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T&P single muon efficiencies for low p_T dimuon triggers in 2015

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Abstract

Single muon trigger and reconstruction efficiencies for low p_T dimuon triggers are studied within the tag and probe (T&P) framework, applied to dimuons in the J/ψ mass window. The muon (offline) reconstruction efficiency as well as the efficiency of the track quality cuts typically used in B-physics analyses, are described in detail, along with the muon tracking efficiency. Given that all quarkonium triggers in 2011 ran a (dimuon) vertexing module at the end of the HLT path, we also discuss its efficiency as a function of the pair p_T and $|y|$. All efficiencies (measured as a function of p_T in several pseudo-rapidity bins) are compared to detailed MC simulations, properly reflecting the L1 and HLT menus used during the 2015 data taking in the 50ns scenario.

Contents

1 Introduction

The Tag and Probe (T&P) method is a well established framework within CMS to study the single muon detection efficiencies. Despite of its wide usage across all analyses containing muons, every study needs to be set up in a different way. Setting up the "fitter scripts" needs quite some attention in order not to introduce biases in the method, as well as designing the individual scripts such that the corresponding efficiencies are fully factorizable. This has been achieved by setting up the initial fitter scripts in close collaboration with the MUON POG [1]. Moreover, it should be emphasized that correlations among the two muons induced by the detector or trigger system cannot be reproduced by the T&P *single* muon efficiencies. The single muon efficiencies need to be studied such that they are not affected by possible inefficiencies or biases due to the presence of the second muon. Possible correlations, whose net result is often referred to under the term "ρ factor", need to be studied through other methods. This factor enters the expression to build the dimuon detection efficiencies from the product of the single muon efficiencies, as a generic "correction factor".

Low p_{T} single muon triggers were highly prescaled in 2015, and only exist during partial data taking periods. Moreover, the fraction of events containing a J/ψ dimuon is very small, such that the collected data samples are not large enough for the assessment of data driven efficiencies. For this reason, special efficiency triggers were developed to study the single muon detection efficiencies in an unbiased way. These are "dimuon" triggers with a mass cut in the J/ψ region of two complementary topologies: MuX_TrackY (being effectively a "single" muon trigger path) and MuX_L2MuY. The former allows an unbiased assessment of the muon related efficiencies (offline reconstruction in the muon chambers, as well as L1 and L2 trigger efficiencies), while the latter allows the study of the muon offline silicon tracking and track quality selection efficiencies, as well as the L3 trigger efficiency.

In the current document we follow the approach suggested by the MUON POG to first study the muon offline reconstruction efficiencies, and then the trigger efficiencies with respect to offline muons. The full procedure is split into the following 2 steps:

1. $\epsilon_{\mathrm{Track}}$: offline muon tracking efficiency in the Silicon tracker
2. $\epsilon_{\mathrm{MuonID}}|\epsilon_{\mathrm{Track}}$: offline muon reconstruction and quality cuts efficiency in the muon chambers with respect to a Silicon track
3. $\epsilon_{\mathrm{L1\cdot L2}}|(\epsilon_{\mathrm{MuonID}}|\epsilon_{\mathrm{Track}}))$: combined L1·L2 trigger efficiency with respect to an offline reconstructed muon with given quality criteria
4. $\epsilon_{\mathrm{L3}}|(\epsilon_{\mathrm{L1\cdot L2}}|(\epsilon_{\mathrm{MuonID}}|\epsilon_{\mathrm{Track}})))$: L3 trigger efficiency with respect to the previous condition

The tracking efficiency was studied extensively in the past and has turned out to be $(99 \pm 1)\%$, independently of the muon's p_T or η. We have not repeated this study here and use this value, as recommended by the MUON POG.

2 Data sets and run dependences

The data collected with the physics and efficiency triggers of the B-physics group are stored in the `Charmonium` primary data set (PD). A graphical representation of the events triggered by the physics triggers relevant for low mass dimuon physics can be seen in Fig. 1; details of the time evolution of the B-PAG trigger menu can be found in Ref. [2].

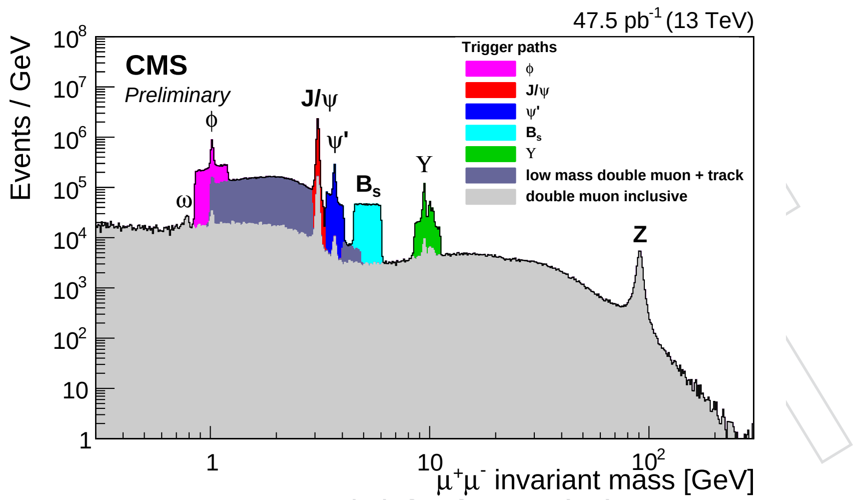

Figure 1: Dimuon mass distributions, using the offline reconstructed variables, triggered by the trigger paths listed in the legend box.

