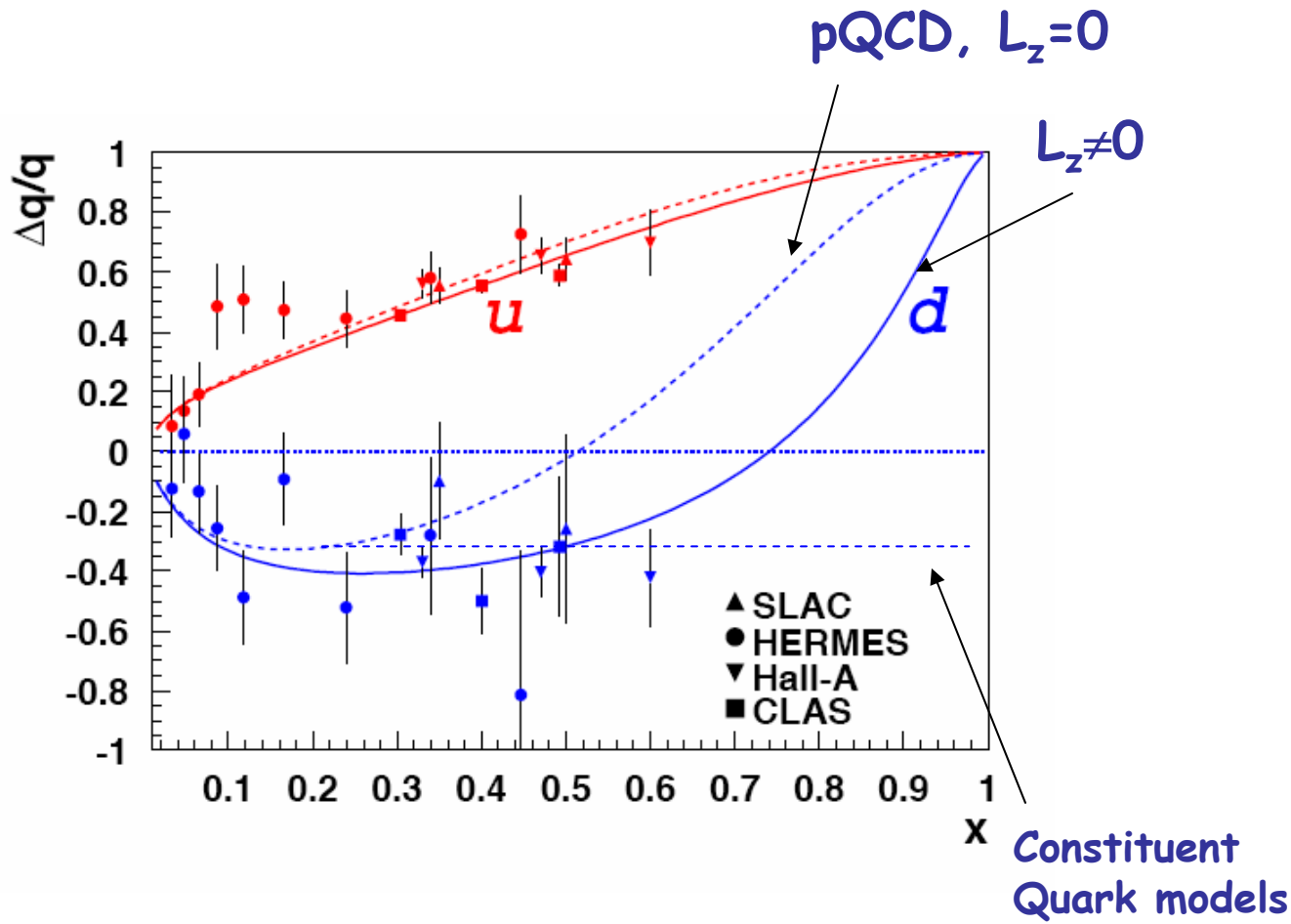
HERMES




HERMES 2004
JLab at 11 GeV
CTEQ5M $\bar{u}+\bar{d}$
Meson Cloud Model
Chiral Quark Soliton Model
$\Delta\bar{u}(x)-\Delta\bar{d}(x)$
x
3
2
1
0
−1
−2
0
0.1
0.2
0.3
0.4
0.5

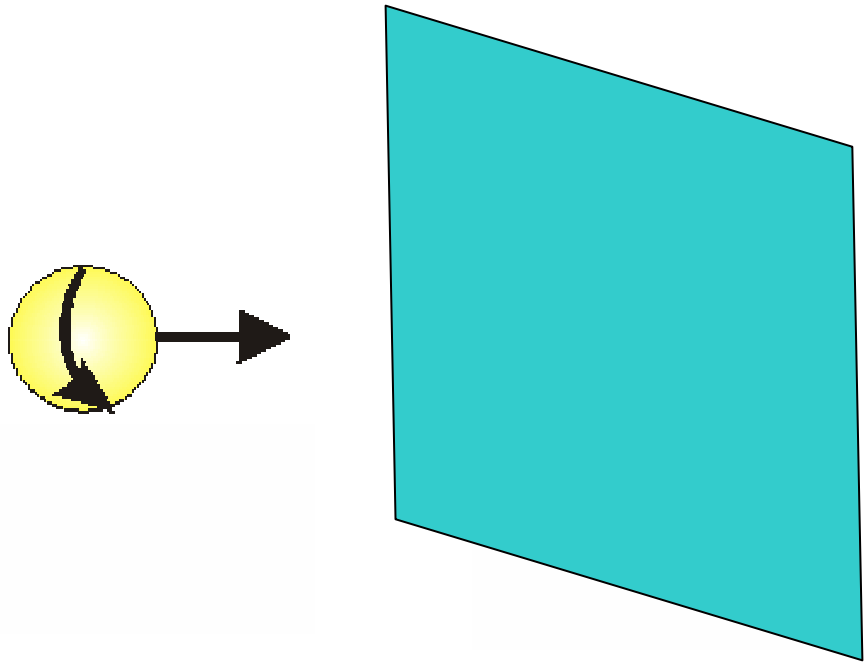
Avakian, Brodsky, Deur, Yuan

- also specific interest in large-x region :



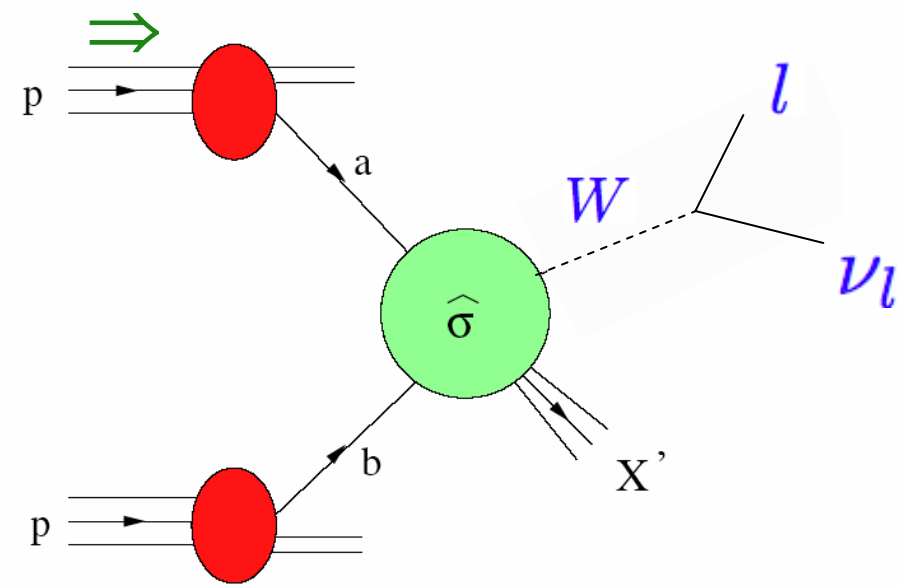
II. Basics of W production at RHIC

At RHIC:



If parity conserved:

