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, $\mathcal{C}_\ell$,

$$\mathcal{C}_\ell(y) \equiv \frac{d\sigma^{\ell^+}/dy - d\sigma^{\ell^-}/dy}{d\sigma^{\ell^+}/dy + d\sigma^{\ell^-}/dy}, \qquad (1)$$

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: $d\sigma^{W^\pm \to \ell^\pm}/dy$

We consider the process:

$$H_1 + H_2 \to W^- + X \to \ell^- + \bar{\nu} + X,$$

$$H_1 + H_2 \to W^+ + X \to \ell^+ + \nu + X.$$

We find the scaling law

$$\frac{d\sigma^{\ell^\pm}(s,\xi_1)}{d\xi_1} \approx s^\alpha \times F^\pm(\xi_1, H_1, H_2), \quad y \gg 0, \qquad (2)$$

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

$$\xi_1 \equiv \frac{M_W}{\sqrt{s}} e^y. \qquad (3)$$

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

$$x\bar{q}_i(x,Q^2) \approx xq_i(x,Q^2) \approx N_i\, x^{-\alpha} \qquad (\alpha > 0).$$

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

Scaling: $\mathcal{C}_\ell$

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

$$\mathcal{C}_\ell^{H_1,H_2}(s,\xi_1) \approx F(\xi_1, H_1, H_2). \quad y \gg 0,$$

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

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

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

$$\mathcal{C}_\ell^{pp}(s,\xi_1) \approx \mathcal{C}_\ell^{pPb}(s',\xi_1), \quad y > 0.$$

$y < 0$: scaling between pPb, PbPb collisions:

$$\mathcal{C}_\ell^{pPb}(s,\xi_2) \approx \mathcal{C}_\ell^{PbPb}(s',\xi_2), \quad y < 0.$$

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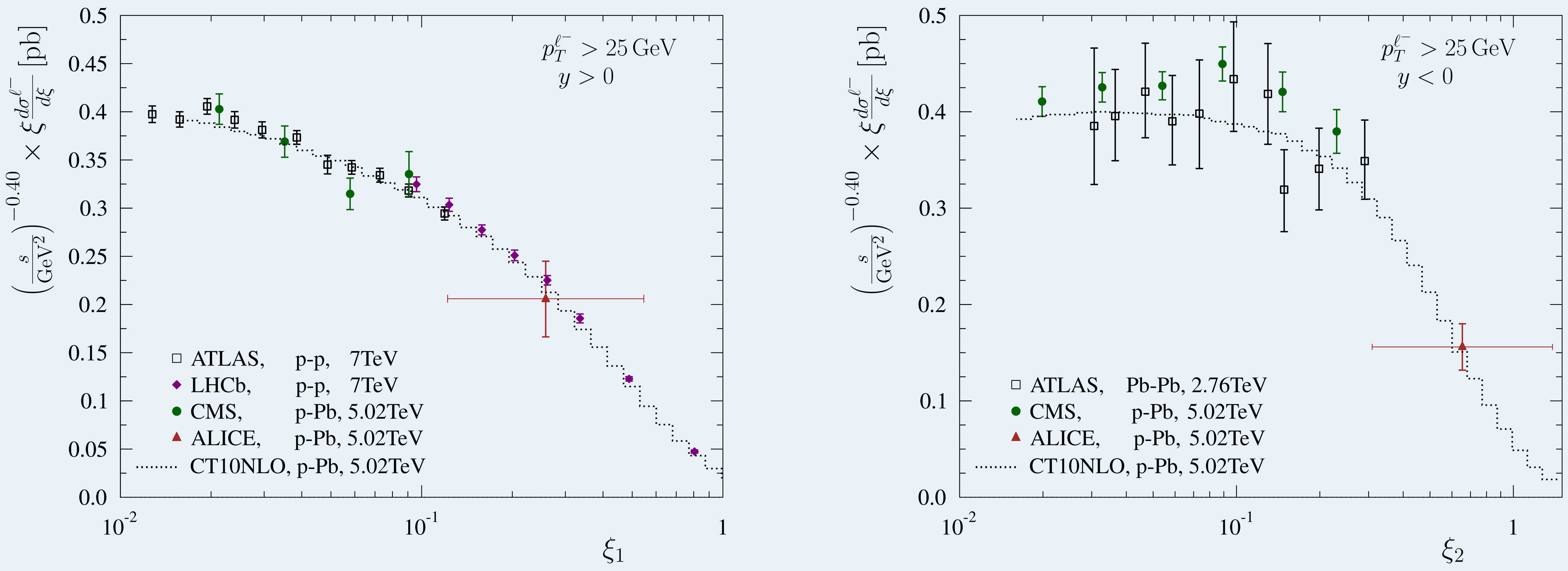
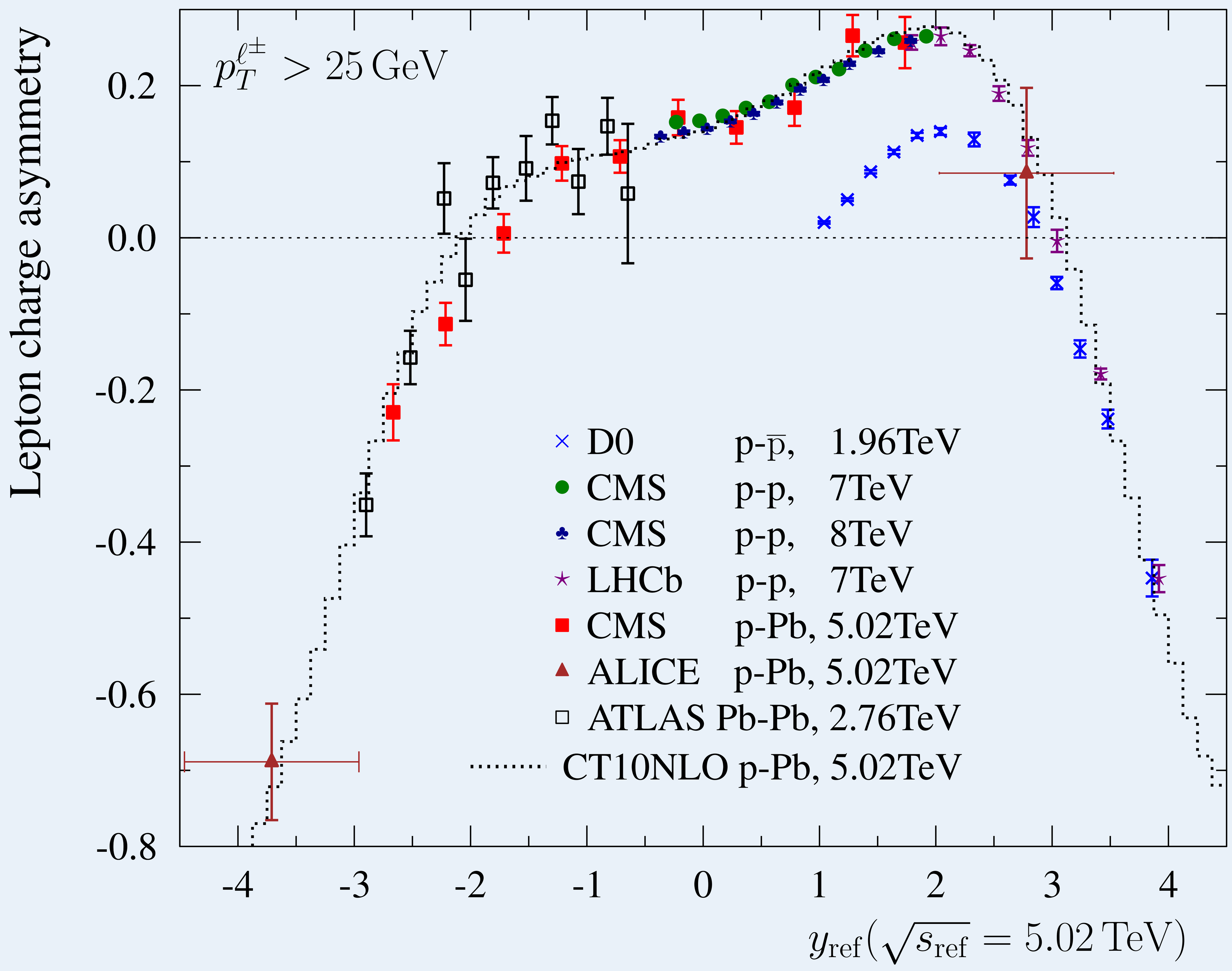
Comparison with data: $d\sigma^{W^\pm \to \ell^\pm}/dy$



