Data driven muon identification efficiency measurement in ATLAS with $J/\psi \to \mu^+\mu^-$ decays

G. Chiodini [1] N. Orlando [1, 2] and S. Spagnolo [1, 2] and the ATLAS Collaboration

[1]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy.,

[2]Dipartimento di Fisica, Università del Salento, Italy.

We present the muon identification efficiency measurement as performed in the ATLAS experiment by using the so-called "tag and probe" method at the J/ψ resonance; a detailed description of these studies can be found in [1]. The tag and probe method allows to select an unbiased sample of muons by searching for an Inner Detector (ID) track ("the probe") that, along with a well reconstructed muon ("the tag") forms a system with invariant mass consistent with a di-muon resonance. By this procedure a sample of low p_T probes are selected independently of the ATLAS Muon Spectrometer (MS) and can be used to measure the efficiency for reconstructing a muon with MS measurement.

Two categories of muons are reconstructed in ATLAS using the Muon Spectrometer data: Combined (CB) muons, that require the reconstruction of consistent tracks in the MS and in the ID, and Segment tagged (ST) muons, that give additional efficiency as they can recover muons, typically of low p_T, which did not cross enough precision chambers to allow an independent momentum measurement in the MS. The two classes of muons are implemented in two different reconstruction chains, hereafter referred as chain 1 (Staco) and chain 2 (MuId).

Events were selected on-line by single muon trigger and are requested to be good collision events were selected by requiring at least one reconstructed primary vertex with three or more associated ID tracks [1].

Tags are selected among CB muons associated to a good quality ID track and satisfying the following criteria:

- $p_T > 4$ GeV, $|\eta| < 2.5$;
- distance of closest approach to the primary vertex in the transverse plane $|d_0| < 0.3$ mm and in the longitudinal coordinate $|z_0| < 1.5$ mm. Distance of closest approach significances $|d_0|/\sigma(d_0) < 3$ and $|z_0|/\sigma(z_0) < 3$;
- matching with the muon triggering the event.

For each tag in the event, probes are selected as any good ID track with

- $p > 3$ GeV, $|\eta| < 2.5$;
- the probe and the tag tracks can be refitted to a common vertex with $\chi^2/\text{ndof} < 6$;
- distance between tag and probe $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 3.5$;
- requested opposite charge tag and probe pairs falling in the invariant mass window between 2 GeV to 3.6 GeV

In the high multiplicity of LHC events, an ID track can pass all the selection criteria in association with more than one tag in the event. In such cases, in order to avoid testing the muon reconstruction result more than once for the same probe, a unique probe-to-tag association is chosen based on the minimum χ^2 of common vertex fit. Furthermore, in order to prevent an enhanced probability of reconstructing probes in events topologies with nearby tag and probe tracks we request $\eta_{tag} - \eta_{probe} > 0.5$ or $\phi_{tag} - \phi_{probe} > 0.22$.

The tag and probe pairs were divided into two categories, those in which the probe was reconstructed as a muon (matched) and those in which the probe was not reconstructed as muon (unmatched). Figure 1 shows the invariant mass distribution for a sub-sample of the selected tag and probe pairs.

The mass distribution is shown separately for probes classified as matched and unmatched with respect to CB and to CB+ST chain 2 muons.

The reconstruction efficiency was obtained as the ratio of the number of events in the peak of the matched distribution to the total number of events in the two mass peaks. A binned maximum log-likelihood fit was performed simultaneously on the two distributions, with the following parametrizations:

Matched
$$f_M(m) = N_{\text{tot}}\, \epsilon\, G(m\,;\, \mu_M, \sigma_M) + P_M(m)$$

Unmatched
$$f_U(m) = N_{\text{tot}}\, (1-\epsilon)\, G(m\,;\, \mu_U, \sigma_U) + P_U(m)$$

where $G(m;\mu,\sigma)$ is a Gaussian distribution with mean μ and standard deviation σ, used to de-

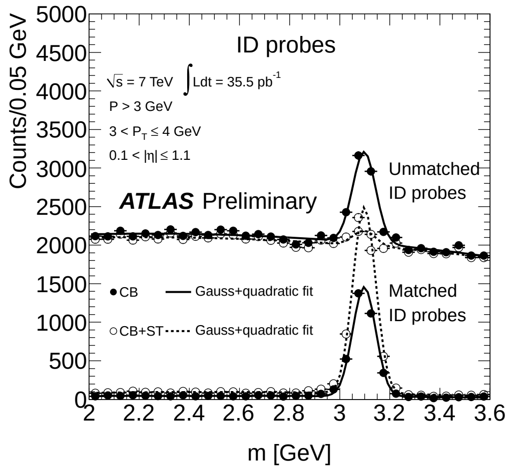

Figure 1. Invariant mass of the unmatched (upper points) and matched (lower points) tag and probe pairs for CB (filled circles) and CB+ST (empty circles) muons of chain 2 for $0.1 < |\eta| < 1.1$ and 3 GeV$< p_T < 4$ GeV. The curves show the fits described in the text.

