2002 CTEQ Summer School

Rapidity Distribution of W Boson

C.-P. Yuan

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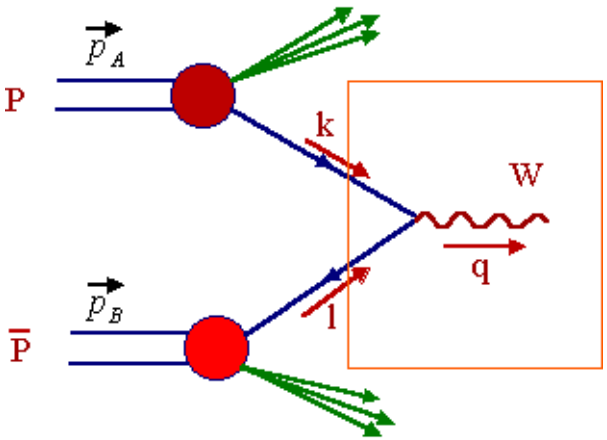
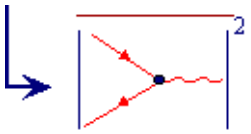
Fixed order pQCD prediction

$\alpha_S^{(0)}$



$$\sigma = \int dx_A dx_B f_{i/A}(x_A,\mu) f_{i/B}(x_B,\mu) \cdot d\hat{\sigma}$$

$$d\hat{\sigma} = \underbrace{\overline{|M|^2}}_{\downarrow} (2\pi)^4 \delta^{(4)}(q-k-l) \frac{d^3q}{(2\pi)^3 2q_0}$$



$$s = (p_A + p_B)^2$$

$$k = x_A p_A$$

$$l = x_B p_B$$

$$Q \equiv \sqrt{Q^2} = \sqrt{q^2},$$

$$\mu = Q = M_W,$$

$$x_A = \frac{Q}{\sqrt{S}} e^{y}, \qquad x_B = \frac{Q}{\sqrt{S}} e^{-y}$$

By changing variables:

$$\tau = x_A x_B = \frac{\hat{s}}{S}\,, \qquad y = \frac{1}{2}\ln\left(\frac{x_A}{x_B}\right)$$

we get

$$dx_A\, dx_B = d\tau\, dy$$

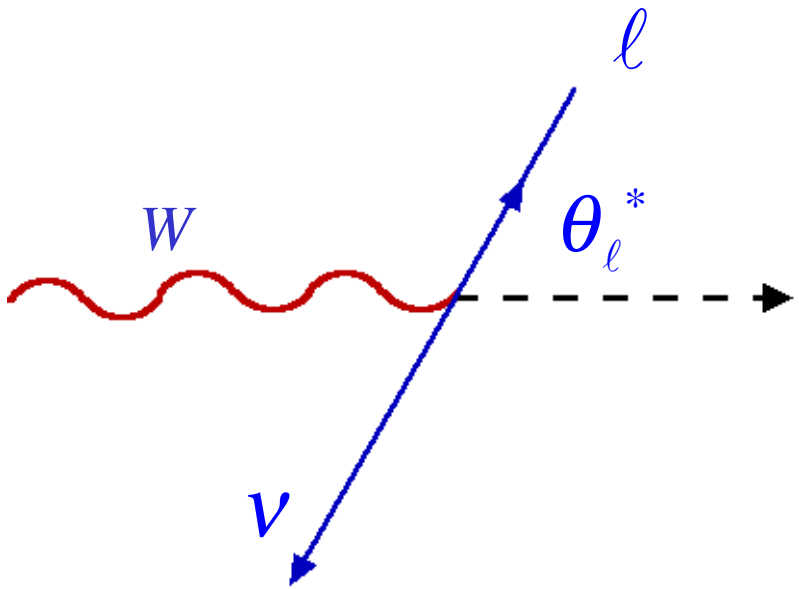
where y *is the* *rapidity* *of the* W *boson.*

$$\Rightarrow \quad \frac{\mathrm{d}\sigma}{\mathrm{d}y\,\mathrm{d}\tau} = \frac{\mathrm{d}\sigma}{\mathrm{d}x_A\,\mathrm{d}x_B} = f_{i/A}\left(x_A,\mu\right) f_{i/B}\left(x_B,\mu\right)\cdot d\hat{\sigma}$$

$\Rightarrow$ pQCD can predict rapidity distribution

In the rest frame of W, the (pseudo) rapidity of the decay lepton is

$$y_\ell^* = -\ln\left(\tan\left(\frac{\theta_\ell^*}{2}\right)\right)$$



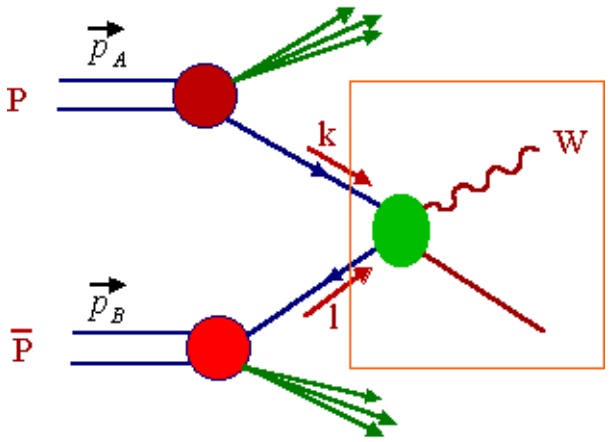
→ In the Lab frame,
the rapidity of the (massless) lepton is

$$y_\ell = y + y_\ell^*$$

Note: In the parton model, the partons from hadron do not have transverse momentum.