The two types of efficiency triggers exist in the following instances: Mu7p5_L2Mu2_Jpsi, Mu7p5_Track2_Jpsi and Mu7p5_Track7_Jpsi. The latter two are both aimed to study the same kind of efficiency, but with a different p_T coverage of the probe muon, $p_T \gtrsim 2$ and $7\ GeV/c$, respectively. The high p_T instance covers the region where the efficiencies should reach their saturation values. Because of the higher trigger rate, the low p_T version has a significantly larger prescale than its "high p_T" counterpart, except for the first data taking period (low luminosity conditions) in which both triggers have the same prescale.

The studies presented here were obtained by covering the run periods summarized in Table 1.

Table 1: Datasets used for the T&P studies discussed in this note.

data set	trigger menu	run range
Run2015B-PromptReco-v1	50ns_5E33	250985 − 253620

The T&P skims were produced using the following certification files for the PromptReco data:

- Cert_246908-251883_13TeV_PromptReco_Collisions15_JSON_MuonPhys_v2.txt

3 Setup of the T&P fitter scripts

The T&P producer script is defined not only to prepare all the needed variables for the corresponding fitter scripts, but also to filter on events triggered by either the HLT_MuX_TrackY_Jpsi or the HLT_MuX_L2MuY_Jpsi efficiency trigger paths.

The way the fitter scripts are set up is done in a similar fashion for all the 4 single muon efficiencies: the tag muon is matched to the L3 leg ("HLT_MuX") of the efficiency trigger paths. The probe is then matched to the second leg in the efficiency path, i.e. the "TrackY" in the case of the muon related efficiency studies, or the "L2MuY" object in the case of the tracker related efficiencies. The passing probes are the fraction of all probes that pass a given, well defined criterion, to be discussed in the individual sections below.

In the case of the efficiency of the trigger dimuon vertexing module, which is used in all the quarkonium physics triggers of the `Charmonium` PD, a slightly different procedure needs to be adopted, given that it is not a single muon but rather a dimuon whose efficiency is probed: the T&P skim needs to be prepared with the option

```
    arbitration   = cms.string("OnePair")
```

In this way the pair becomes the probe. The efficiency of any of the vertexing modules (last L3 filter in any of the quarkonia trigger paths) can be studied with respect to the specially designed triggers HLT_Dimuon6_Jpsi_NoVertexing and HLT_Dimuon0er16_Jpsi_NoVertexing, which do not contain the vertexing module in their trigger path. In the current study, we use the vertexing module of the HLT_Dimuon16_Jpsi and HLT_Dimuon10_Jpsi_Barrel trigger paths, given that its configuration is identical to the ones of the inclusive J/ψ, ψ' and Υ trigger paths: it simply requests that the dimuon secondary vertex has a fit χ^2 probability larger than 0.5 %.

4 MC sample

The T&P studies are performed in an analogous way on a J/ψ MC sample. For this purpose, a 30M events official MC production has been requested [3]:

https://cms-pdmv.cern.ch/mcm/requests?prepid=BPH-RunIISpring15DR74-00003
&page=0&shown=1055

5 Offline muon reconstruction and quality cuts efficiency

The probes for the muon reconstruction and quality cuts efficiencies are offline tracks of the collection `generalTracks` with two additional requests: p_{T} above a certain threshold, lower than what can be reasonably reconstructed as a muon; matched to the `TrackY` leg of the efficiency trigger path. Passing probes are those that satisfy the series of tracking related quality cuts ("BMuQual"):

- `highPurity`
- `TMOneStationTight`
- `trackerLayersWithMeasurement` > 5
- `pixelLayersWithMeasurement` > 0
- $|dxy| < 0.3$ cm and $|dz| < 20$ cm.

These are cuts widely used in the quarkonium related analyses. According to the efficiency studies shown in Fig. 3, the efficiencies of these cuts are slightly $|\eta|$ dependent, with only a mild p_{T} turn-on behaviour, being between 96 % and 98 % for $p_{\mathrm{T}} > 10\,\mathrm{GeV}/c$. The background under the J/ψ peak in the three probe samples ("Passing", "Failing" and "All" probes) is rather small and the analysed sample is also large enough such that the data driven efficiencies are obtained with a good statistical accuracy, showing a clear trend, faithfully reproduced by the MC T&P efficiencies.

