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Forward-backward asymmetry measurement in $\mathrm{pp} \to \mathrm{Z}/\gamma^* + \mathrm{X} \to \mu^+\mu^- + \mathrm{X}$ events with the ATLAS experiment

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Summary. — The vector and axial-vector nature of the electroweak current leads to an asymmetry in lepton polar angle distribution in the rest frame of Z/γ^*: the measurement of this quantity, around Z pole, can provide a precise determination of the effective weak mixing angle of the Standard Model. In this contribution the forward-backward asymmetry measurement in the muon channel will be presented with data collected with the ATLAS experiment during 2010.

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1. – The forward-backward asymmetry

The forward-backward asymmetry, A_{FB}, is one of the important precision measurements that can be done at the Large Hadron Collider (LHC) [1]. It will improve the knowledge of Standard Model parameters giving a direct insight on the vector (g_V^f) and axial-vector (g_A^f) couplings to the Z boson, and thus to the effective weak mixing angle, and test the existence of possible New Physics scenarios.

At the LHC the Drell-Yan process is $q\bar{q} \to Z/\gamma^* \to \mu^+\mu^-$. The differential cross section for fermion pair production can be wirtten as

$$\begin{aligned}\frac{\mathrm{d}\sigma(q\bar{q}\to\mu^+\mu^-)}{\mathrm{d}\cos\theta} = C\frac{\pi\alpha^2}{2s}\Big[&Q_\mu^2 Q_q^2(1+\cos^2\theta) + \\ &Q_\mu Q_q \mathrm{Re}(\chi(x))(2g_V^q g_A^\mu(1+\cos^2\theta) + 4g_A^q g_A^\mu\cos\theta) + \\ &|\chi(s)|^2\left(\left({g_V^q}^2+{g_A^q}^2\right)\left({g_V^\mu}^2+{g_A^\mu}^2\right)(1+\cos^2\theta)+8g_V^q g_A^q g_V^\mu g_A^\mu\cos\theta\right)\Big],\end{aligned} \tag{1}$$

where C is the color factor, θ is the emission angle of the lepton(anti-lepton) relative to the quark(anti-quark) in the rest frame of the lepton pair. The first and the third term

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in eq. (1) correspond to the pure γ^* and Z exchange respectively while the second term corresponds to the Z/γ^* interference. The angular dependence of the various terms is either $\cos\theta$ or $(1+\cos^2\theta)$. The $\cos\theta$ term integrates to zero in the total cross section but induces the forward-backward asymmetry. The differential cross section in eq. (1) can be simplified into

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = A(1+\cos^2\theta) + B\cos\theta\,, \tag{2}$$

where A and B are functions that take into account the weak isospin and charge of the incoming fermions and Q^2 of the interaction. Events with $\cos\theta > 0$ are called forward events, and events with $\cos\theta < 0$ are called backward events. The integrated cross section for forward events is thus $\sigma_F = \int_0^1 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta$ and the integrated cross section for backward events is $\sigma_B = \int_{-1}^0 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta$. The forward-backward asymmetry A_{FB} is defined as

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{\int_0^1 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta - \int_{-1}^0 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta}{\int_0^1 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta + \int_{-1}^0 \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\mathrm{d}\cos\theta} = \frac{N_F - N_B}{N_F + N_B} = \frac{3B}{8A}\,, \tag{3}$$

where N_F and N_B are the number of forward and backward events.

When the incoming quarks participating in the Drell-Yan process have no transverse momentum relative to their parent baryons, θ is determined unambiguously from the four-momenta of the leptons by calculating the angle that the lepton makes with the proton beam in the center-of-mass frame of the muon pair. When either of the incoming quarks has significant transverse momentum, however, there exists an ambiguity in the four-momenta of the incoming quarks in the frame of the dilepton pair, since one can not determine the four-momenta of the quark and antiquark individually. The Collins-Soper formalism [2] is adopted to minimize the effects of the transverse momentum of the incoming quarks. In this formalism, the polar axis is defined as the bisector of the proton beam momentum and the negative of the anti-proton beam momentum when they are boosted into the center-of-mass frame of the dilepton pair. The variable θ^* is defined as the angle between the lepton and the polar axis. Let $Q(Q_T)$ be the four momentum (transverse momentum) of the dilepton pair, P_1 and P_2 be the four-momentum of the lepton and anti-lepton respectively, all measured in the lab frame. $\cos\theta^*$ is then given by

$$\cos\theta^* = \frac{2}{Q\sqrt{Q^2+Q_T^2}}(P_1^+P_2^- - P_1^-P_2^+)\,, \tag{4}$$

where $P_i^{\pm} = \frac{1}{\sqrt{2}}(P_i^0 \pm P_i^3)$, with P^0 and P^3 representing the energy and the longitudinal component of the momentum.