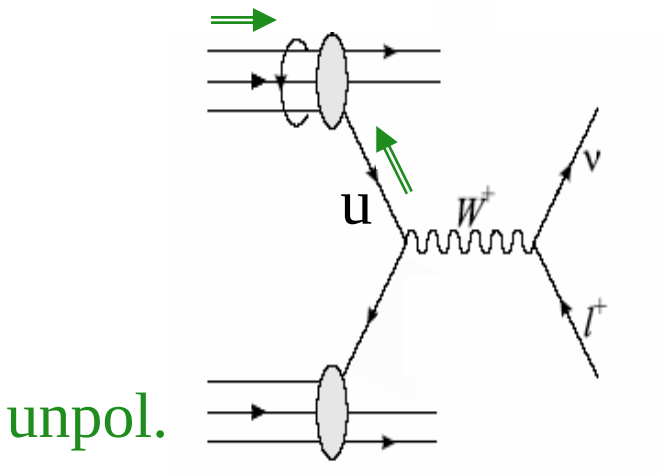
$$\mathbf{A_L} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \mathbf{0}$$



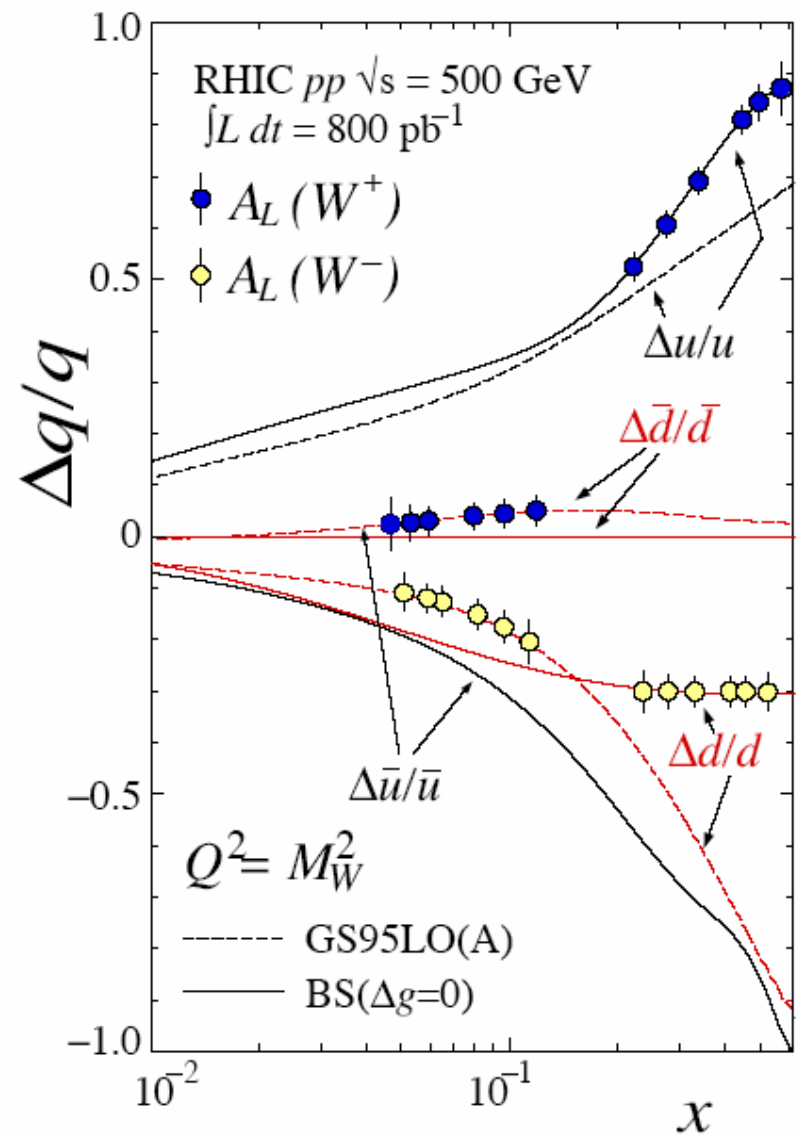
$$d\sigma^+ - d\sigma^- = \sum_{f_1,f_2} \int dx_1 \int dx_2 \; \Delta f(x_1, M_W^2)\; f(x_2, M_W^2)\; \left[d\sigma^+ - d\sigma^-\right]_{f_1 f_2 \to W} + \mathcal{O}\left(\frac{\lambda^2}{M_W^2}\right)$$

universal

partonic scatt.
perturbative QCD



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



- large scale Q~M_W: pQCD
- complementary to SIDIS, cleaner
- large asymmetries "guaranteed" (at large x)

- typically probed values of x relatively large (smallest accessible x is $M_W^2/S \sim 0.03$)
- will get only small part of first moments of pdfs
- to test model predictions, x-dependence actually more relevant
- recall, also large-x region an area for model predictions (and the lattice)
- ultimately, become part of "global analysis" of all RHIC data

III. Theory aspects

Main issues:

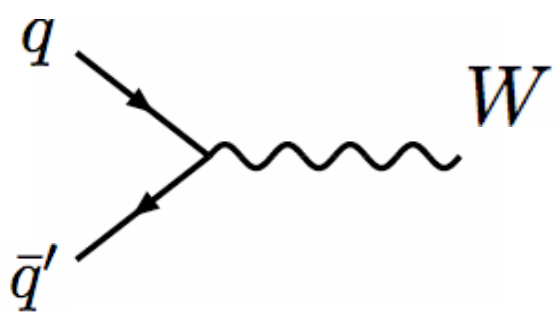
- radiative corrections:
  higher-order QCD corrections

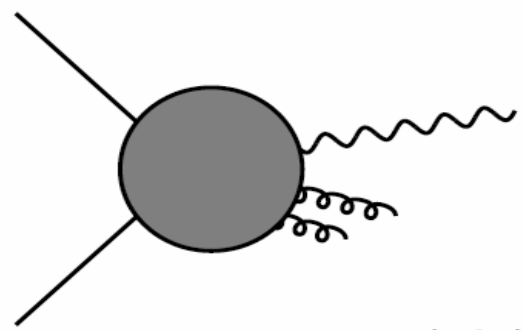
- take into account W decay :
  y_{lepton} instead of y_W (RHIC acceptance !)
  Hadronic decays (2 jets) ?

Best developed tool: RhicBos

P. Nadolsky, C.P. Yuan

- Monte-Carlo integrator with NLO and NNLL $q_\perp$ resummation accuracy



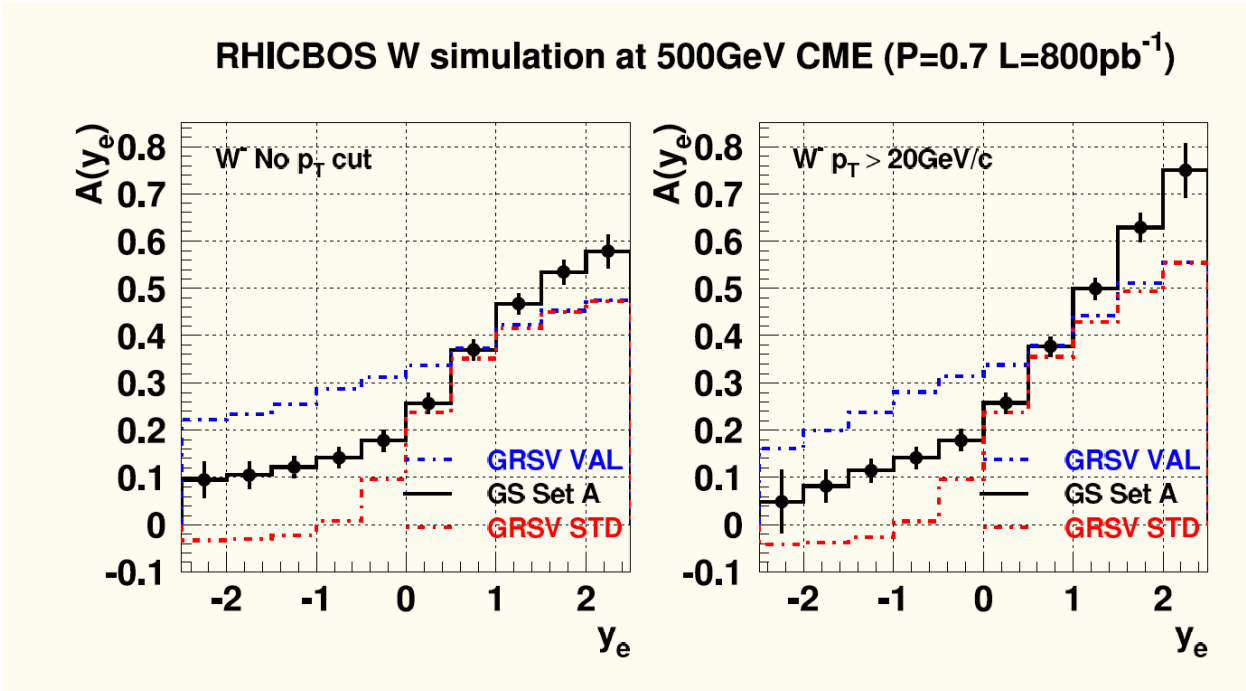


LO: $\delta(q_\perp)$

HO: $\dfrac{\alpha_s^k \ln^{2k-1}\left(\frac{q_\perp^2}{Q^2}\right)}{q_\perp^2} + \ldots$