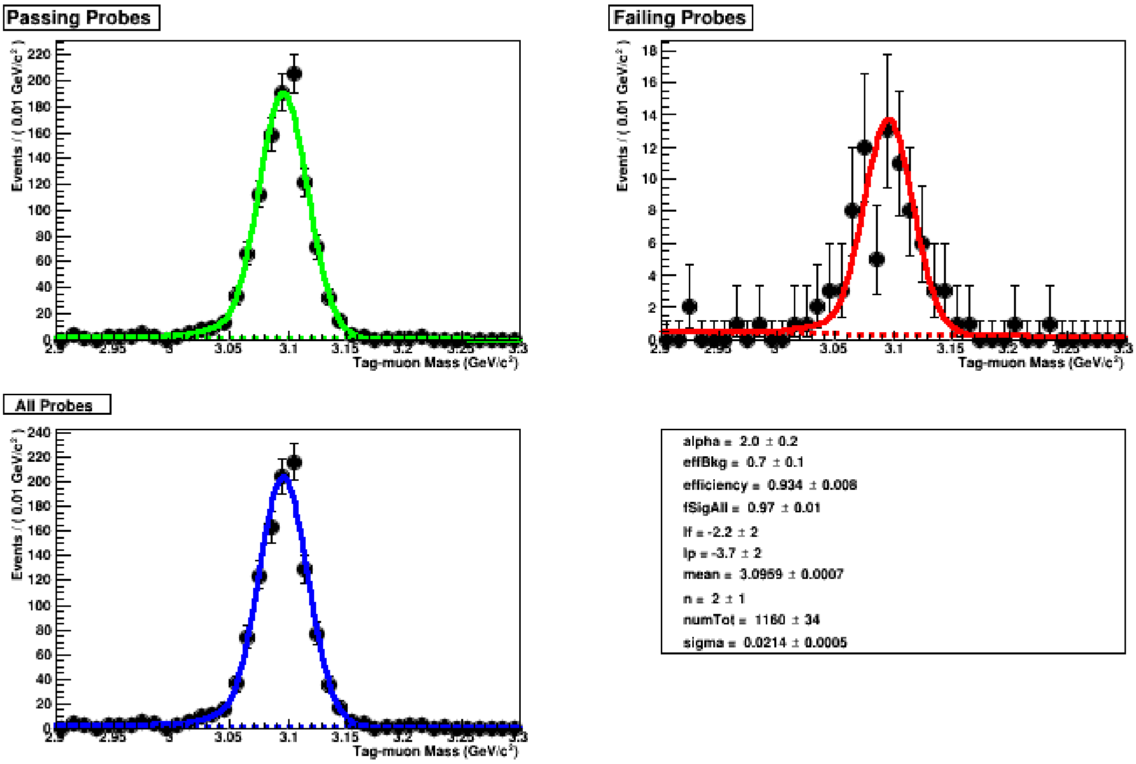

Figure 2: Example of the fitted mass distributions of "Passing", "Failing" and "All Probes" in case of the muon reconstruction and quality cuts efficiency for one particular bin ($0 < |\eta| < 0.9$ and $3.5 < p_{\mathrm{T}} < 4\,\mathrm{GeV}/c$).

Given that the probes are all tracks, with no quality requirements applied, the background in the "All Probe" and "Failing Probe" samples is not negligible, as can be seen in Fig. 2. The muon reconstruction efficiencies are close to 100 %.

Given the difficulties during the fit process, it is understandable that the trends of the p_{T} differential efficiency curves are not well established from the T&P studies on real data. The MC consists of the signal only, and is not affected by this limitation and shows a rather clear trend, indicating efficiencies larger than 95 %, flattening out at around 6 GeV$/c$. It should be noted that the MC can describe the data rather accurately, given the large uncertainties. It could, hence, be favourable in the data analyses to use the MC based T&P efficiencies instead of the data driven ones.

We want to underline that we studied the muon reconstruction efficiency separately for "cowboy" and "seagull" dimuons, boh in data as well as MC, and do not find any differences. For this reason, the muon reconstruction efficiency, as well as the efficiency of the muon quality cuts were studied on the basis of "seagull" dimuons only.

