Extraction of the Weak-Mixing-Angle from Drell-Yan data in Run2 of the ATLAS Experiment

Herbstschule 2025

Lukas Bayer
DESY

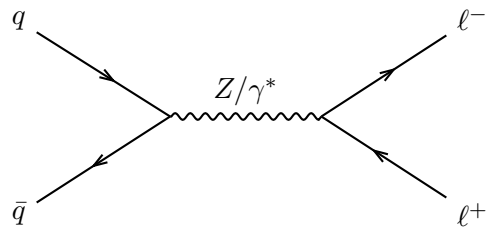

Abbildung 1: Drell-Yan production of lepton pair from quark annihilation via Z or photon (LO)

The scattering process under investigation in my analysis is the Drell-Yan process, producing a pair of leptons (electrons or muons and their respective anti-particles) from quark-antiquark annihilation. At leading order (LO) this happens via s-channel resonance of a Z boson or off-shell photon, as depicted in the Feynman diagram of figure 1. By selecting events with a di-lepton invariant mass close to the Z boson's rest mass, the photonic channel can be suppressed in comparison to the Z channel. Higher order corrections including initial state radiation can introduce a non-zero transverse momentum to the mediating boson. The full differential Drell-Yan cross-section depends on this transverse momentum p_T^Z, the rapidity y^Z of the Z boson, the invariant mass $m^Z = m^{\ell\ell}$ of the di-lepton final state and two decay angles, conventionally defined in the Collins-Soper frame [1]. That angular dependence can be expanded into a sum of eight spherical harmonic polynomials multiplied by angular coefficients A_{0-7} [2]:

$$\begin{aligned}\frac{\mathrm{d}\sigma}{\mathrm{d}p_t^Z\,\mathrm{d}y^Z\,\mathrm{d}m^Z\,\mathrm{d}\cos\theta_{CS}\,\mathrm{d}\cos\phi_{CS}} &= \frac{3}{16\pi}\frac{\mathrm{d}\sigma^{U+L}}{\mathrm{d}p_t^Z\,\mathrm{d}y^Z\,\mathrm{d}m^Z} \\ &\Big\{(1+\cos^2\theta_{CS}) + \frac{1}{2}A_0(1-3\cos^2\theta_{CS}) + A_1\sin 2\theta_{CS}\cos\phi_{CS} \\ &+ \frac{1}{2}A_2\sin^2\theta_{CS}\cos 2\phi_{CS} + A_3\sin\theta_{CS}\cos\phi_{CS} + A_4\cos\theta_{CS} \\ &+ A_5\sin^2\theta_{CS}\sin 2\phi_{CS} + A_6\sin 2\theta_{CS}\sin\phi_{CS} + A_7\sin\theta_{CS}\sin\phi_{CS}\Big\}\end{aligned}$$

Measuring these angular coefficients allows us to determine the cross-section in the full solid angle. In practice this can be achieved by fitting sets of Monte-Carlo templates of the harmonic polynomials to the observed data.

The aim of this project is to use the full Run 2 dataset of the ATLAS experiment at 13 TeV beam energy to measure four-fold differential cross-sections of the Drell-Yan process to the highest precision yet achieved with a hadron collider. These measurements are sensitive to parton distribution functions and standard model parameters like the strong coupling constant and the weak mixing angle.

In the first stage of this project, electrons and muons in the central ($|\eta| < 2.5$) part of the detector are used to measure the cross-section differential in (p_T^Z, y^Z, θ_{CS}, ϕ_{CS}).

Then, in the second stage, a third channel with one central and one forward ($2.5 < |\eta| < 4.9$) electron per event is added and the cross-section is measured differentially in (m_{ll}, y^Z, θ_{CS}, ϕ_{CS}). The inclusion of forward electrons makes additional performance work necessary, but it increases sensitivity to the forward-backward asymmetry, which is proportional to the A_4 coefficient. Since the forward-backward asymmetry is a direct consequence of parity violation in weak neutral currents, it is also related to the weak mixing angle, whose precise determination is the final goal of this project.

By interfacing xFitter with DYTurbo we can calculate precise theoretical predictions of A_4 depending on the value of the effective weak mixing angle $\sin\theta_{W,\text{eff}}$ and parton distribution functions (PDFs). Fitting templates of these predictions to our measurements then allows us to extract $\sin\theta_{W,\text{eff}}$ and constrain PDFs at the same time.

Literatur

[1] John C. Collins und Davison E. Soper. "Angular distribution of dileptons in high-energy hadron collisions". In: *Phys. Rev. D* 16 (7 Okt. 1977), S. 2219–2225. DOI: 10.1103/PhysRevD.16.2219. URL: https://link.aps.org/doi/10.1103/PhysRevD.16.2219.

[2] The ATLAS Collaboration. "Measurement of the angular coefficients in Z-boson events using electron and muon pairs from data taken at $\sqrt{s} = 8$ TeV with the ATLAS detector". In: *Journal of High Energy Physics* 2016.8 (Aug. 2016). DOI: 10.1007/jhep08(2016)159. URL: https://doi.org/10.1007%2Fjhep08%282016%29159.