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Measurement of the Z boson invisible width at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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A measurement of the invisible partial decay width of the Z boson is presented which constitutes a precision test of the electroweak structure of the Standard Model of particle physics. The Z boson decay width into invisible particles is measured with the ATLAS detector at the Large Hadron Collider using 37 fb^{-1} recorded proton-proton collisions at a centre-of-mass energy of 13 TeV. Events with missing transverse momentum and at least one highly energetic jets are compared to events with Z boson decays into pairs of electrons or muons associated with jets. The corresponding ratios are corrected for detector effects and combined to form a ratio of branching fractions $\hat{R}^{\text{miss}}$. Combining this ratio with the leptonic Z boson width measured at the Large Electron-Positron Collider yields $\Gamma(Z \to \text{inv}) = 506 \pm 2$ (stat.) $\pm$ 12 (syst.) MeV. This result is in excellent agreement with the Standard Model prediction as well as previous measurements, and represents the single most precise recoil-based measurement of the invisible partial width of the Z boson.

The 12th Large Hadron Collider Physics Annual Conference - LHCP2024
3-7 June 2024
Northeastern University, Boston, US

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https://pos.sissa.it/

PoS(LHCP2024)244

ATL-PHYS-PROC-2024-101
30 October 2024

1. Introduction

The measurement of the invisible decay width of the Z boson presents a precision test of the electroweak sector of the Standard Model (SM) and potential deviations to the SM prediction can be interpreted as indications for physics beyond the SM.
The presented measurement of the invisible width of the Z boson by the ATLAS experiment [1] using $37\,\text{fb}^{-1}$ recorded proton-proton collisions at a centre-of-mass energy of 13 TeV follows the recoil-based measurements (initial state photon) at LEP performed at ALEPH [2], OPAL [3] and L3 [4] and (hadronic-recoil) at the CMS experiment [5]. The LEP combination and the result by CMS reach both a precision of roughly 3%, which is about an order of magnitude larger than the LEP lineshape result obtained by the subtraction of all visible partial decay widths from the total width of the Z boson determined by the LEP experiments [6].

2. Analysis Strategy

The invisible width of the Z boson is extracted by utilizing the ratio of the number of $Z(\rightarrow \text{inv}) + \text{jets}$ to $Z(\rightarrow \ell\ell) + \text{jets}$ events with $\ell = e, \mu$, which are required to contain at least one energetic jet with $p_\text{T} \geq 110$ GeV. Correcting both the numerator and the denominator to a common phase space ensures a cancellation of the dominant systematic uncertainties. The respective ratio is defined as a function of $p_\text{T,Z}$, the Z boson p_T, which is required to exceed 130 GeV,

$$R^\text{miss}(p_\text{T,Z}) \equiv \left(\frac{d\sigma(Z+\text{jets})\times BR(Z\rightarrow\text{inv})}{dp_\text{T,Z}}\right) / \left(\frac{d\sigma(Z+\text{jets})\times BR(Z\rightarrow\ell\ell)}{dp_\text{T,Z}}\right), \tag{1}$$

with $BR(Z \rightarrow \ell\ell)$ indicating electron or muon branching ratios.

Minor backgrounds such as $t\bar{t}$, single-top and diboson are estimated by their respective Monte Carlo simulations whereas data-driven methods are used to determine the background contribution from non-collision and QCD multijet events in the $Z(\rightarrow \text{inv}) + \text{jets}$ region. The normalisation of the $W(\rightarrow l\nu) + \text{jets}$ with leptons out of acceptance or efficiency are derived in dedicated control regions for electrons and muons and validated in a tau control region. In the single lepton control regions and the di-lepton signal regions backgrounds from fake leptons are estimated via the matrix method. The corresponding spectra with their respective statistical and systematic uncertainties are shown in Figure 1 for $Z(\rightarrow \text{inv}) + \text{jets}$ (left) and $Z(\rightarrow \mu\mu) + \text{jets}$ (right).