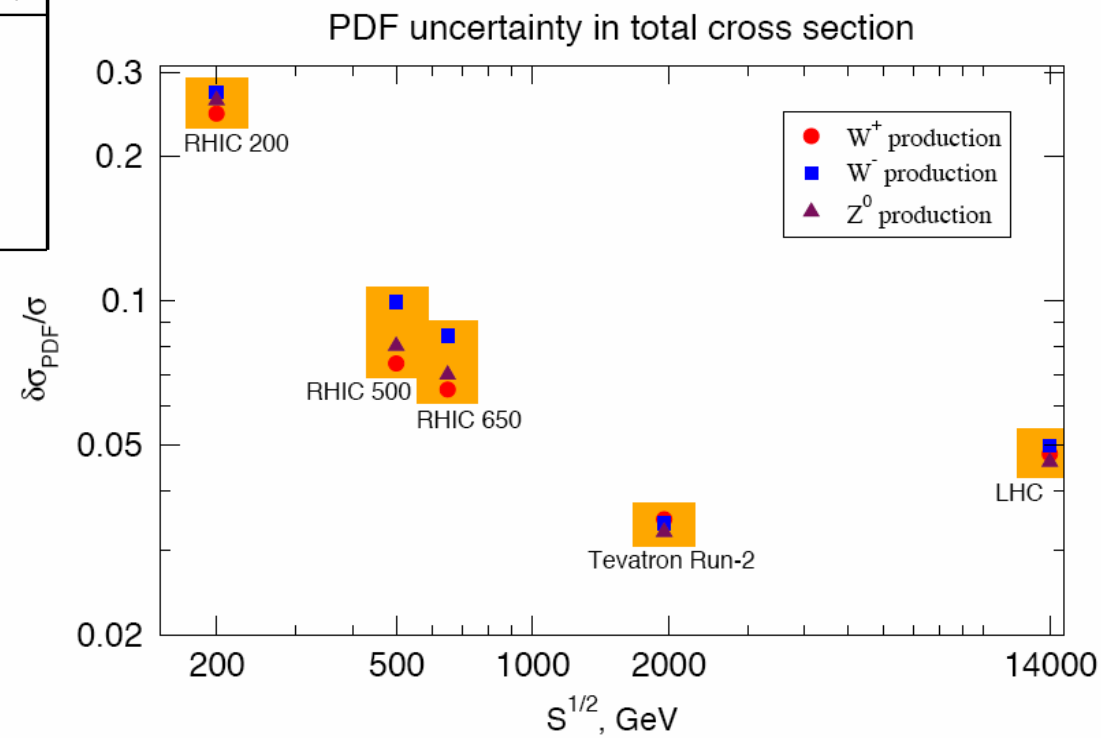
(NLO relatively important, resummation moderately so)

- Leptonic decays fully included.
  Lepton distributions for realistic acceptance.


RHICBOS W simulation at 500GeV CME (P=0.7 L=800pb^{-1})
W^- No p_T cut
W^- p_T > 20GeV/c
$A(y_e)$
y_e
GRSV VAL
GS Set A
GRSV STD

Nadolsky, Yuan

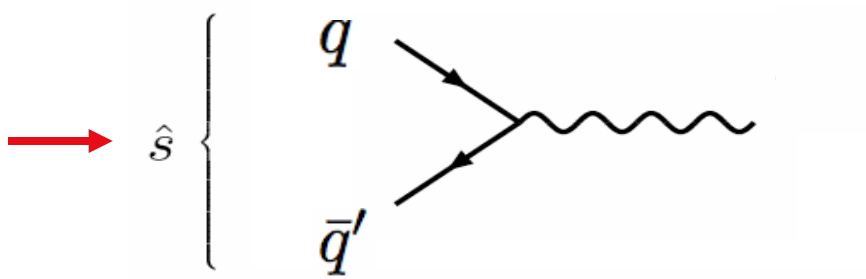
		$\sqrt{s} = 500\text{GeV}$ $\mathcal{L} = 800\ \text{pb}^{-1}$
W^+	$x\|_{y_W=0}$ $\sigma \pm \delta\sigma_{PDF}\left(\frac{\delta\sigma_{PDF}}{\sigma}\right)$ $N \pm \sqrt{N}(1/\sqrt{N})$	0.16 $124 \pm 9\,(0.07)$ $99200 \pm 300\,(0.003)$
W^-	$x\|_{y_W=0}$ $\sigma \pm \delta\sigma_{PDF}\left(\frac{\delta\sigma_{PDF}}{\sigma}\right)$ $N \pm \sqrt{N}(1/\sqrt{N})$	0.16 $41 \pm 4\,(0.10)$ $32800 \pm 200\,(0.006)$
Z^0	$x\|_{y_Z=0}$ $\sigma \pm \delta\sigma_{PDF}\left(\frac{\delta\sigma_{PDF}}{\sigma}\right)$ $N \pm \sqrt{N}(1/\sqrt{N})$	0.18 $10.0 \pm 0.8\,(0.08)$ $8010 \pm 90\,(0.01)$



Recent work on higher-order QCD corrections:

"Threshold resummation"

Mukherjee, WV



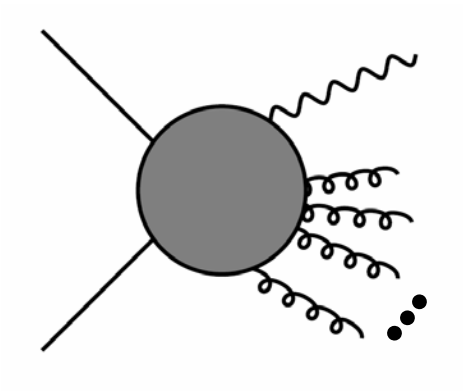
inv. mass $Q = M_W$

$$\hat{s} = Q^2 \quad , \text{ or } \quad z \equiv \frac{Q^2}{\hat{s}} = 1$$

- **partonic cross section :**

$$\frac{d\hat{\sigma}^{(0)}_{q\bar{q}}}{dQ^2} \propto \delta(1-z)$$

- **higher orders :**



$$\frac{d\hat{\sigma}^{(k)}_{q\bar{q}}}{dQ^2} \propto \alpha_s^k \frac{\ln^{2k-1}(1-z)}{1-z} + \ldots$$