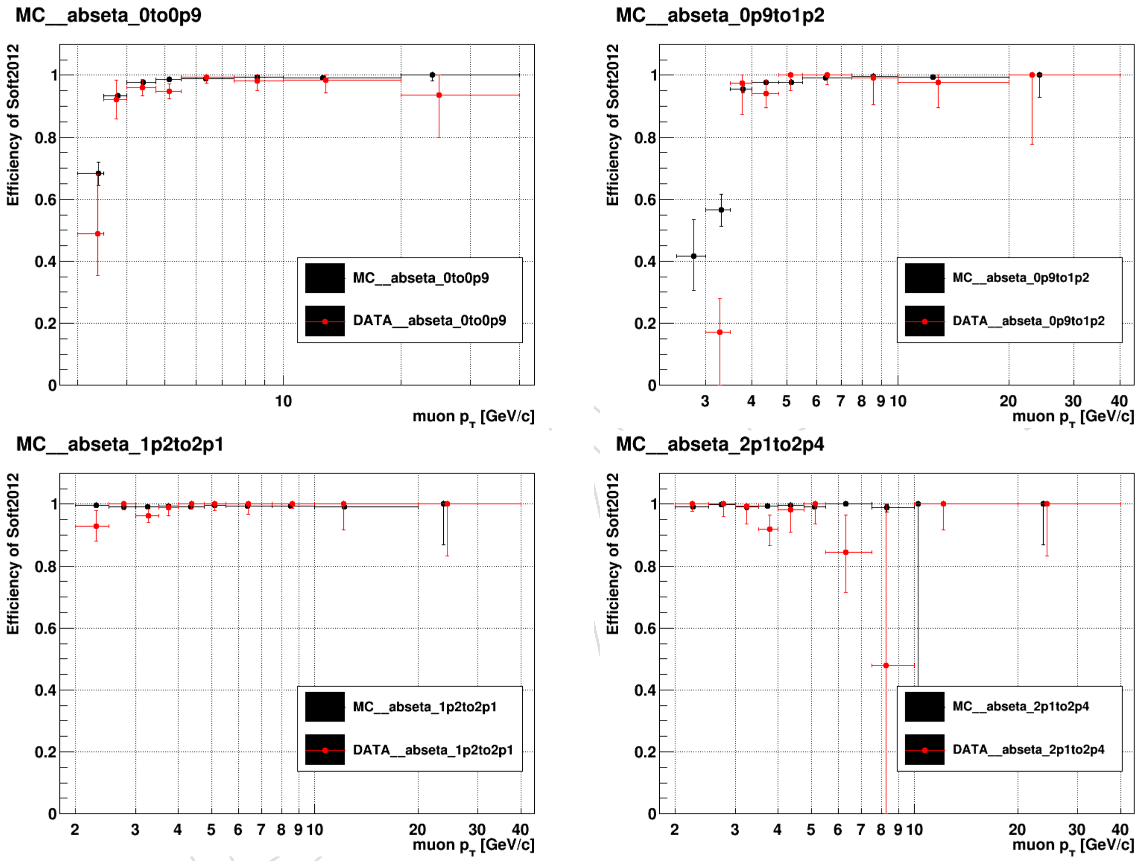

Figure 3: Muon reconstruction and quality cuts efficiency versus p_{T} for small slices in $|\eta|$.

6 L1·L2 trigger efficiency

We investigate the L1·L2 trigger efficiencies with respect to reconstructed muons, satisfying the quality criteria (“BMuQual”) outlined in Section 5. Besides, we match the probe to the `TrackY` part of efficiency trigger object. Passing probes are those matched to the L2 filter ”hltL2fL1sL1DoubleMu10MuOpenL1f0L2PreFiltered0 (full-coverage triggers filter) or hltL2fL1sL1DoubleMu0er16NoOSL1f0L2PreFiltered0” (barrel triggers filter). Given that all the dimuon triggers in the Charmonium PD use one of these L2 filters and most of them are unprescaled, no prescale factors need to be taken into account. It should be noted that, even though the MuX_TrackY trigger is a “single” muon trigger and has different L1 requirements (different L1 quality bit), with respect to the physics trigger under study there is no bias in the extraction of the corresponding L1 (and L2) trigger efficiencies: the quality criteria imposed on single muon triggers are, in general, *stricter* than for double muon triggers. If the pair is inefficient in a given event, it is not because of the tag possibly being inefficient, given that a matching is requested to a dimuon trigger filter.

The resulting efficiencies, for the L1_DoubleMu10 and L1_DoubleMu0er16 seed can be seen in p_{T} differential form in Fig. 4 and Fig. 5 respectively. .

Also here, the data have sufficient statistical accuracy, such that a clear trend is visible, showing the expected p_{T} turn-on behaviour in each of the $|\eta|$ slices. The rise of the turn-on curve is sufficiently steep such that the plateau value is reached below 10 GeV/c.

The MC based T&P efficiencies reproduce well the overall trend, in practically all $|\eta|$ slices. The values are not identical, partially because the centre of gravity of a given bin is slightly different in data and MC, given that the generation was performed flat in p_{T}.