After the subtraction of the various backgrounds and the application of a bin-by-bin detector correction, restoring mainly the out of acceptance and efficiency leptons in the $Z(\rightarrow \ell\ell) + \text{jets}$ regions, the R^miss ratios can be derived. These are shown as a function of $p_\text{T,Z}$ in Figure 2 for electrons (left) and muons (right) in the denominator.

$\Gamma(Z \rightarrow \text{inv})$ is then derived from the multiplication of the most probable value $\hat{R}^\text{miss}$, which is extracted via a linear fit considering statistical and systematic uncertainties, with the at LEP very precisely measured leptonic width [6, 8] of the Z boson:

$$\Gamma(Z \rightarrow \text{inv}) = \hat{R}^\text{miss} \cdot \Gamma(Z \rightarrow \ell\ell). \tag{2}$$

3. Results

The invisible width of the Z boson is measured to be 506 ± 2 (stat.) ± 12 (syst.) MeV. The dominant systematic uncertainties are due to lepton uncertainties in the denominator of the ratio.

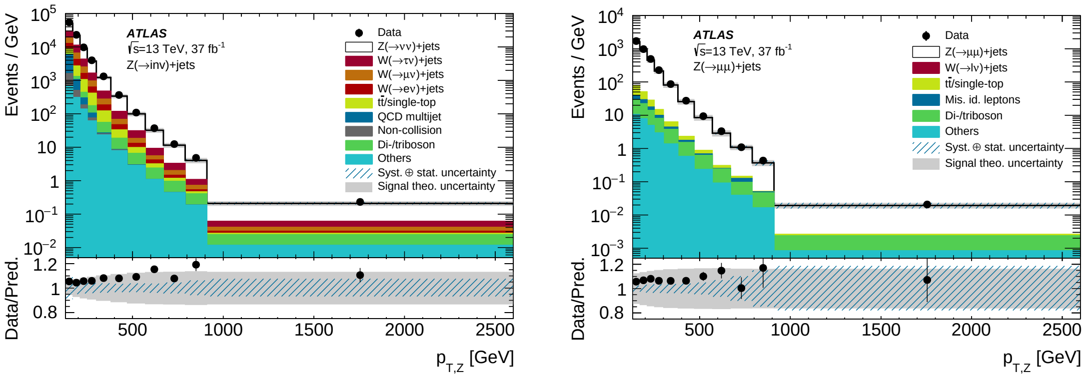

Figure 1: The $p_{\mathrm{T,Z}}$ spectra are shown for both data and predictions in the $Z \rightarrow$ inv (left) and $Z \rightarrow \mu\mu$ (right) signal region and the corresponding ratio of data to prediction in the lower panels. The statistical uncertainties are presented as error bars whereas the total combined statistical and systematic uncertainties are displayed as the blue hashed bands. The theory uncertainties on the respective signal processes, presented in white, are shown by the grey bands[7].