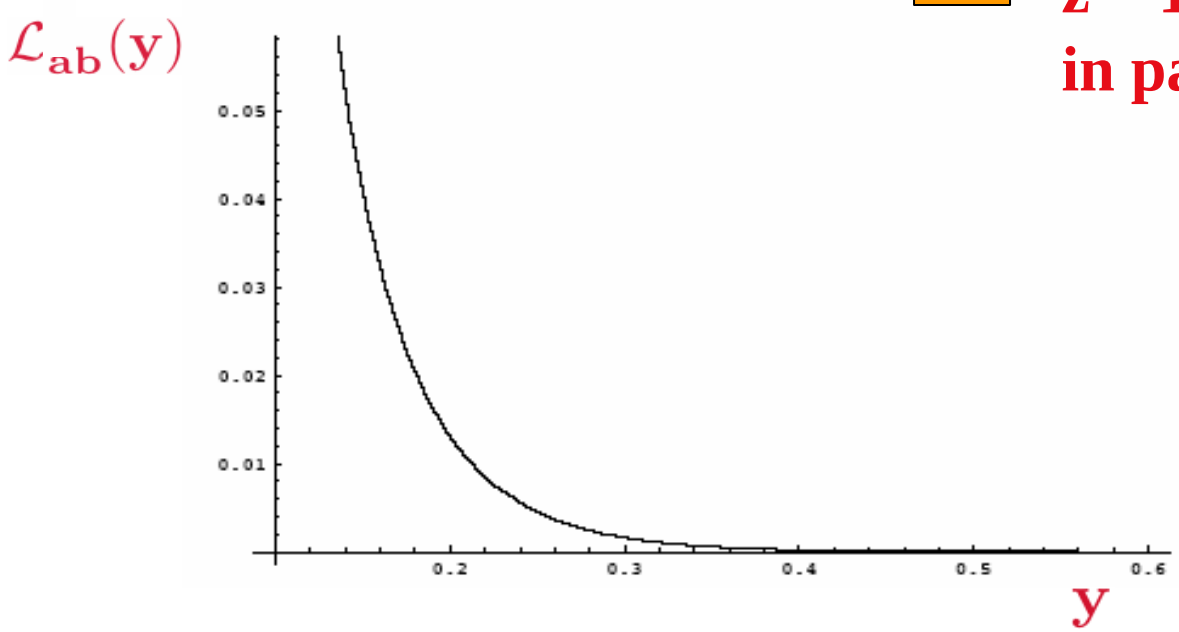
- **enhanced by parton distributions :**

$$\tau = Q^2/S$$

$$\sigma \propto \sum_{a,b} \int_\tau^1 \frac{dx_a}{x_a} f_a(x_a) \int_{\tau/x_a}^1 \frac{dx_b}{x_b} f_b(x_b)\, \hat{\sigma}_{ab}(z = \tau/x_a x_b)$$

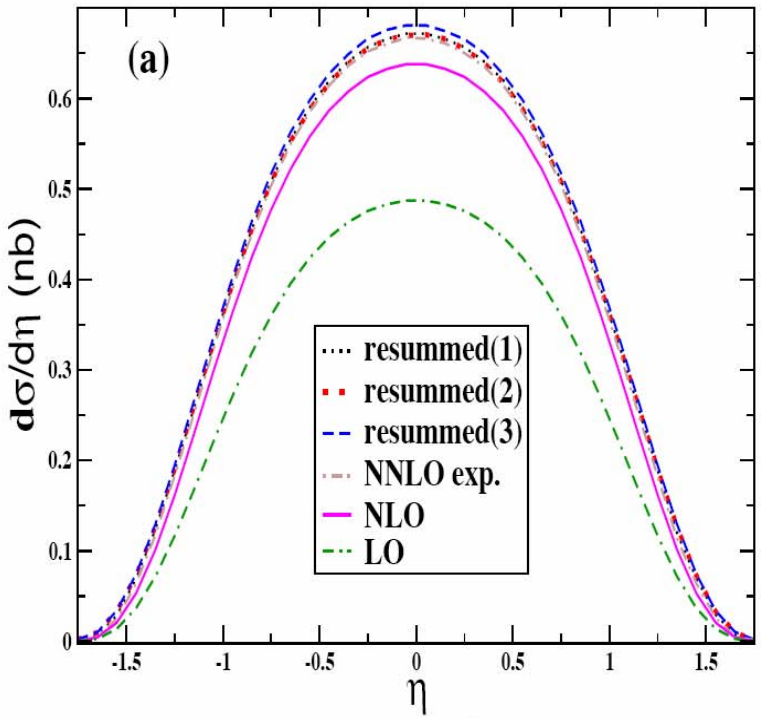
$$= \sum_{a,b} \int_\tau^1 \frac{dz}{z} \mathcal{L}_{ab}\left(\frac{\tau}{z}\right) \hat{\sigma}_{ab}(z)$$