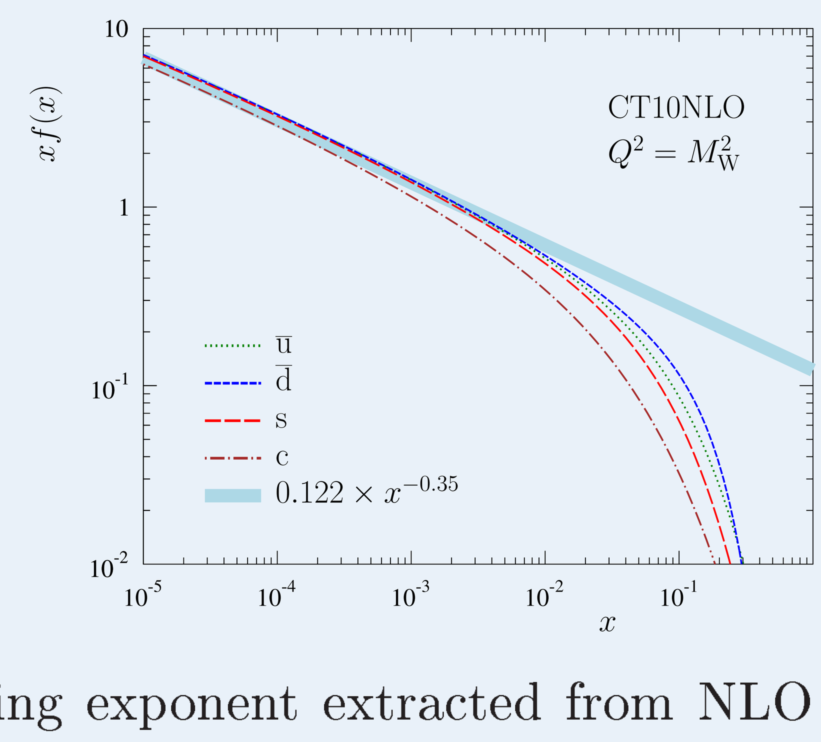
Absolute spectra for ℓ^- in different collision systems, scaled by $(s/\mathrm{GeV}^2)^{-0.40}$.

Comparison with data: $\mathcal{C}_\ell$



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

Scaling exponent



Scaling exponent extracted from NLO calculations compared to CT10NLO PDFs.

Summary

The cross section $d\sigma^{W^\pm \to \ell^\pm}/d\xi_{1,2}$ 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 $\mathcal{C}_\ell$ is approximately independent of $\sqrt{s}$ at fixed $\xi_{1,2}$. For $y \gg 0$ ($y \ll 0$) $\mathcal{C}_\ell$ also depends effectively only on the nature of the forward- (backward-) going nucleon or nucleus.