→ W boson moves along beam axis.

$\alpha_S^{(1)}$



$$T = Q^2 - \sqrt{q_T^2 + Q^2}\sqrt{S}\ e^{-y},$$

$$U = Q^2 - \sqrt{q_T^2 + Q^2}\sqrt{S}\ e^{y},$$

$$\hat{s} = \xi_A \xi_B S$$

$$\hat{t} = \xi_A \left(T - Q^2\right) + Q^2$$

$$\frac{\hat{s}\,\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}} = \frac{1}{16\pi^2}\overline{|M|^2}$$

M =

Again, pQCD can predict the rapidity distribution of the *W* boson and its decay lepton.

Lepton Charge Asymmetry

Consider $W^+ \to \ell^+ \nu$ and $W^- \to \ell^- \bar{\nu}$

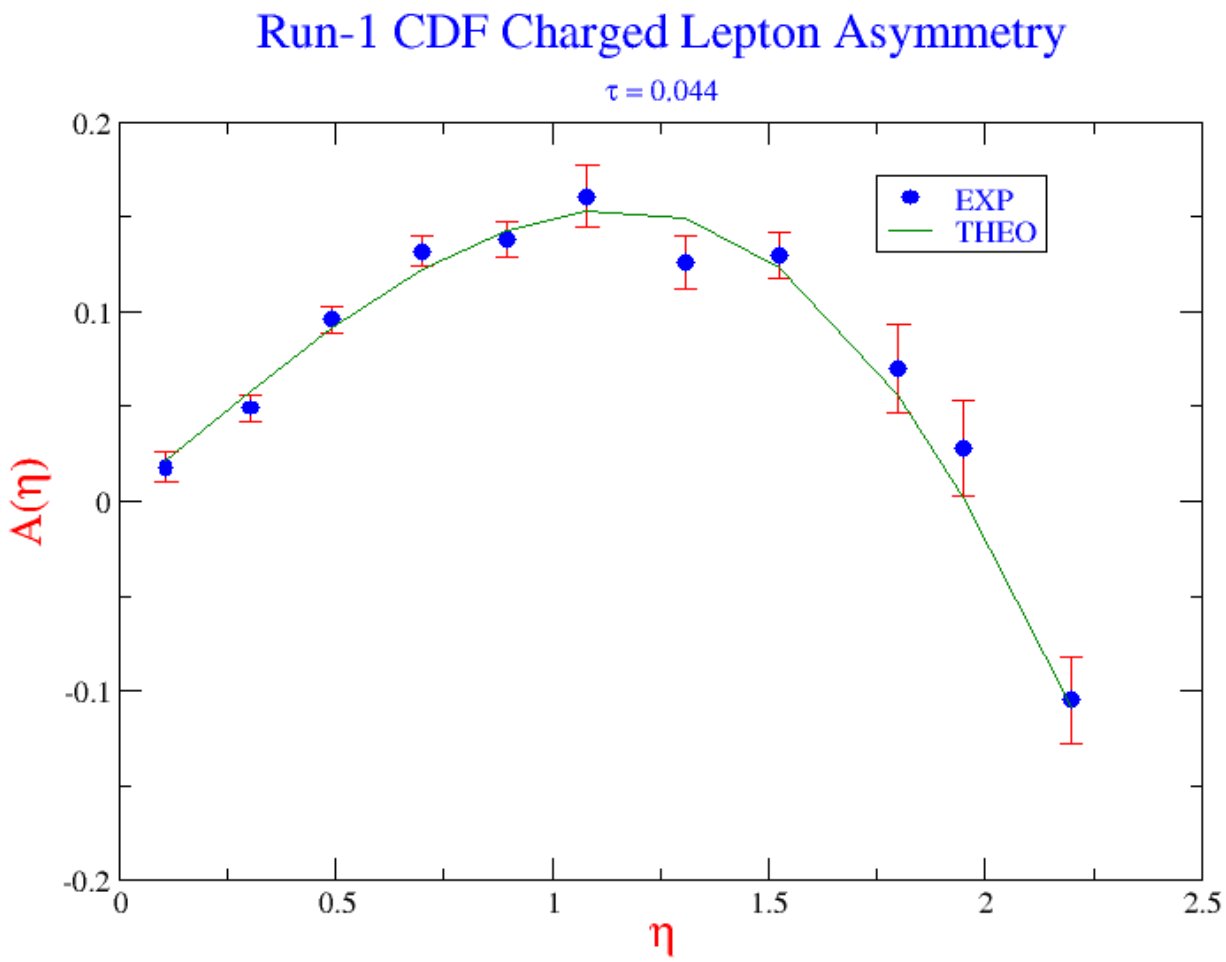
Define the Asymmetry to be

$$A(y_\ell) = \frac{\frac{d\sigma}{dy_\ell}(\ell^+) - \frac{d\sigma}{dy_\ell}(\ell^-)}{\frac{d\sigma}{dy_\ell}(\ell^+) + \frac{d\sigma}{dy_\ell}(\ell^-)}$$

