Scaling properties of inclusive $W^\pm$ production at hadron colliders

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**Introduction**

One of the most precisely measured observables at hadron colliders is the rapidity dependence of the lepton charge asymmetry, $C_\ell$, 

$$C_\ell(y) = \frac{d\sigma^+}{dy} - \frac{d\sigma^-}{dy}$$

(1)

where $y$ is the rapidity of the charged lepton ($\ell = e, \mu$) originating from the leptonic decay of the $W$ boson. We present a simple scaling law for this asymmetry which also predicts that measurements in different collision systems are straightforwardly related.

**Scaling: $d\sigma^{W^\pm} / dy$**

We consider the process:

- $H_1 + H_2 \rightarrow W^- + X \rightarrow \ell^- + \nu + X$,
- $H_1 + H_2 \rightarrow W^+ + X \rightarrow \ell^+ + \nu + X$.

We find the scaling law

$$d\sigma^{\ell}(s, \xi) \propto s^{\alpha} \times F^\pm(\xi_1, H_1, H_2), \quad y \gg 0,$$

(2)

with $\sqrt{s}$ the center-of-mass energy, and

$$\xi_1 \equiv \frac{M_W}{\sqrt{s}} e^y.$$ 

(3)

$F^\pm(\xi_1, H_1, H_2)$ is a function that does not depend explicitly on $s$ or $y$, and $\alpha$ is the effective exponent for the sea-quark PDF at low $x$:

$$x_{\ell q}(x, Q^2) \approx xq(x, Q^2) \approx N_1 x^{-\alpha} \quad (\alpha > 0).$$

Similar scaling for $y \ll 0$, with $\xi_2 \equiv \frac{M_W}{\sqrt{s}} e^{-y}$. 

**Scaling: $C_\ell$**

Since the $\sqrt{s}$ dependence in Eq. (2) is completely in the common prefactor $s^{\alpha}$,

$$C_\ell^{H_1, H_2}(s, \xi_1) \approx F(\xi_1, H_1, H_2), \quad y \gg 0,$$

For the approximate flavor independence of the sea quarks at small $x$,

$$C_\ell^{H_1, H_2}(s, \xi_1) \approx F(\xi_1, H_1), \quad y \gg 0,$$

independently of the nature of hadron $H_2$ (nucleon, anti-nucleon, nucleus) probed at small $x$. Similar scaling again for $y \ll 0$ (with $\xi_2$).

At the LHC, scaling holds even at $y \sim 0$, because the probed $x$ is already small.

**Heavy ions at the LHC**

- $y > 0$: scaling between pp, pPb collisions:
  $$C_\ell^{pP}(s, \xi_1) \approx C_\ell^{pPb}(s', \xi_1), \quad y > 0.$$

- $y < 0$: scaling between pPb, PbPb collisions:
  $$C_\ell^{pPb}(s, \xi_2) \approx C_\ell^{pPb}(s', \xi_2), \quad y < 0.$$ 

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**Comparison with data: $d\sigma^{W^\pm} / dy$**

**Comparison with data: $C_\ell$**

The world data on lepton charge asymmetry as a function of $y_{rel}$ taking $\sqrt{s_{rel}} = 5.02$ TeV. $y_{rel} \equiv y \pm \frac{1}{2} \log \frac{M_W}{\sqrt{s}}$, such that e.g. $\xi_1(y, \sqrt{s}) = \xi_1(y_{rel}, \sqrt{s_{rel}})$ for $y > 0$.

**Summary**

The cross section $d\sigma^{W^\pm} / d\xi_{1,2}$ in forward/backward directions at fixed value of the scaling variable $\xi_{1,2} = (M_W/\sqrt{s}) e^{\pm y}$ should approximately obey a one-parameter power law in $\sqrt{s}$. Consequently, the lepton charge asymmetry $C_\ell$ is approximately independent of $\sqrt{s}$ at fixed $\xi_{1,2}$. For $y > 0$ ($y < 0$) $C_\ell$ also depends effectively only on the nature of the forward-(backward-) going nucleon or nucleus.