Resummation for longitudinal spin asymmetries in W-boson production

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Highlights

- Need for NLO lepton-level asymmetries in $p^{\rightarrow}p \rightarrow W^{\pm}X \rightarrow l_1\bar{l}_2X$
- Effects of multiple parton radiation on differential distributions
- Numerical results

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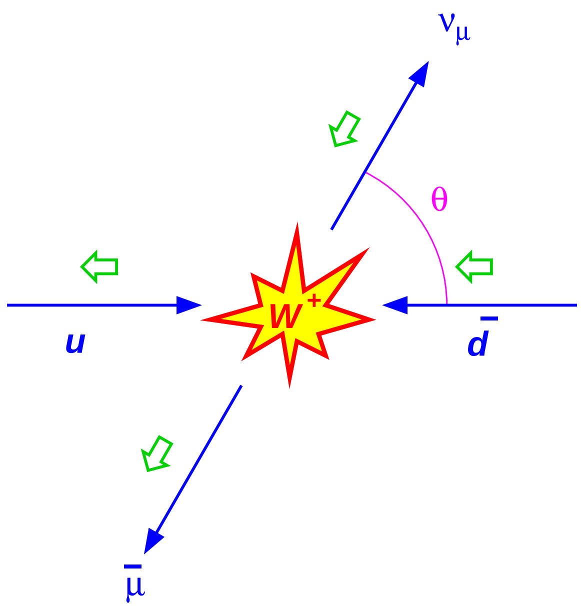
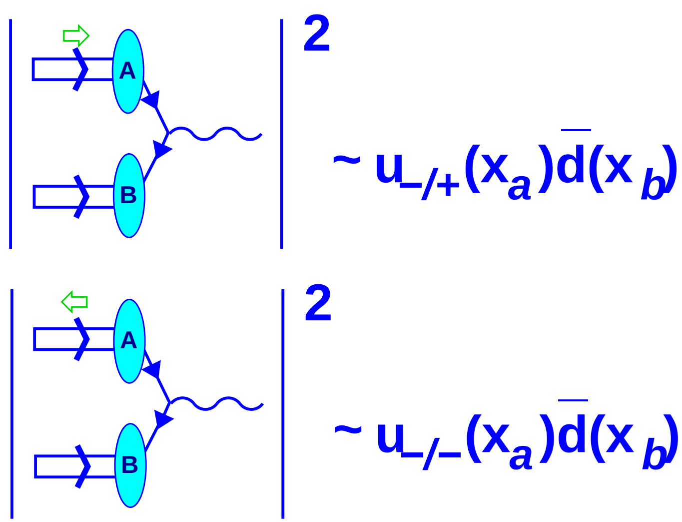
$W^{\pm}$-bosons as ideal polarimeters





Define

$$\Delta\sigma_L = \frac{1}{4}\left(\sigma^{\rightarrow\rightarrow} + \sigma^{\rightarrow\leftarrow} - \sigma^{\leftarrow\rightarrow} - \sigma^{\leftarrow\leftarrow}\right)$$

Then

$$\frac{d\Delta\sigma_L(pp \xrightarrow{W^+} l_1\bar{l}_2X)}{dx_a dx_b d\cos\theta d\varphi} \propto$$

$$-\Delta u(x_a)\bar{d}(x_b)\,(1+\cos\theta)^2 +$$

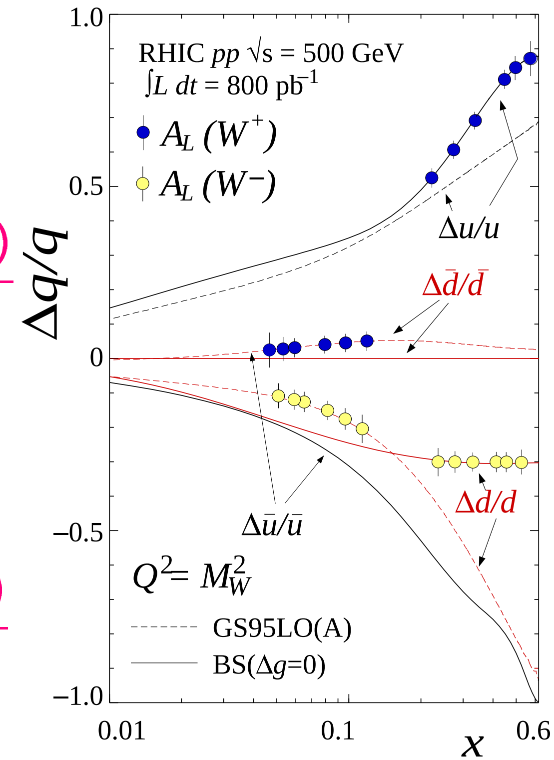
$$+\Delta\bar{d}(x_a)u(x_b)\,(1-\cos\theta)^2$$