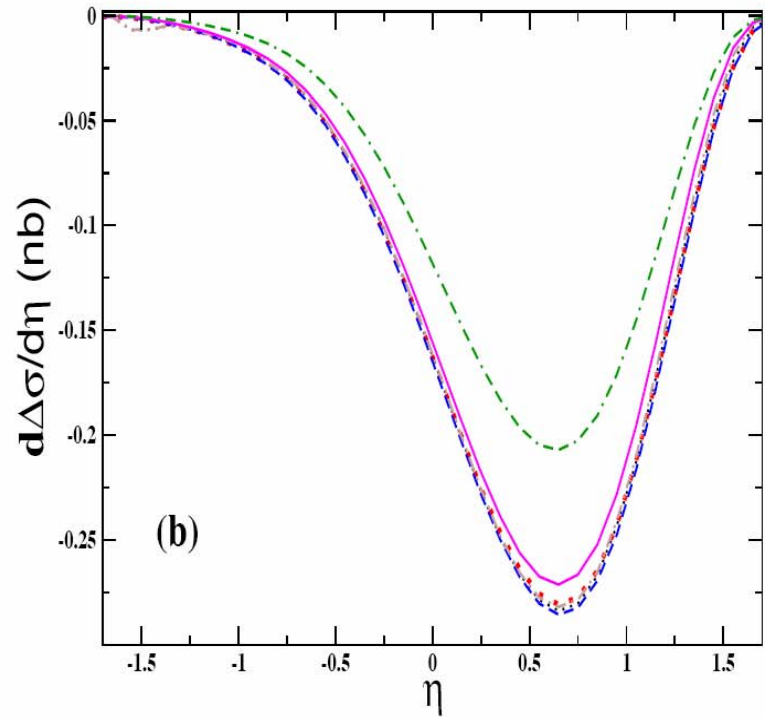
z = 1 emphasized, in particular as τ→1

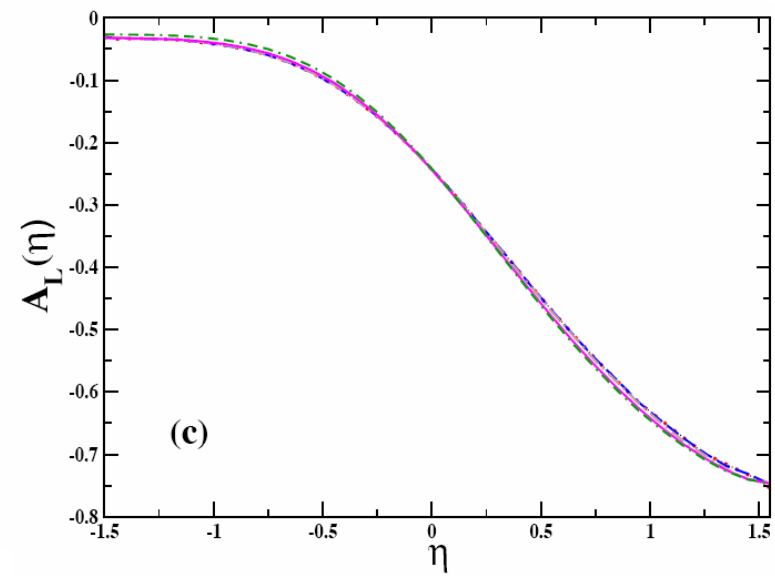


Mukherjee, WV

W^+





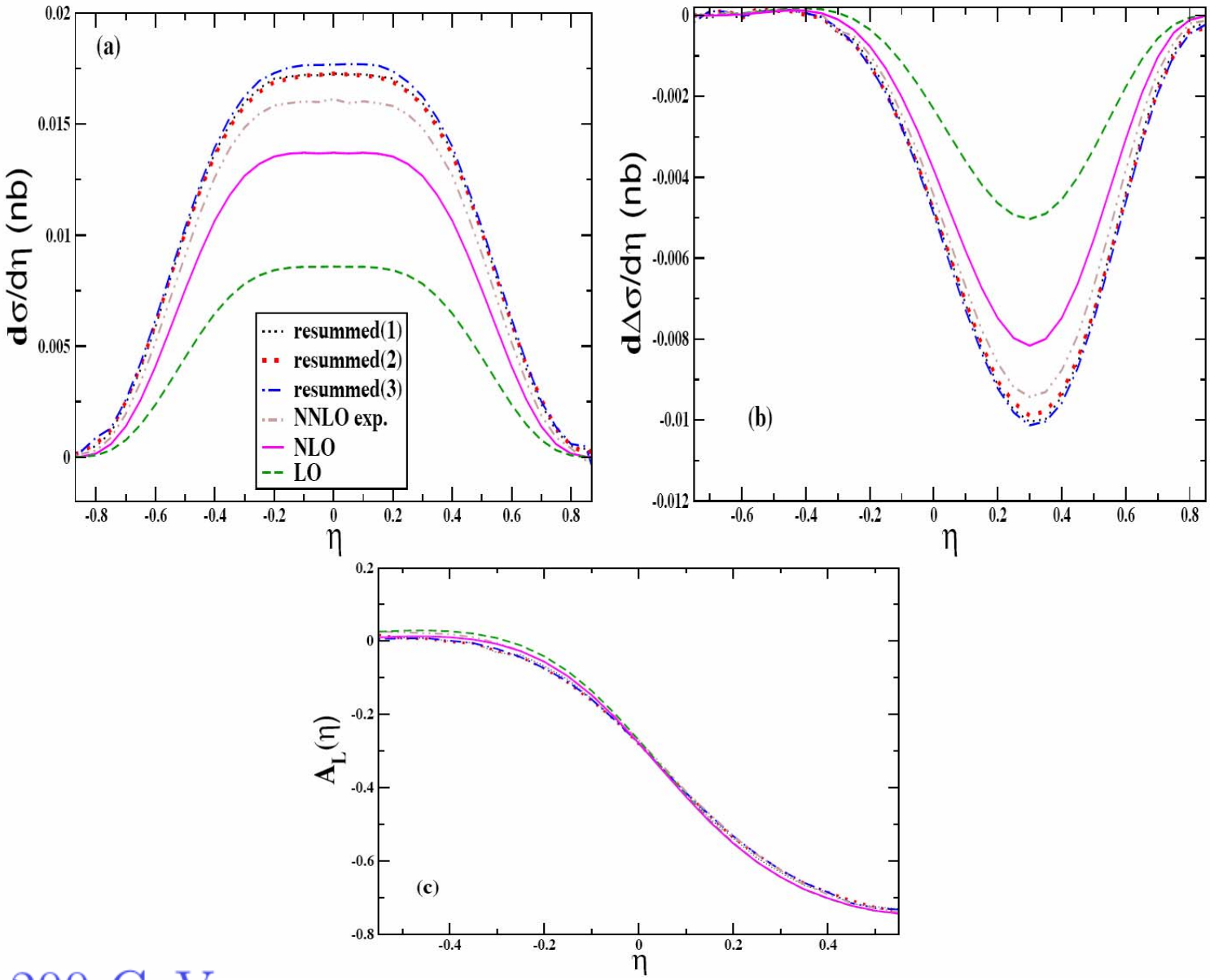


All-order resummation of

$$\alpha_s^k \frac{\ln^{2k-1}(1-z)}{1-z} + \ldots$$

Sterman; Catani, Trentadue

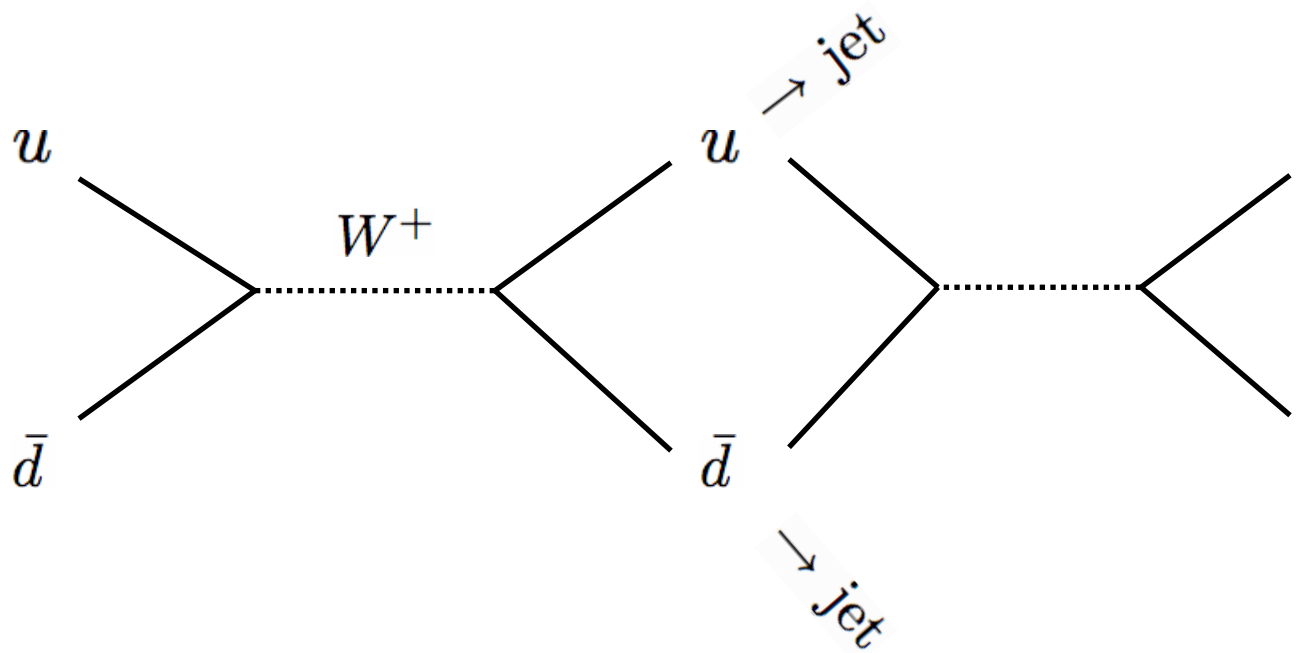
$$\sqrt{s} = 500 \text{ GeV}$$



$\sqrt{s} = 200$ GeV

Renewed interest in hadronic W decays: Arnold, Metz, WV; Nadolsky

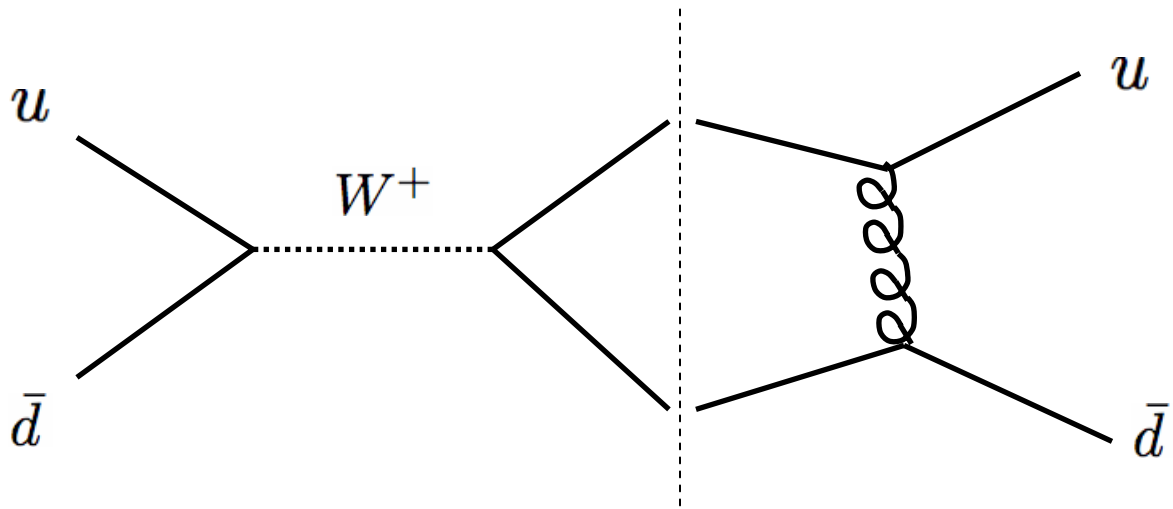
First thing that comes to mind:



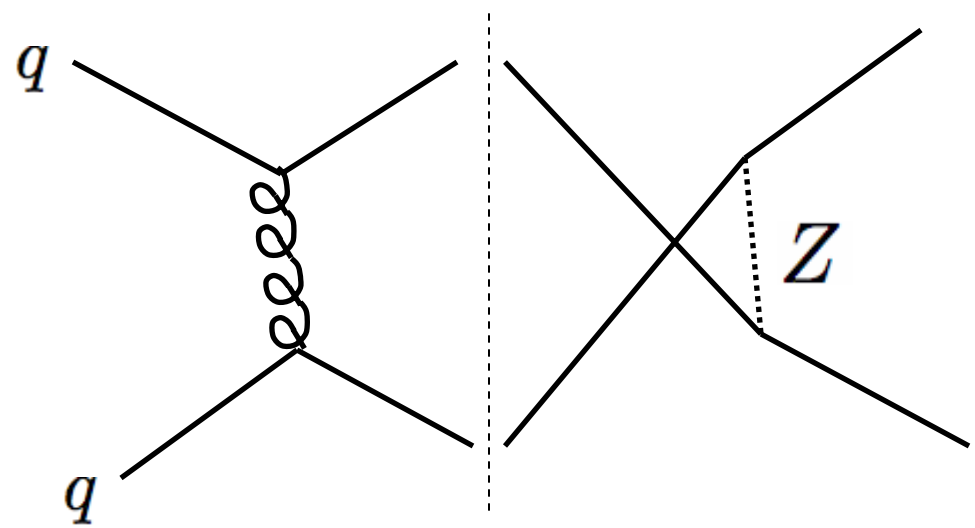
(El.weak)^2 α_W^2 **"doubly resonant"**

Bourrely, Soffer

However, A_L also arises from (QCD ⊗ El.weak):



Also:



+

- higher event rates (BR)
- can choose events with both jets seen. get $d\sigma/dy_W$ directly
- perhaps tool to see first PV signal

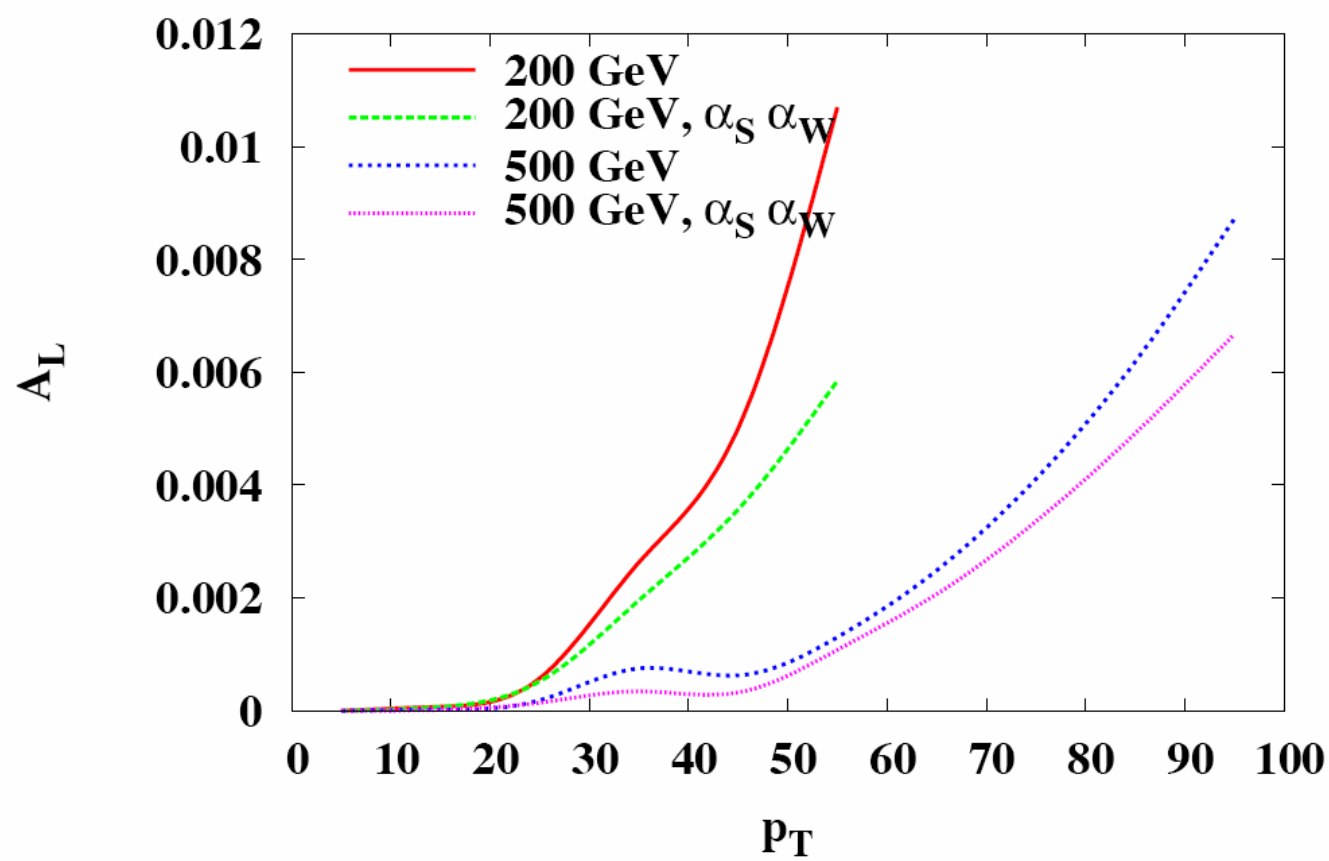
−

- many partonic channels (even for resonant ones)
- no W charge identification
- separation of W, Z hard?
- denominator is QCD 2 jet cr.sec. → A_L small (however, S/B better than at Tevatron)
- higher-order corrections?

