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

G. Chiodini , 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.

The study of quarkonia at LHC is important in order to clarify the production mechanism and test non-relativistic QCD predictions; in addition, quarkonia decays into di-lepton final states provide useful control samples to measure trigger and reconstruction efficiency, and to calibrate low momentum scale and resolution of different sub-detectors.

The ATLAS experiment measured with 2010 proton-proton collisions data at $\sqrt{s} = 7$ TeV the double differential cross section for the $J/\psi \rightarrow \mu^+\mu^-$ and separated the contribution between prompt (direct hard production and hadron fragmentation) and non-prompt components (from long lived B-mesons decays) [1].

In order to measure a cross section the detector effect must be unfolded from the observed distributions. This is obtained by weighting each event with the inverse of the overall detection probability: $w^{-1} = A(\vec{p_1}, \vec{p_2}) \cdot \epsilon_{trig}(\vec{p_1}, \vec{p_2}) \cdot \epsilon_{\mu^+}(\vec{p_1}) \cdot \epsilon_{\mu^-}(\vec{p_2})$, where A is the J/ψ dimuon decay kinematic acceptance given by the ATLAS detector fiducial volume, ϵ_{trig} is the trigger efficiency, $\epsilon_{\mu^{+(-)}}$ is the single muon off-line reconstruction efficiency, and $\vec{p_j}$ is the j-th muon's vector momentum.

In the above quoted reference the muon reconstruction efficiency was estimated from simulations. A data driven determination of the reconstruction efficiency is however necessary in order to take into account the realistic status of the detector, during the early data taking phase, and the real performance of the muon identification algorithms on real data from not perfectly calibrated and aligned detectors. Eventually the comparison of reconstruction efficiency measured in data and in Monte Carlo allows to quote "scaling factors" for the correction of expected selection performance. We performed a measurement of the muon reconstruction efficiency relative to the inner detector tracking in (p_T,η) bins using the $J/\psi \rightarrow \mu^+\mu^-$ decay in real data by exploiting the tag-and-probe technique. The efficiency maps obtained have been directly used (or referred in order to apply scaling factors to the simulation) in Physics analyses of the 2010 data with low momentum muons in the final state (an example [2] is the update with high statistics of the results in [1]).

The method is based on a search for a high quality muon reconstructed both in the inner tracker and in the muon spectrometer and firing the trigger (the tag) accompanied by an inner detector track (the probe) of opposite charge; if the tag and probe pair converges to a common vertex and has invariant mass close to the J/ψ mass, the probe is an unbiased muon candidate that can be used to test the efficiency of the muon reconstruction, with respect to the inner detector efficiency, that is known to be very close to 100%.

In ATLAS two kinds of reconstructed muons are available for Physics analysis: Combined Muons (CB), obtained from a combined fit of two statistically compatible tracks reconstructed independently in the muon spectrometer and in the inner detector, and Segment Tagged Muons (ST), obtained from an inner detector track that extrapolated to the muon spectrometer statistically overlaps with at least a track segment. ST muons allow to recover efficiency in poorly instrumented regions and for muons of low p_T that, bent by the magnetic field, do not cross enough precision chamber stations to allow a measurement of the momentum in the MS.

Due to the configuration of the magnetic field in the muon spectrometer, muons with positive and negative charge are bent differently. This effect introduces a charge dependence of the muon reconstruction and trigger efficiencies, which is particularly relevant at very large polar angles, where muons of one charge may be bent outside the detector geometrical acceptance, and at low transverse momentum, where muons of one charge may be bent back before reaching the middle or outer stations.