Single-spin asymmetries $\frac{d\Delta_L\sigma/dy_W}{d\sigma/dy_W}$ in $W^{\pm}$ production are sensitive to the flavor structure of the polarized quark sea

Leading order single-spin asymmetries

$$A_L^{W^+}(y_W) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)} = \begin{cases} -\Delta u(x_a)/u(x_a), & x_a \to 1 \\ \Delta\bar{d}(x_a)/d(x_a), & x_b \to 1 \end{cases}$$

$$A_L^{W^-}(y_W) = \frac{-\Delta d(x_a)\bar{u}(x_b) + \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)} = \begin{cases} -\Delta d(x_a)/d(x_a), & x_a \to 1 \\ \Delta\bar{u}(x_a)/\bar{u}(x_a), & x_b \to 1 \end{cases}$$



Source: G. Bunce et al., hep-ph/0007218

Would be an ideal test of $\Delta q/q$ and $\Delta\bar{q}/\bar{q}$ if $W^{\pm}$-bosons were observed directly

Interest in fully differential cross sections at the lepton level

- Partial angular coverage of Phenix and Star detectors

  - $\not{E}_T$ and momentum of $W^\pm$ cannot be reconstructed

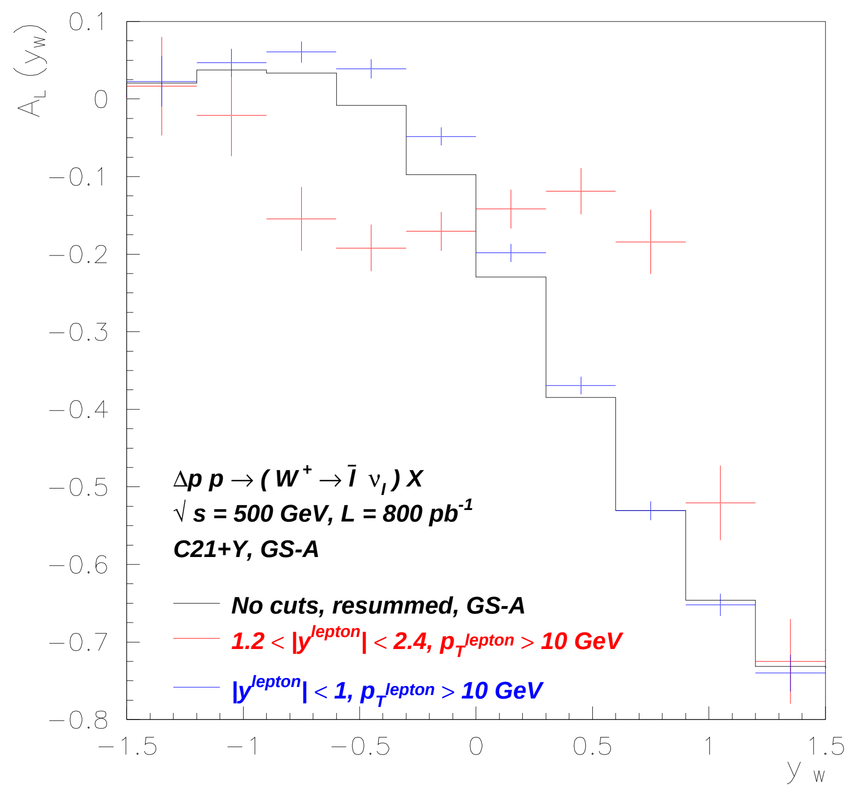
  - y_W can be approximately reconstructed in a limited event sample and only if dynamics is well understood