$$A_L \sim \frac{\alpha_W \alpha_s + \alpha_W^2 + \ldots}{\alpha_s^2 + \ldots}$$

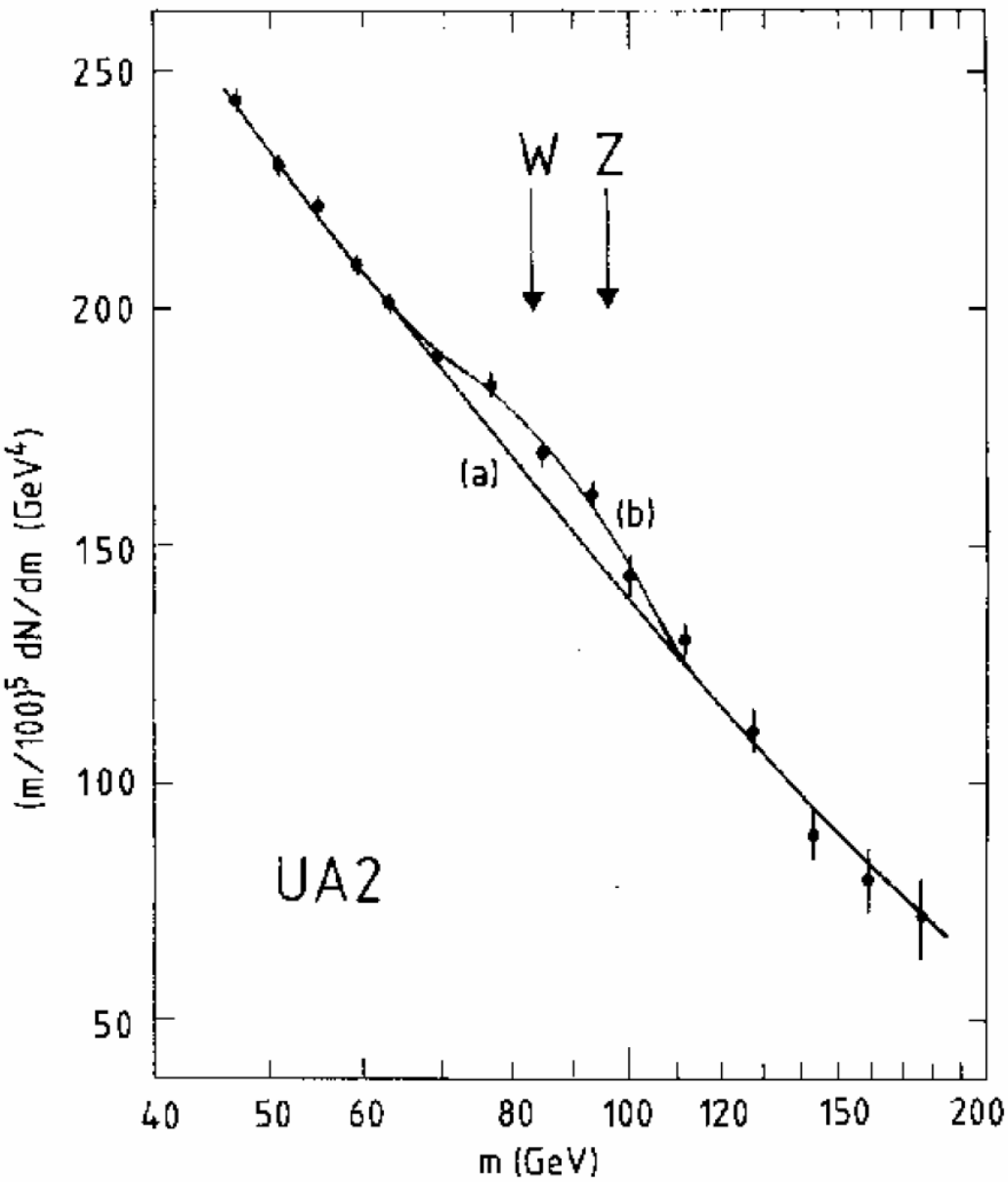
Moretti, Nolten, Ross; Arnold, Metz, WV

One example:


0.012
0.01
0.008
0.006
0.004
0.002
0
A_L
0
10
20
30
40
50
60
70
80
90
100
p_T
200 GeV
200 GeV, α_S α_W
500 GeV
500 GeV, α_S α_W

Potential improvements -- need study:

- better variables (e.g. dijet pair mass m_{jj})
- perhaps techniques for subtraction of main QCD background ?

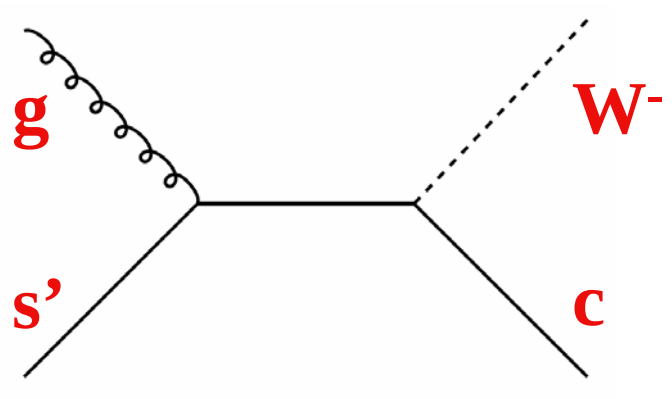

W
Z
(a)
(b)
UA2
250
200
150
100
50
40
50
60
80
100
120
150
200
m (GeV)
(m/100)^5 dN/dm (GeV^4)

IV. Future opportunities

Access to strangeness at RHIC II ?

- associated W+charm production ?

Sudoh, Yokoya



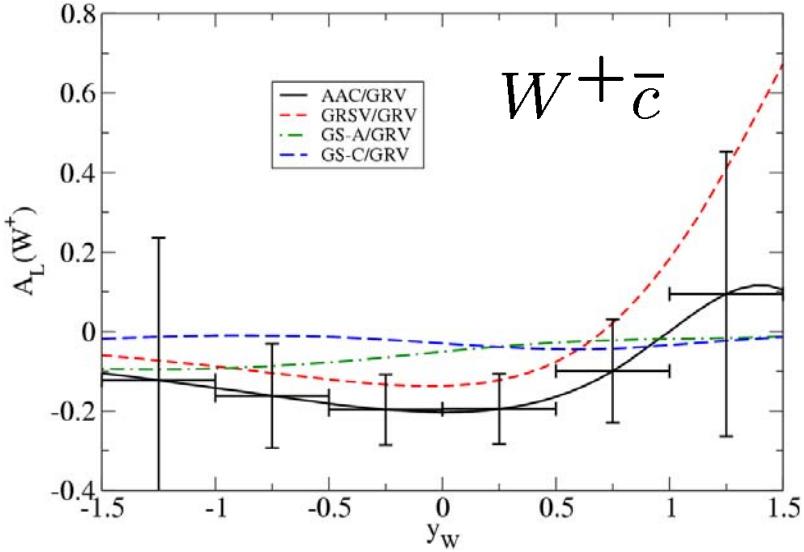
"D-tagged W's"

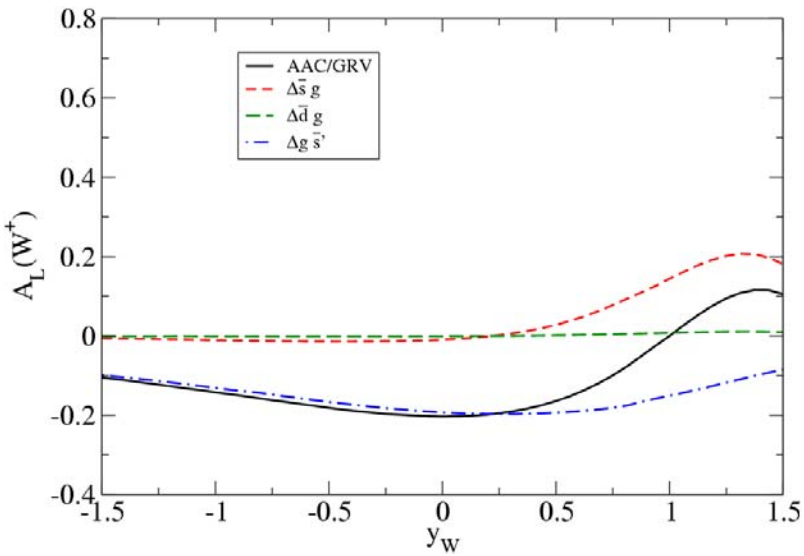
$$s' = \cos^2\theta_c \cdot s + \sin^2\theta_c \cdot d$$

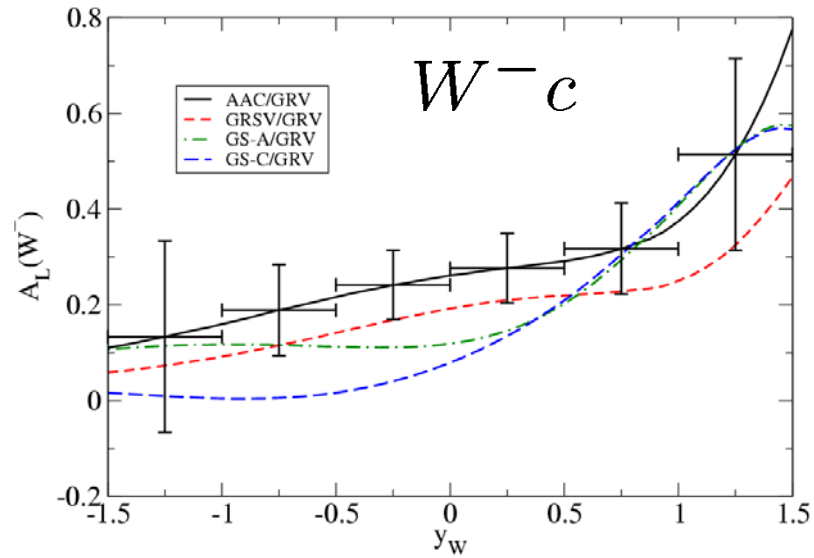
$$A_L = \frac{\Delta s_1' \, g_2 \, \Delta\hat{\sigma}_{sg} + \Delta g_1 \, s_2' \, \Delta\hat{\sigma}_{gs}}{s_1' \, g_2 \, \hat{\sigma}_{sg} + g_1 \, s_2' \, \hat{\sigma}_{gs}}$$