In Figure 1 the invariant mass distribution of tag and probe pairs for probes contributing (and not contributing) to a reconstructed muon are shown for a selected (p_T,η) bin. A signal peak can be clearly separated from the combinatorial background, using the discriminating power of the tag and probe invariant mass. The number of signal probes is estimated by statistically subtracting the fake contribution with several tech-

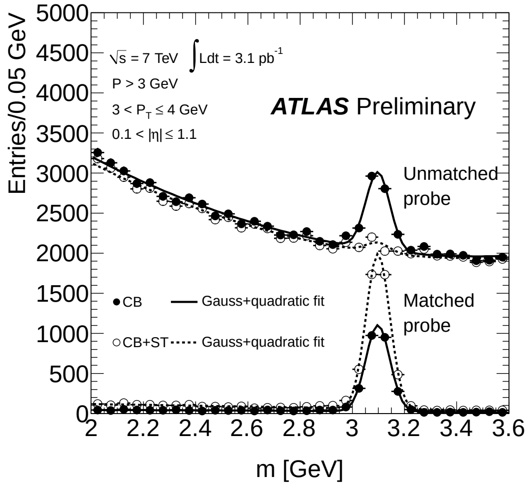

Figure 1. Invariant mass of the unmatched (upper points) and matched (lower points) tag-probe pairs for CB (filled circles) and CB+ST (empty circles) muons of chain 1 for $0.1 < |\eta| < 1.1$ and $3 < \mathrm{pT} < 4$ GeV. The curves show the combined fits described in the text.

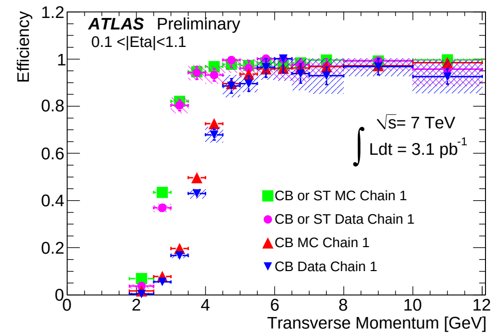

Figure 2. Efficiency for CB and CB+ST muons of chain 1 as a function of pT for $0.1 < |\eta| < 1.1$ data and MC. The error bars represent the statistical uncertainties while the band around the data points represent the statistical and systematic uncertainties added in quadrature.

niques: same sign subtraction, side band background, s-plot method[3] and fitting method. We selected as baseline the fitting method (Gaussian and polynomial model for signal and background respectively) due to its smooth behavior and to the possibility to extract the efficiency from a concurrent fit of the distribution for non-reconstructed and reconstructed probes.

Comparisons with the simulation are made using $5{\times}10^6$ QCD events with prompt J/ψ decaying to muon pairs generated with Pythia 6, implementing NRQCD Color Octet Model, and MRST LO parton distribution functions. The same analysis procedure is applied to such simulated signal events after re-weighting to reproduce the probe (p_T, η) distribution in the data and, therefore, avoid finite size phase space binning effect when the efficiency is steeply changing like for low momentum muons and in the transition between central and forward regions.

In Figure 2 the efficiency maps for CB and CB+ST muons integrated along the azimuthal angle and in the muon spectrometer central region are reported for real and reweighted simulated data showing a quite good agreement both in the turn-on curve that in the plateau region. The results are obtained using an integrated luminosity of 3.1 pb^{-1}. For transverse momenta greater than 5 GeV the efficiency is greater than 98%.

The reported systematics errors were evaluated by changing the background and signal parameterization, which turns out to be the most important effect. Several other systematic checks have been done, such as: tag impact parameter cuts and probe selection cleaning by requiring a mip signature in the calorimeter, tag-trigger matching criteria, different MC re-weighting techniques; they were all found to determine very small shift of the efficiency measurement.

The good agreement between efficiency extracted from real data and simulated data using data driven methods results in “scale factors” very close to 1. This implies a good and realistic detector description achieved by the ATLAS simulation software and allows to extend in a reliable way Physics studies to the low momentum muon regime, in spite of the non optimal detector performance, in order to enlarge the Physics reach of the experiment with the Large Hadron Collider data.

REFERENCES

1. ATL-CONF-2010-045, “Measurement of the $J/\psi \rightarrow \mu\mu$ differential cross section and fraction from B-decays”
2. ATL-COM-PHYS-2011-082, “A measurement of the differential cross sections for the $J/\psi \rightarrow \mu^+\mu^-$ resonance and the non-prompt J/ψ cross section fraction with pp collisions at $\sqrt{s} = 7$ TeV in ATLAS”.
3. M. Pivk and F. R. Le Diberder, “sPlot:a statistical tool to unfold data distributions”. arXiv:0402083v3 [physics].