  -

$$A_L(y_W)\Big|_{\substack{with\\lepton\\cuts}} \neq A_L(y_W)\Big|_{\substack{without\\lepton\\cuts}}$$

Due to the spin-1 of $W^\pm$boson, cuts affect the numerator and denominator of $A_L(y_W)$ differently

Impact of leptonic cuts on the measurement of $A_L(y_W)$



Due to the spin-1 of $W^{\pm}$ boson, cuts affect the numerator and denominator of $A_L(y_W)$ differently

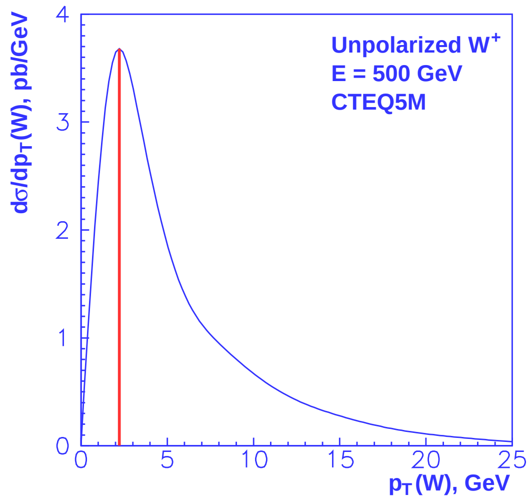
Interest in NLO fully differential cross sections

- ✲ Sizeable NLO corrections (30%) to the numerator and denominator

- ✲ NLO accuracy required by the global analysis of polarized PDF's

- ✲ Indefinite sign of $\Delta f(x) \Rightarrow$ possible radiation zeros at the LO

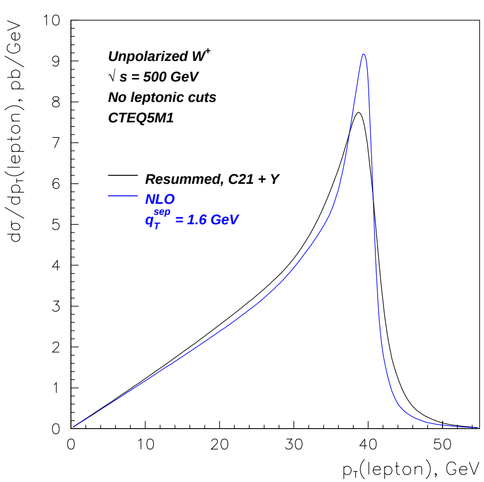
Transverse momentum distributions

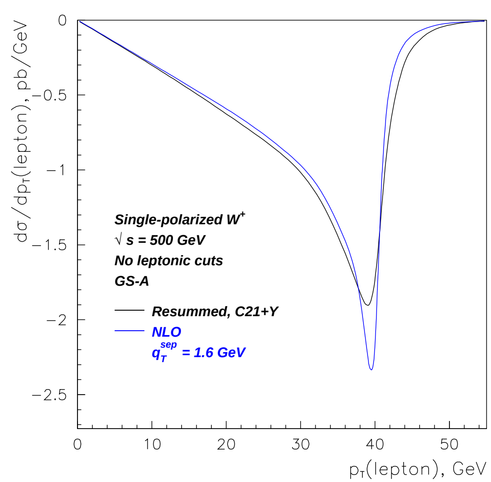


$p_T^W \neq 0$! The shape of $d\sigma/dp_T^W$ at $p_T^W \to 0$ cannot be described at a finite order of PQCD: calculation of the sum

$$\frac{1}{p_T^2}\sum_{n=1}^{\infty}\left(\frac{\alpha_S}{\pi}\right)^n \sum_{m=0}^{2n-1} v_{mn}\left(\ln^m \frac{Q^2}{p_T^2} \quad \text{or} \quad \delta(\vec{p}_T)\right)$$

is needed





Similar multiple parton radiation effects in lepton p_T distributions

Our calculation

- ✲ $\mathcal{O}(\alpha_S)$ fully differential cross section

$$\frac{d\sigma}{d^3\vec{p}_l d^3\vec{p}_{\nu_l}}[\,pp \to (\gamma^*, W^\pm, Z^0)X\,]$$