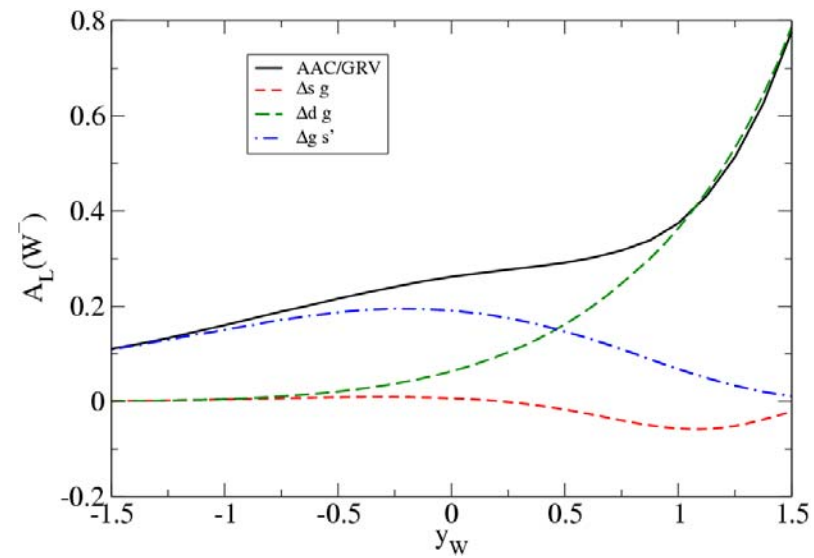
$\sigma(W^- c) \sim 4.2$ pb $\qquad \sigma(W^+ \bar{c}) \sim 2.5$ pb

Sudoh, Yokoya









Polarization : $P = 0.7$

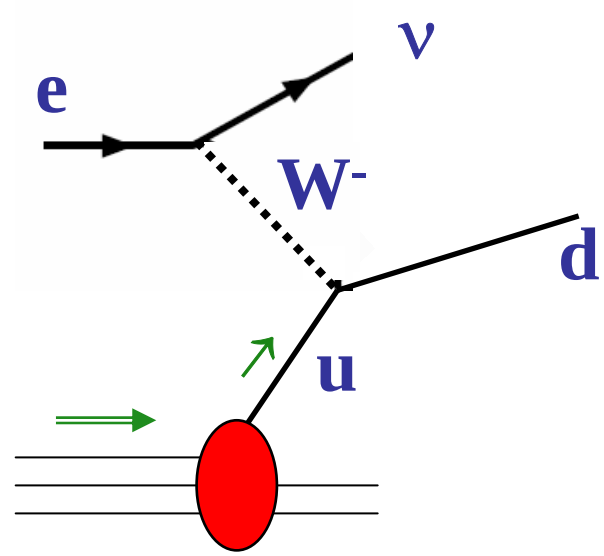
Luminosity : $L = 800\ \mathrm{pb}^{-1}$

Detection efficiency : $\epsilon = 0.1$

Requires high luminosity

W physics at eRHIC

- charged current DIS

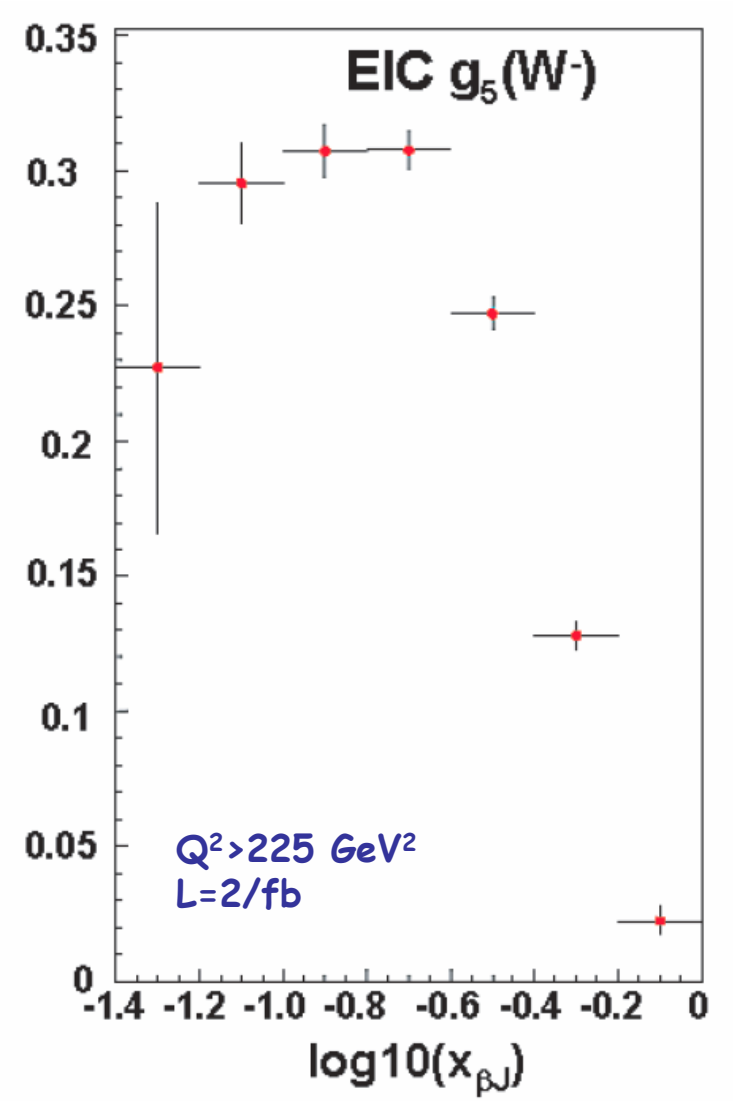


$$\frac{d^2\sigma^{\lambda,\Rightarrow}}{dx dQ^2} - \frac{d^2\sigma^{\lambda,\Leftarrow}}{dx dQ^2} \propto C\left(G_v, G_a, \lambda\right)\left[\lambda\, xy(2-y)\, g_1 + (1-y)\, g_4 + xy^2\, g_5\right]$$

$$g_1^{W^-}(x) = \Delta u(x) + \Delta\bar{d}(x) + \Delta\bar{s}(x) \qquad g_5^{W^-}(x) = \Delta u(x) - \Delta\bar{d}(x) - \Delta\bar{s}(x)$$

$$A^{W^-} = \frac{2b g_1^{W^-} + a g_5^{W^-}}{a F_1^{W^-} + b F_3^{W^-}}$$

Anselmino et al.; …



$$g_5 \propto \Delta u - \Delta\bar{d} - \Delta\bar{s}$$

Contreras et al.

$$\int_0^1 dx \left[g_5^{W^+,p} - g_5^{W^-,n} \right] = -\left(1 - \frac{2\alpha_s}{3\pi}\right) g_A$$

Stratmann, WV

- electroweak parameters? $\sin^2(\Theta_W)$?

Conclusions & Outlook:

- good control of theory: higher-order corrections, resummations. Power corrections likely small.
- hadronic decays useful ? Needs further work.
- further opportunities at RHIC II and eRHIC

$$y_l^{lab} = y_l^* + y_W, \quad \text{where} \quad y_l^* = \frac{1}{2}\ln\left[\frac{1+\cos\theta^*}{1-\cos\theta^*}\right]$$

$$p_T^{\text{lepton}} = p_T^* = \frac{M_W}{2}\sin\theta^*$$

$$\left(\frac{d^2\sigma}{dy_W\, d\cos\theta^*}\right)_{W^+} \sim \quad u(x_1)\bar{d}(x_2)(1-\cos\theta^*)^2 + \bar{d}(x_1)u(x_2)(1+\cos\theta^*)^2$$

$$\left(\frac{d^2\sigma}{dy_W\, d\cos\theta^*}\right)_{W^-} \sim \quad d(x_1)\bar{u}(x_2)(1+\cos\theta^*)^2 + \bar{u}(x_1)d(x_2)(1-\cos\theta^*)^2$$