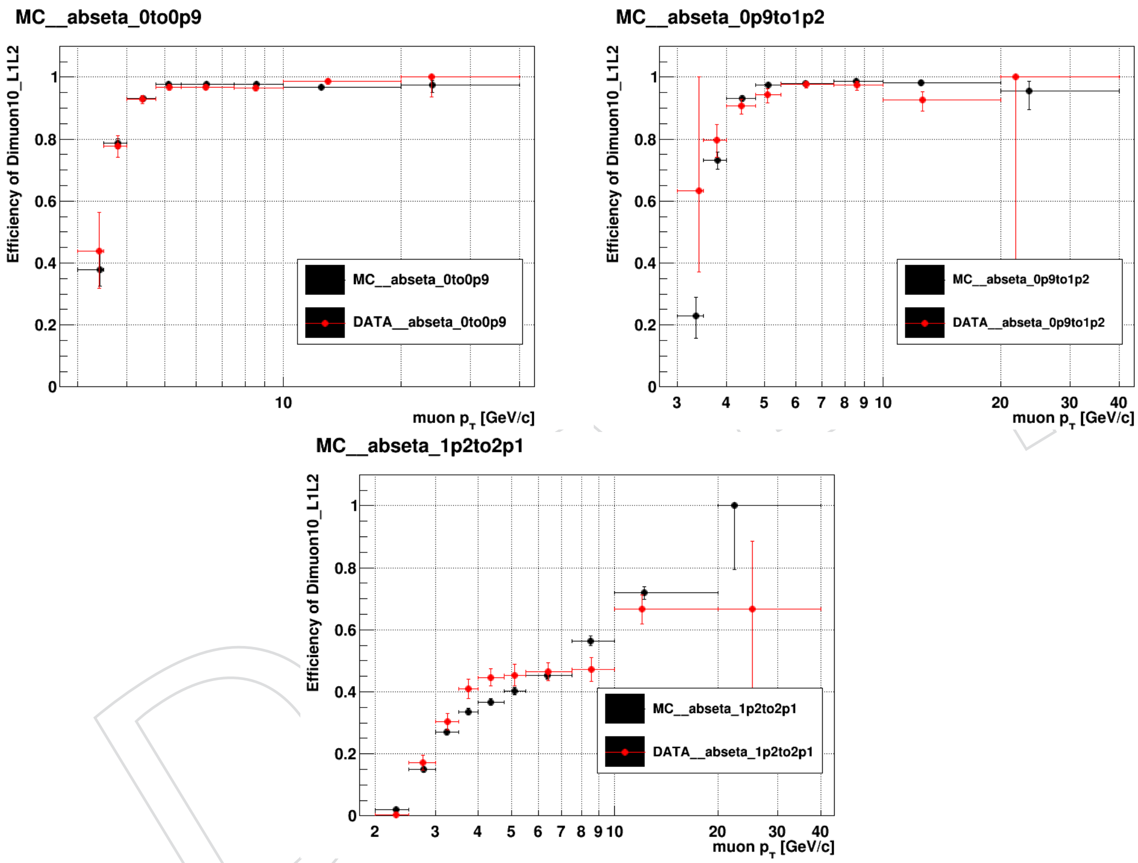

Figure 4: L1·L2 trigger efficiency, using the L1_DoubleMu10 seed, versus p_T in various slices in $|\eta|$.

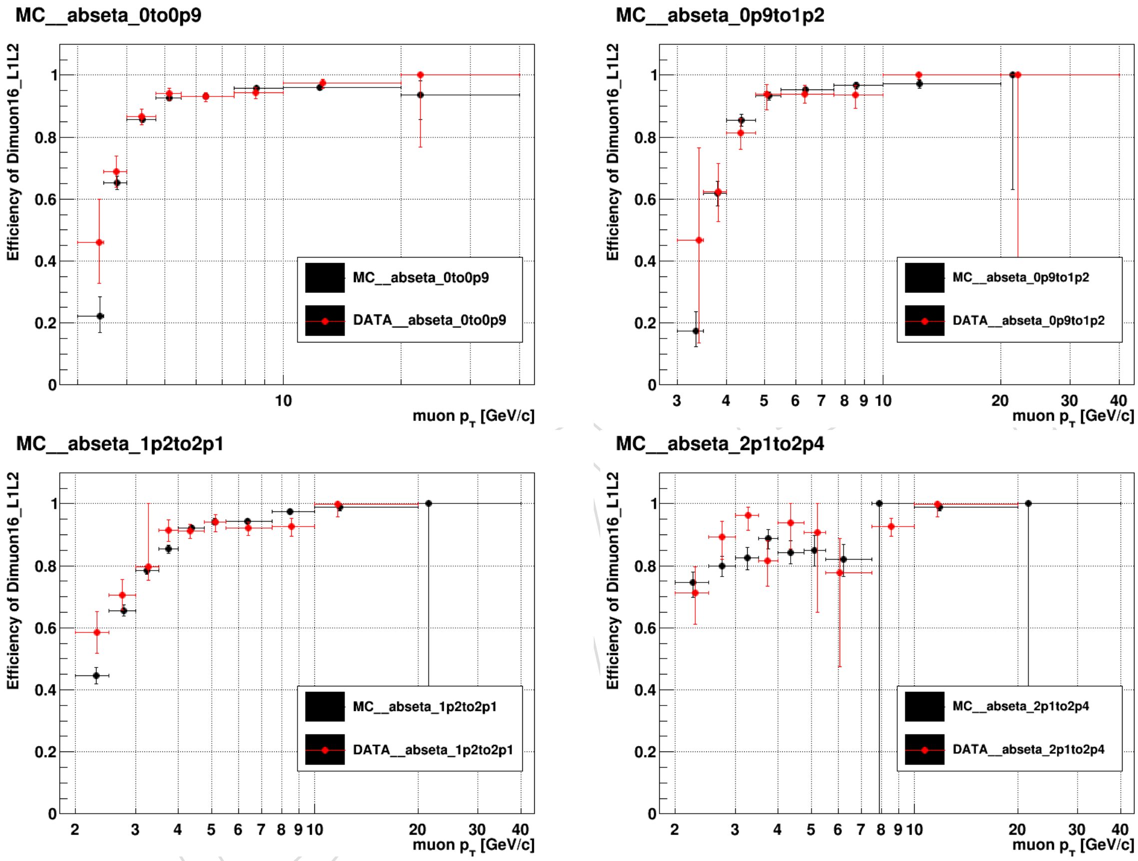

Figure 5: L1·L2 trigger efficiency, using the L1_DoubleMu0er16 seed, versus p_T in various slices in $|\eta|$.