  for arbitrary beam polarizations ⇒lepton-level A_L, A_{LL}
- ✲ γ_5 matrices from the axial current and spin projectors; the t'Hooft-Veltman and dimensional reduction schemes used
- ✲ In the region $p_T^W \to 0$, logarithmic terms are summed through all orders in the transverse position space formalism *(Collins, Soper, Sterman, 1985)*

$$\frac{d\sigma_{h_A h_B}}{dQ^2 dy dp_T^2 d\Omega_l} \approx \int \frac{d^2b}{(2\pi)^2} e^{i\vec{p}_T\cdot\vec{b}} \widetilde{W}_{h_A h_B}(b, Q, x_A, x_B)$$

  $\widetilde{W}_{h_A h_B}(b, \dots)$ is the sum of soft and collinear perturbative contributions, as well as long-distance nonperturbative contributions

Monte-Carlo integration program

RhicBos (ResBos for RHIC) is a Monte-Carlo package to generate

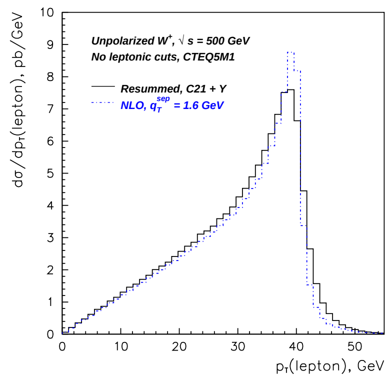
- ✲ resummed distributions, matched to the NLO cross section at large p_T
- ✲ finite-order distibutions using phase space slicing

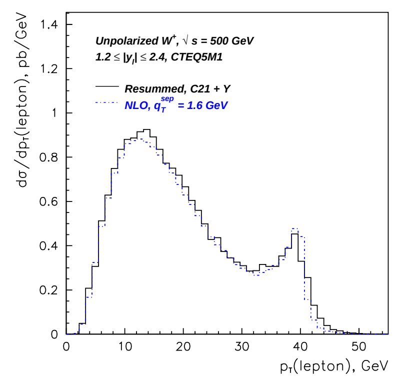
The Fortran code and input grids available at

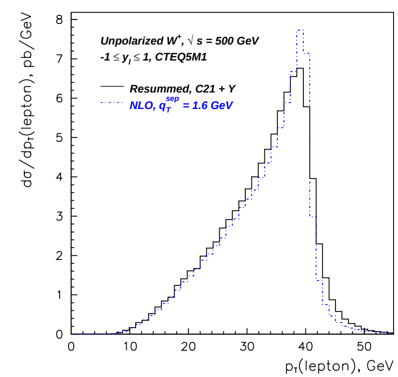
http://schwinger.physics.smu.edu/~nadolsky/RhicBos