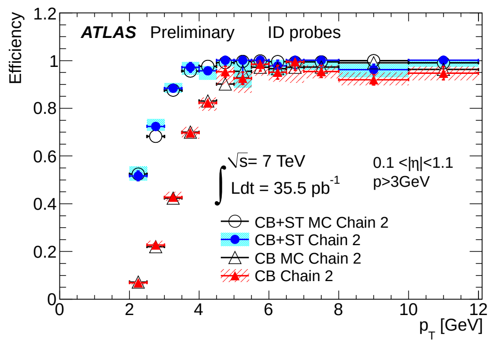

Figure 2. Efficiency for CB and CB+ST muons of chain 2 as a function of p_T in the barrel for data and MC. The error bars represent the statistical uncertainties while the band around the data points represents the statistical and systematic uncertainties added in quadrature.

scribe the signal peak, and P is a second order polynomial function used to describe the background. The main parameters extracted from the fit are the number of tag and probe pairs in the signal peak $N_{\rm tot}$ and the reconstruction efficiency ϵ. The Figure 2 shows the efficiency for chain 2 in the barrel region ($0.1 < |\eta| < 1.1$) with respect to ID tracks with $p > 3$ GeV as a function of the probe p_T. The simulation describes the data well.

The uncertainty on the reconstruction efficiency measurement is dominated by the statistical and systematic contribution from the large background in the unmatched sample. The background can be significantly suppressed if the probes are selected among the ID tracks that are identified as calorimeter-tagged (CT) muons.

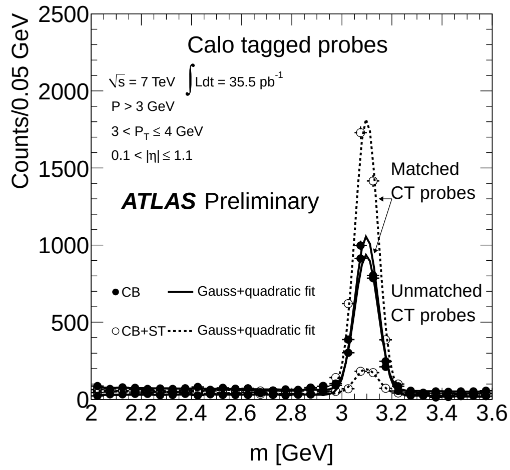

Figure 3. Invariant mass of the unmatched and matched tag and probe pairs for CB (filled circles) and CB+ST (empty circles) muons of chain 2 for $0.1 < |\eta| < 1.1$ and 3 GeV$< p_T < 4$ GeV. The probes are selected among calorimeter-tagged muons. The curves show the fits described in the text.

The calo-tagging algorithm flags ID tracks as calorimeter tagged muons by using the energy deposit in the calorimeter as a discriminant variable. The mass distributions for tag and probe pairs, where the probe is calo-tagged, is shown in Figure 3 for probes matched and unmatched to offline reconstructed muons.

In conclusion, the tag and probe method at the J/ψ resonance provides a powerful technique for high precision muon identification efficiency measurement over the full ATLAS detector acceptance; the agreement between data and MC is remarkable in a large fraction of the allowed phase space for both the reconstruction chains and algorithms. Scaling factors defined as data over MC efficiency ratios are provided to correct the residual mis-modeling of the ATLAS detector performance in order to increase the accuracy of the muon reconstruction effect unfolding as needed by a wide spectrum of physics analysis performed in the ATLAS experiment. In particular an accurate muon reconstruction efficiency measurement at low transverse momentum will allow to extend the experimental sensitivity to Standard Model Higgs search at low mass with the decay channels $h \to WW^{(*)}$ and $h \to ZZ^{(*)}$ exploiting the clear experimental signature of electroweak bosons decays into muons.

REFERENCES

1. N. Orlando on behalf of the ATLAS Collaboration, Muon reconstruction efficiency measurement in the ATLAS experiment, ATL-COM-PHYS-2011-1754 (2011), submitted to Eur. Phys. J. W.