7 L3 trigger efficiency

The L3 trigger efficiencies presented here are not those specific to a certain L3 trigger filter, but correspond to the intrinsic trigger efficiencies of L3 muons. In other words, the efficiencies shown here do not account for cuts used in specific L3 filters. This is motivated by the fact that, in this way, the full p_T and η ranges of L3 muons can be measured; the effects of other cuts, like the DCA cut (distance of closest approach between the two muons), which is part of practically all L3 muon filters in the Charmonium PD, need to be evaluated in an independent way. Moreover, with the standard T&P skim for efficiency studies of a given probe, as opposed to studies of the *pair*, the effect of this specific cut cannot be evaluated.

In concrete terms, the tag muon is matched (as usual) to the HLT muon in the trigger path HLT_Mu7p5_L2Mu2_Jpsi and the probe muon must pass the corresponding L2 filter ("hltL2fL1sL1DoubleMu10MuOpenL1f0L2PreFiltered0" for full-coverage triggers or "hltL2fL1sL1DoubleMu0er16NoOSL1f0L2PreFiltered0" for barrel triggers) and the "BMuQual" quality criteria. Passing probes are then identified as those that are contained in the collection `hltL3MuonCandidates`. The p_T differential efficiencies, studied for seagull dimuons onlycan be found in Fig. 6 and in Fig. 7.

In practically all $|\eta|$ slices, 100 % efficiency is seen in the bin $4.75 < p_T < 5.5$ GeV/c, i.e. the plateau value is reached for $p_T \gtrsim 5$ GeV/c; the turn-on curve is sharper than for the combined L1·L2 trigger efficiency. Also here, the data driven efficienciescan be accurately described by the corresponding MC T&P efficiencies.

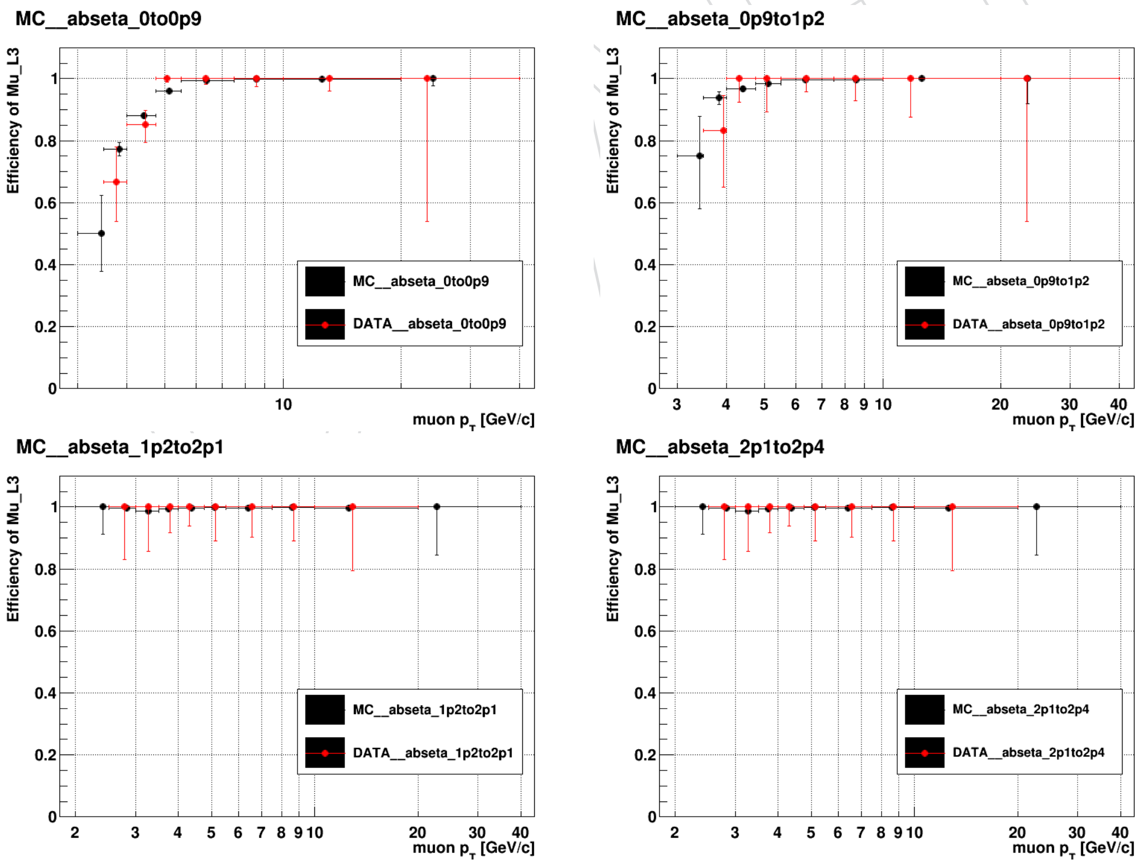

Figure 6: L3 trigger efficiency versus p_T in various slices in $|\eta|$ for full-coverage triggers.