2. – Detector resolution and dilution unfolding results on data

In order to correct the "raw" (*i.e.* detector-level) forward-backward asymmetry and obtain the physics-level A_{FB} the measurement must account for any effect that can change the number of forward and backward events in each $M_{\mu\mu}$ bin.

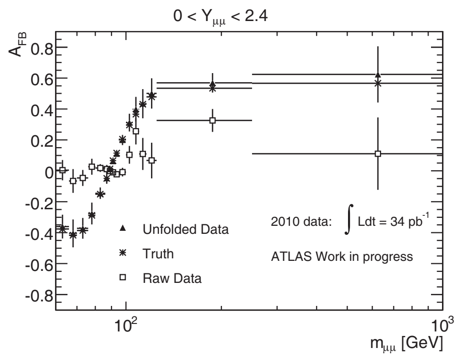

Fig. 1. – Forward-backward asymmetry *vs.* dimuon invariant mass.

The measurement is complicated by detector resolution and QED radiation which cause the true and measured $M_{\mu\mu}$ and $\cos\theta^*$ differ. The correction needs to be made in order to unfold the detector effect. The method of matrix inversion is one of the unfolding methods. Suppose the true numbers of events in the invariant mass bin j is μ_j. We will refer to the vector $\boldsymbol{\mu} = (\mu_1, \ldots, \mu_N)$ as the true histogram. The vector $\boldsymbol{\mu}$ is what we want to measure by unfolding. The observed values is $\mathbf{n} = (n_1, \ldots, n_N)$. The expected number of events to be observed in bin i can be written as $\nu_i = \sum_{i=1}^{N} R_{ij}\mu_j$ where $R_{ij} = \frac{P(\text{observed in bin } i \text{ and true value in bin } j)}{P(\text{true value in bin } j)} = P(\text{observed in bin } i|\text{true value in bin } j)$. The response matrix element R_{ij} is thus the conditional probability that an event will be found in bin i given that the true value was in bin j. If the expectation value for the background processes in bin i (β_i) is known, the vectors $\boldsymbol{\mu}$, $\boldsymbol{\nu}$, $\boldsymbol{\beta}$ and the matrix R are related by $\boldsymbol{\nu} = R\boldsymbol{\mu}+\boldsymbol{\beta}$. The matrix relation can be inverted to give $\boldsymbol{\mu} = R^{-1}(\boldsymbol{\nu}-\boldsymbol{\beta})$. The estimators of $\boldsymbol{\nu}$ is given by the corresponding data value, $\hat{\boldsymbol{\nu}} = \mathbf{n}$. The estimators for the $\boldsymbol{\mu}$ are then $\boldsymbol{\mu} = R^{-1}\,(\mathbf{n} - \boldsymbol{\beta})$. In order to unfold the distribution of A_{FB}, the number of forward events $\boldsymbol{\mu}^F$ and the backward events $\boldsymbol{\mu}^B$ are separately unfolded with two response matrices R^F and R^B, obtained from the forward and backward events produced with the Pythia Monte Carlo event generator. In pp colliders, an extra complication arises from the fact that one does not know which beam the quark belonged to. As a result the A_{FB} is diluted. To correct the dilution a similar approach as in the detector resolution and QED radiation correction has been adopted. A matrix of true *vs.* reconstructed $\cos\theta^*$ has been produced for each $M_{\mu\mu}$ bin. These Monte Carlo based unfolding methods have been tested and closure tests were successful. Both corrections have been applied to 2010 data and the result is reported in fig. 1. Data after complete unfolding (triangle) and physics-level expectation (asterisk) are in very good agreement.

3. – Conclusions

A first measurement of the forward-backward asymmetry in $\mathrm{pp} \to \mathrm{Z}/\gamma^*+\mathrm{X} \to \mu^+\mu^-+\mathrm{X}$ with the ATLAS [3] experiment has been performed and preliminary results with an integrated luminosity of $\sim 34\,\mathrm{pb}^{-1}$ collected in 2010 have been reported. Monte Carlo based corrections for detector resolution and dilution have been tested and closure tests were successfull. When these corrections are applied to data the resulting A_{FB} *vs.* dimuon mass distribution shows a very good agreement with Monte Carlo expectation.

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