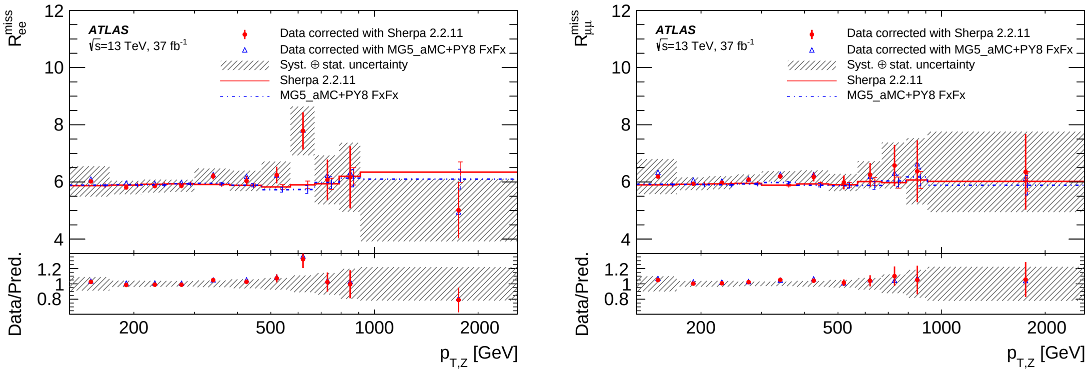

Figure 2: The measured and with Sherpa 2.2.11 (red) and MG5_aMC+Py8 FxFx (blue) corrected R^{miss} ratios are shown for the electrons (left) and muons (right) as a function of $p_{\mathrm{T,Z}}$. Statistical uncertainties are presented as error bars whereas the combined statistical and systematic uncertainties are shown as the hashed grey bands. The predictions for the Sherpa 2.2.11 (red) and for the MG5_aMC+Py8 FxFx (blue) are shown with their respective statistical uncertainties and uncertainties due to an applied γ^* correction considering the additional interaction of charged leptons with photons. The corresponding data to prediction comparisons are presented in the lower panels [7].

The result is the most precise recoil-based measurement to date and is in excellent agreement with the Standard Model prediction of 501.445 ± 0.047 MeV [8] as well as previous measurements. A summary of the various measurements is given in Figure 3.

References

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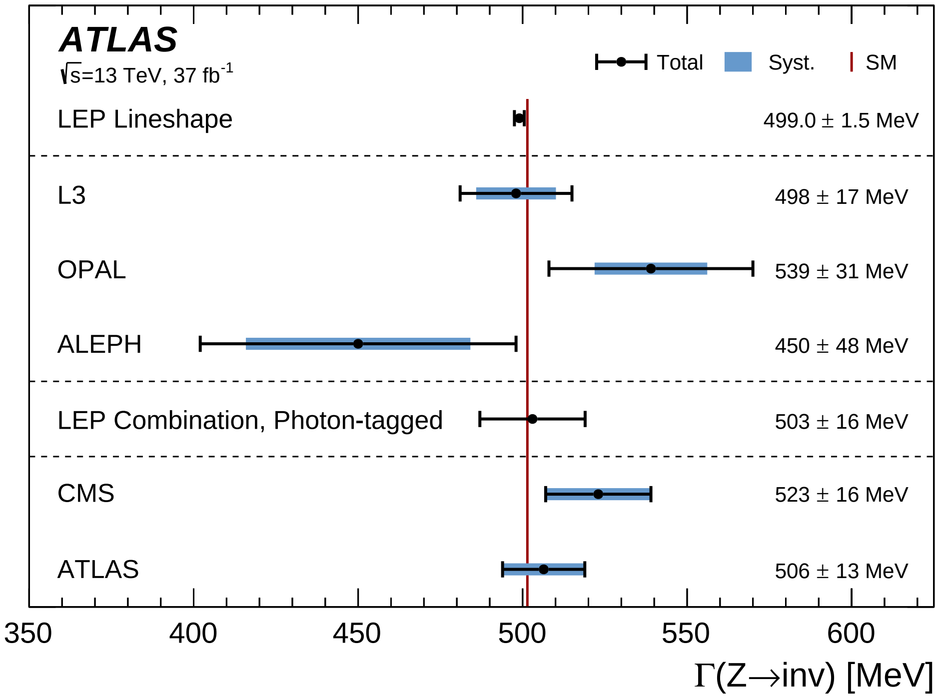

Figure 3: Measurements of $\Gamma(Z \to \text{inv})$ by the L3, OPAL and ALEPH experiments at LEP and their combination studying initial state photons, by the CMS experiment at the LHC are presented together with the here derived ATLAS result are presented alongside the LEP lineshape result and the Standard Model prediction (red solid line). The black error bars show the combined statistical and systematic uncertainties whereas the later are also presented separately by the blue bands. For the LEP combination of the photon-tagged results and the lineshape result only the total uncertainty is shown [7].

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