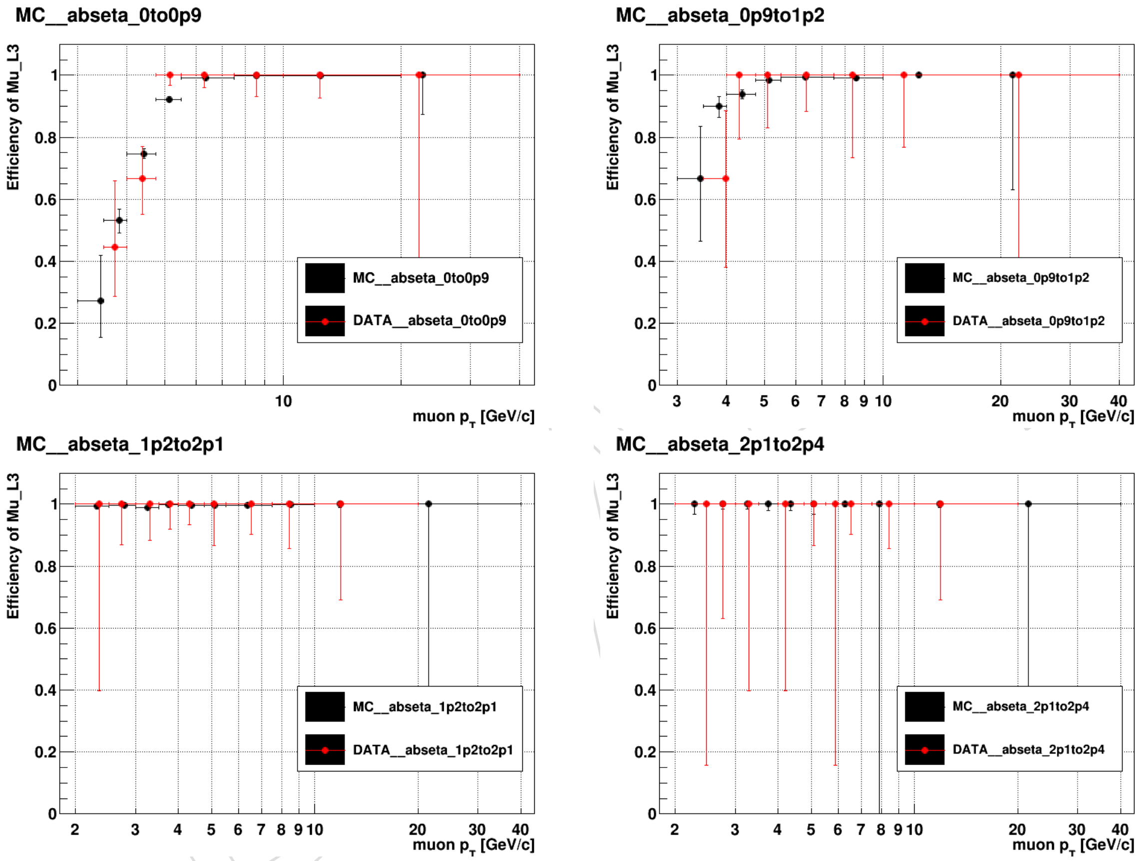

Figure 7: L3 trigger efficiency versus p_T in various slices in $|\eta|$ for barrel triggers.

8 Efficiencies of the dimuon vertexing module

As outlined in Section 3 the T&P framework can also be setup to study the efficiencies of a pair. This is the case of the last L3 filter running in all quarkonium triggers, which performs vertexing between the two muons and then applies selection cuts on the pair, such as a lifetime significance cut, a cut on the vertexing χ^2 probability, etc. In the case of the quarkonium triggers, only a cut on the vertexing probability χ^2, of 0.5 %, is applied. Therefore, the dimuon vertexing efficiency reflects the intrinsic efficiency of the dimuon vertexing algorithm plus the effect of the cut on the vertexing probability χ^2. The corresponding efficiencies, differentially in dimuon p_{T} are depicted in Figs. 8. The bins used in the calculations are:

- $p_{\mathrm{T}} = 10, 16, 20, 40$ GeV/c
- $|y| = 0, 0.9, 1.2, 2.1, 2.4$

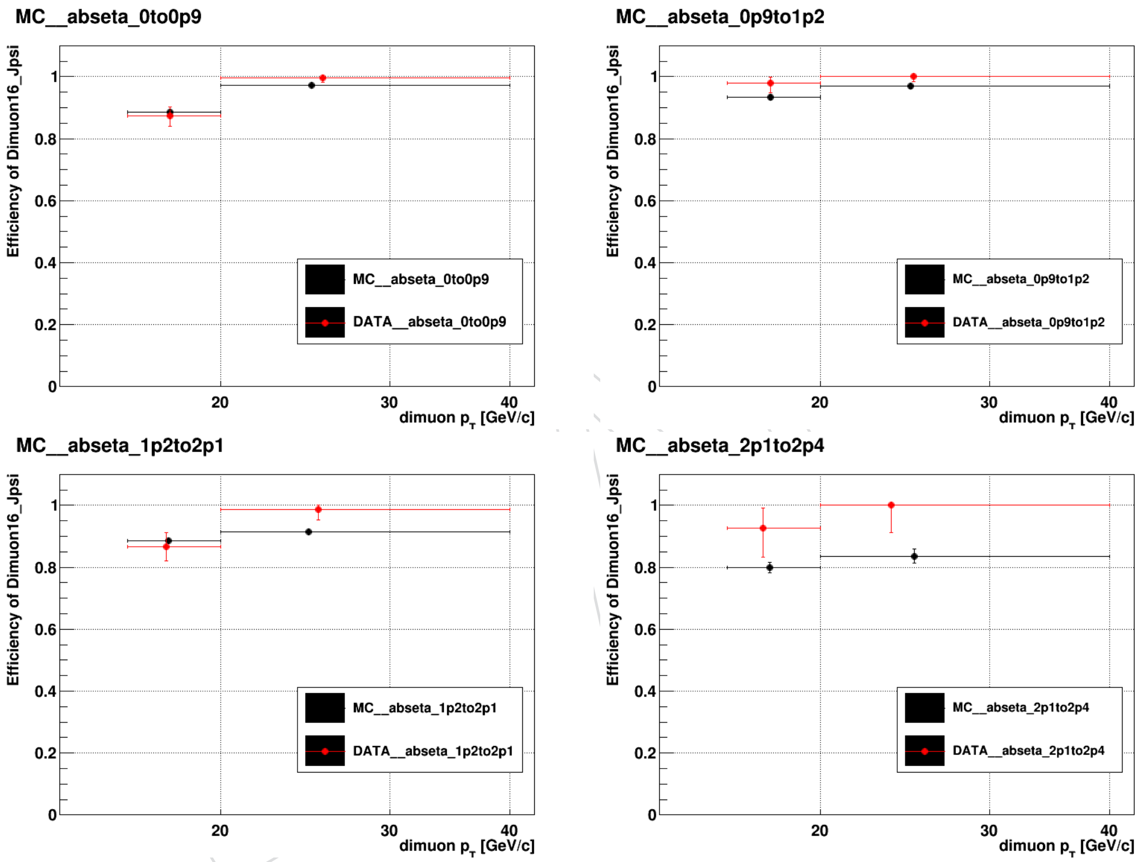

Figure 8: Efficiency of the *online* dimuon vertexing module with a cut on the dimuon vertexing χ^2 probability of 0.5 %, differentially in dimuon p_{T}.

The efficiencies are around 97 %, being relatively flat as a function of p_{T}, with no strong $|y|$ dependence.

Summary

This note presents a coherent study of the single muon efficiencies extracted with the T&P framework, performed on the basis of specially designed efficiency triggers in the J/ψ mass window: the path HLT_MuX_TrackY_Jpsi allows to study in an unbiased way the muon related efficiencies, while HLT_MuX_L2MuY_Jpsi accesses the tracking related efficiencies.

The single muon efficiency was broken into 4 individual parts, "tracking", "MuonID", "L1·L2" and "L3", and studied such that the corresponding efficiencies fully factorize. For completeness, the overall efficiency resulting from the product of the individal efficiencies is also given,

$$\epsilon_{\mu} = \epsilon_{\mathrm{tracking}} \cdot \epsilon_{\mathrm{ID}} \cdot \cdot \epsilon_{\mathrm{L1\cdot L2}} \cdot \epsilon_{\mathrm{L3}} \quad , \tag{1}$$

where each term stands short for the conditional efficiency outlined in Section 1.

Additionally, the T&P framework was used in the special "OnePair" mode, which allows us to study the efficiency of the online dimuon vertexing module (and corresponding filter) which ran after the standard L3 dimuon filter in all 2011 quarkonium triggers, applying cuts on the muon *pair*.

The trigger efficiencies presented here are for "seagull" dimuons only.

Given that the efficiency triggers were operated throughout the full data taking period, sufficient statistics could be collected for a full 2D efficiency study, versus the single muon's p_{T} and $|\eta|$.

All efficiencies are compared to MC based T&P studies, conducted in an analogous way as for the real data. The overall comparison to the MC based efficiencies is rather good.

Acknowledgements

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References

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[3] CMS. https://cmsweb.cern.ch/das/request?input=dataset%3D%2FJpsiToMuMu$_{O}niaMuonFilter$ _TuneCUEP8M1$_{1}3TeV - pythia8\%2FRunIISpring15DR74 - Asympt50ns_{M}CRUN2_{7}4_{V}9A - v2\%2FAODSIMinstance = prod\%2Fglobal$.