W^+production: p_T^{lepton} distributions with experimental rapidity cuts

$$\frac{d\sigma(pp \to W^+X)}{dp_T^{lepton}}:$$







No cuts $\updownarrow$

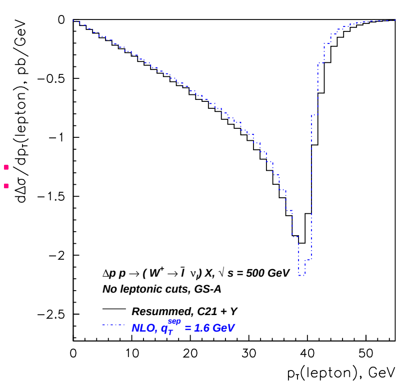
Phenix $\updownarrow$

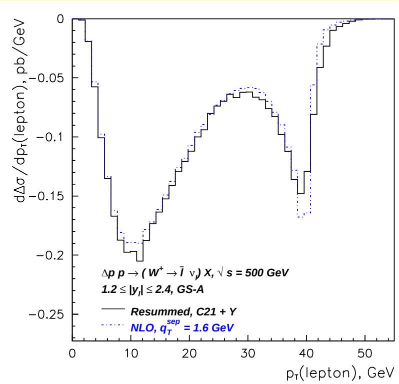
$(1.2 \le |y_l| \le 2.4)$

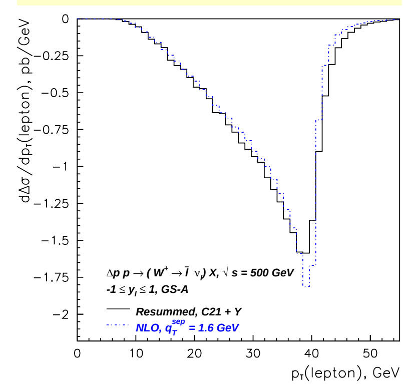
Star $\updownarrow$

$(-1 \le y_l \le 1)$

$$\frac{d\Delta_L\sigma(p^{\rightarrow}p \to W^+X)}{dp_T^{lepton}}:$$

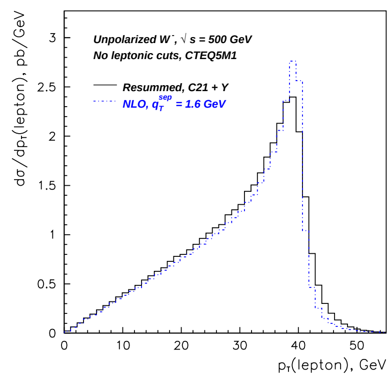


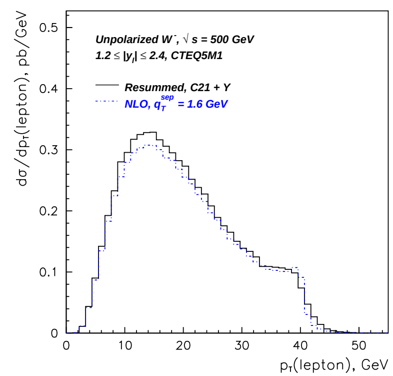


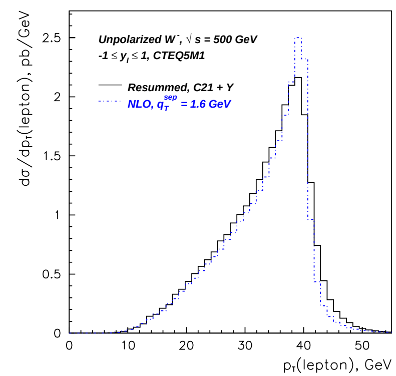


W^-production: p_T^{lepton} distributions with experimental rapidity cuts

$$\frac{d\sigma(pp \to W^- X)}{dp_T^{lepton}}:$$







No cuts $\updownarrow$

Phenix $\updownarrow$

$(1.2 \le |y_l| \le 2.4)$

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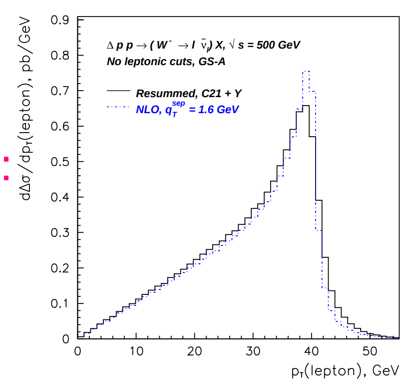
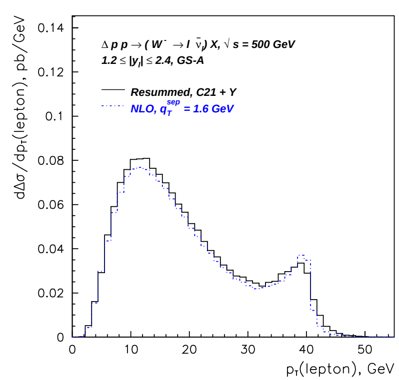
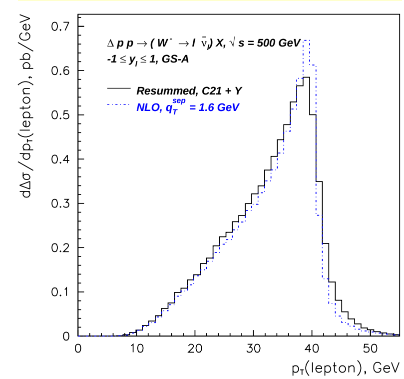
$(-1 \le y_l \le 1)$