If CP is conserved, then

$$A(y_\ell) = \frac{\frac{d\sigma}{dy_\ell}(y_{\ell^+} > 0) - \frac{d\sigma}{dy_\ell}(y_{\ell^+} < 0)}{\frac{d\sigma}{dy_\ell}(y_{\ell^+} > 0) + \frac{d\sigma}{dy_\ell}(y_{\ell^+} < 0)}$$

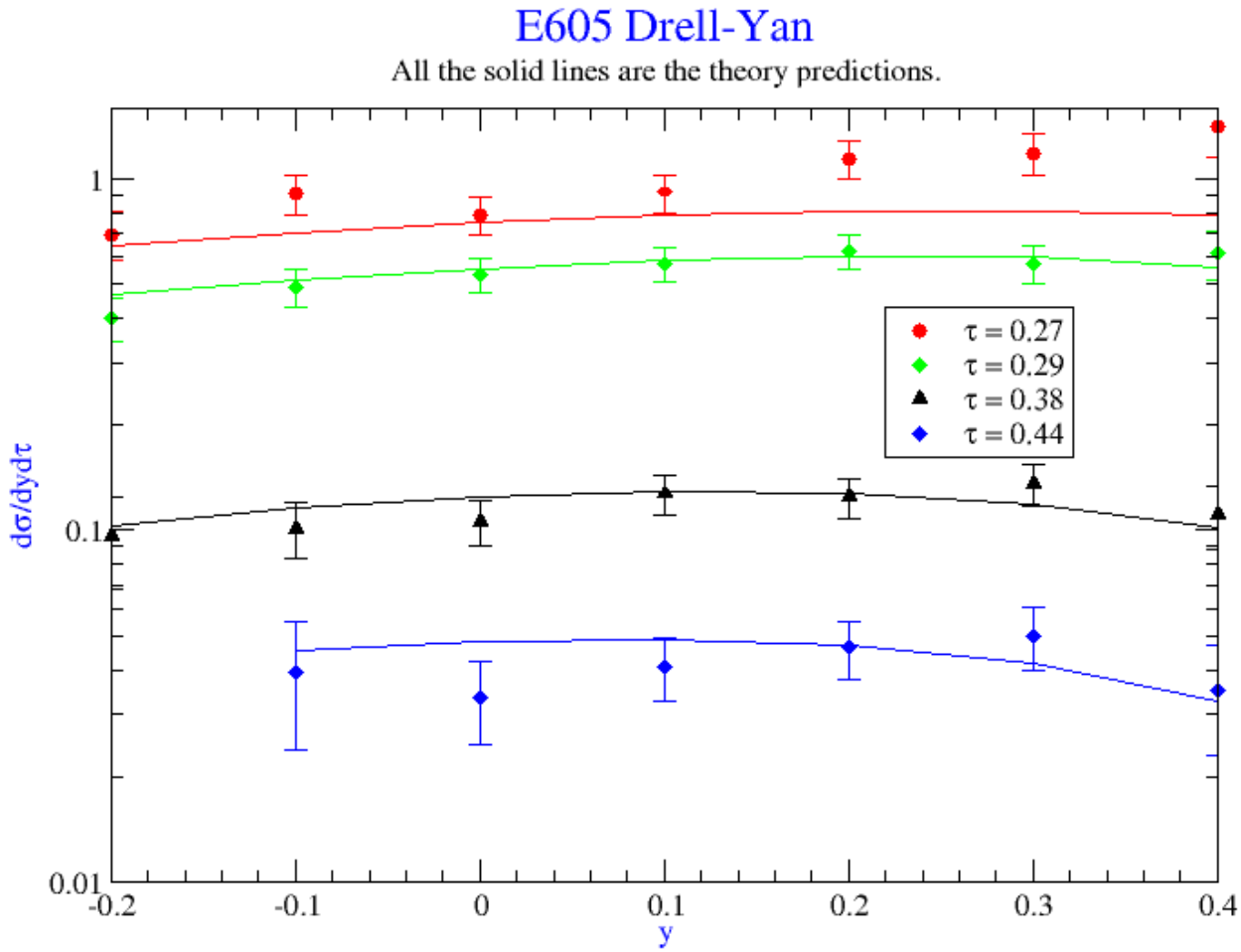
$A(y_\ell)$ is sensitive to the ratio of Parton Distribution Functions: $\frac{u}{d}$



For a massless lepton, the pseudo rapidity η is the same as the rapidity

$$y_\ell = \frac{1}{2}\ln\left(\frac{E+P_z}{E-P_z}\right)$$

Consider Drell-Yan process $p + Cu \rightarrow \mu^+ \mu^- + X$



Compared with a NLO pQCD calculation with CTEQ6M PDF.