$$\frac{d\Delta_L\sigma(p^{\to}p \to W^- X)}{dp_T^{lepton}}:$$

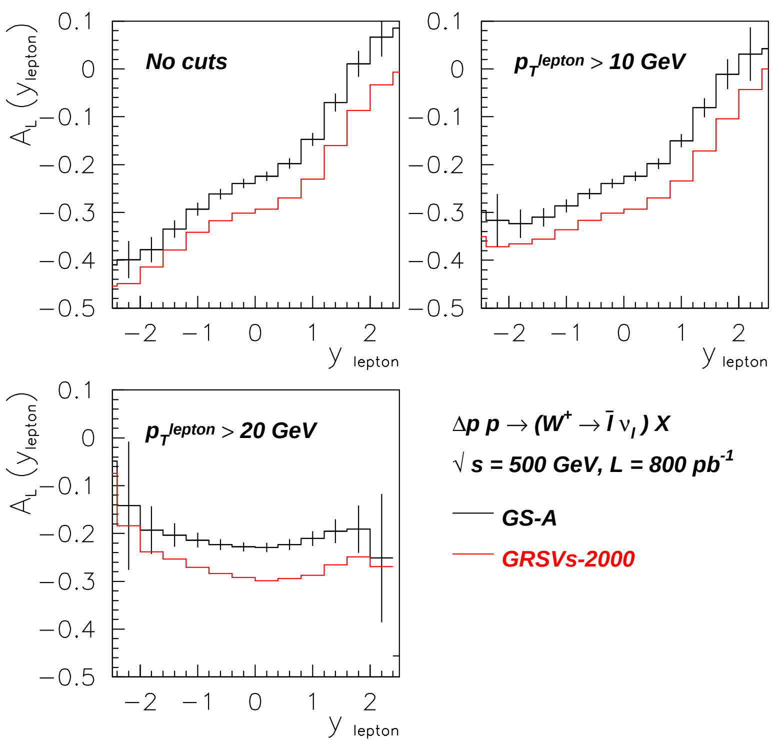




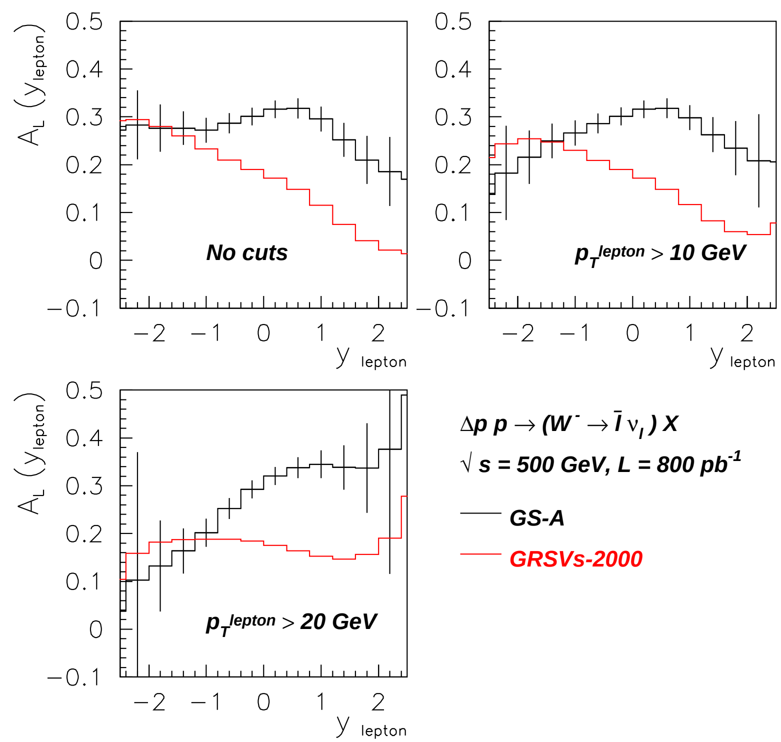


Dependence of $A_L(y^{lepton})$ on the cut on p_T^{lepton}

$\vec{p}p \to W^+X$

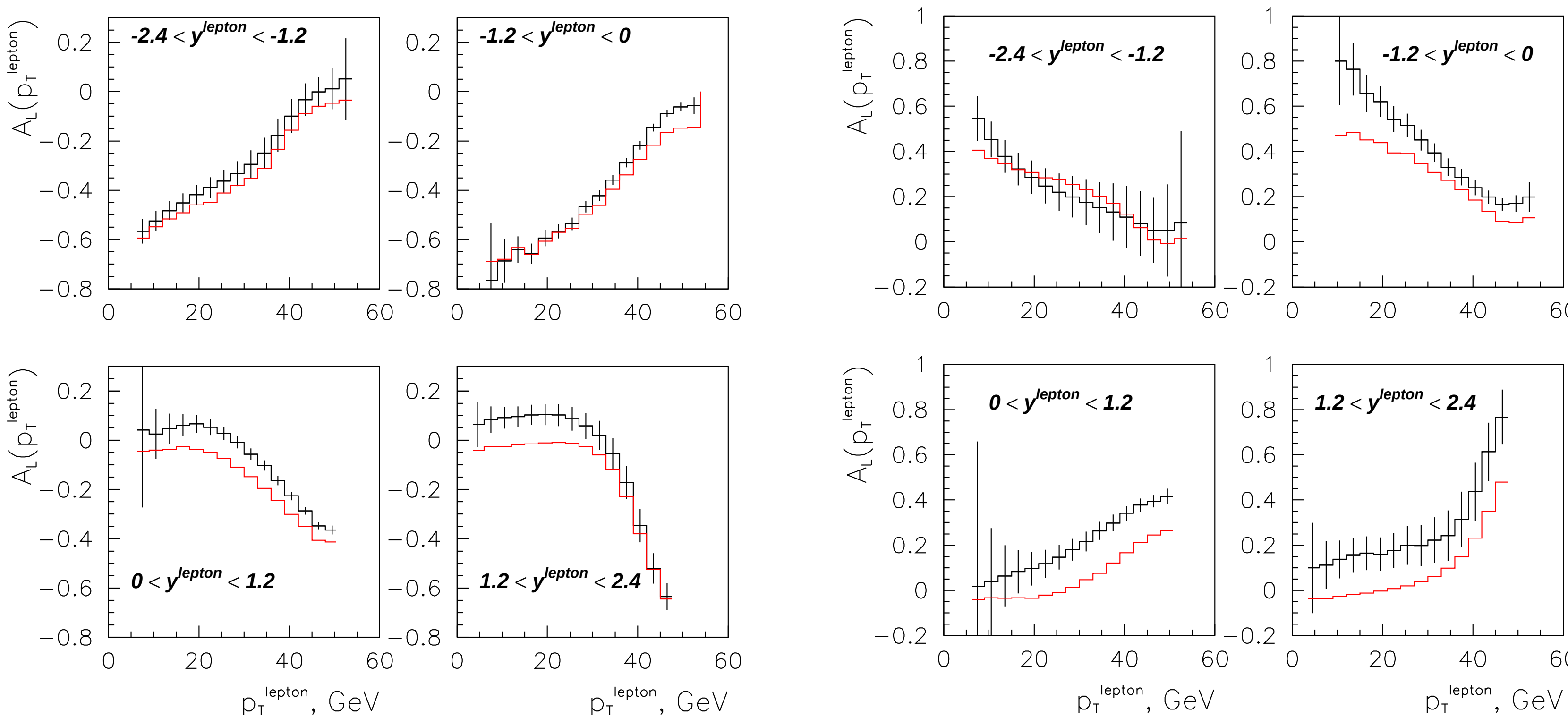


$\vec{p}p \to W^-X$



Dependence of $A_L(p_T^{lepton})$ on the cut on y^{lepton}

$p^{\rightarrow}p \rightarrow W^+X$ $\quad$ $p^{\rightarrow}p \rightarrow W^-X$



Black line: GS-A; red line : GRSVs-2000

“Spin independence” of the Jacobian peak

Due to

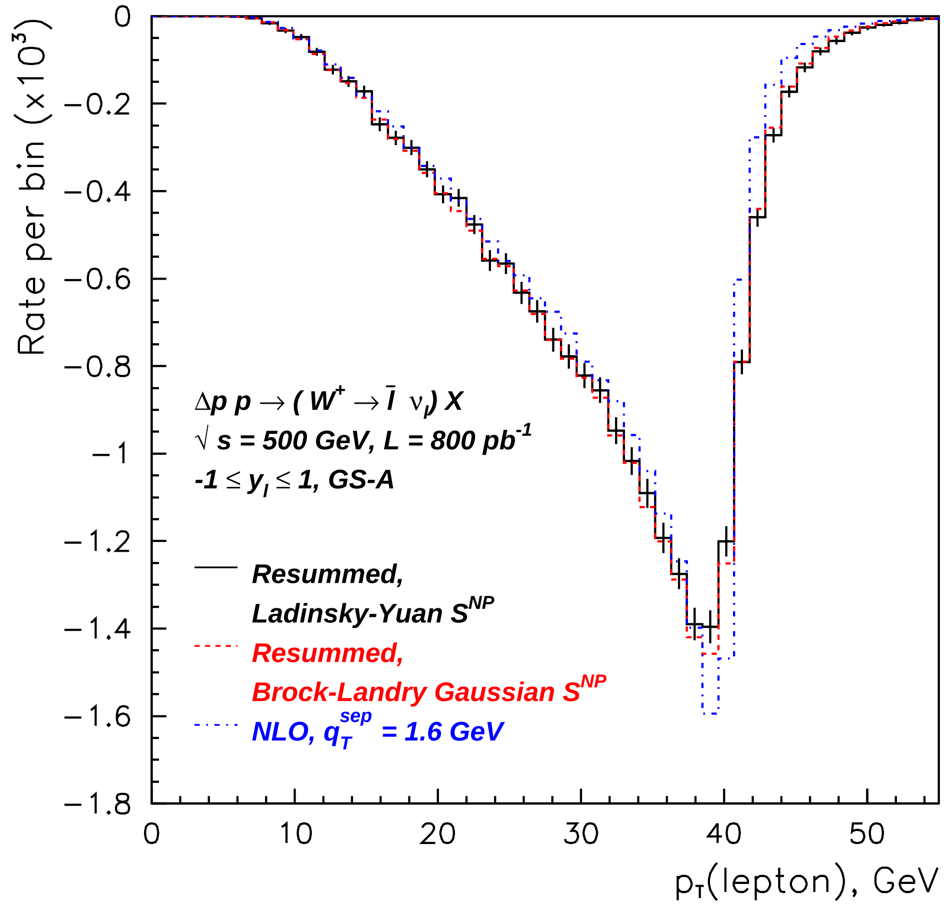
✲ the spin independence of the perturbative Sudakov factor (quark helicity conservation)

✲ reduced importance and probable universality of non-perturbative contributions

the shape of $d\sigma/dp_T^W$ at $p_T^W \to 0$ and Jacobian peak in $d\sigma/dp_T^{lepton}$ can be predicted based on

✲ the unpolarized measurements

✲ measurements of $d\Delta\sigma/dp_T$ in the polarized γ^*, Z^0 production



This consequence of the factorization picture must be tested at RHIC for all types of vector bosons

Summary

1. A consistent $\mathcal{O}(\alpha_S)$ lepton-level study of vector boson ($\gamma^*, W^\pm, Z^0$) production with hadron beams of arbitrary longitudinal polarization is presented

2. The lepton-level spin asymmetries are sensitive and easily measurable observables that are good alternatives to $A_L(y_W)$

3. The arbitrariness in the shape of finite-order p_T-distributions is cured by summation of large logarithmic terms at $p_T^W \to 0$ in the b-space formalism

4. RHIC can easily test the independence of the soft, collinear and nonperturbative contributions to $d\sigma/dp_T^W$ and $d\sigma/dp_T^{lepton}$ from hadronic spin and type of vector bosons