

Automatic measurement of track reconstruction efficiency for data quality monitoring in the CMS experiment

Chin Zhe Tee

Supervised by: Jeremy Andrea, Marco Musich, Tatjana Susa

Project Summary

This project took place within the Tracker Detector Performance Group of the CMS collaboration for 8 weeks, from 1st July 2019 to 23rd August 2019. I was using the first four weeks to familiarize myself with ROOT and C++ as the primary programming language to make simple analysis. Then, the subsequent weeks were utilised to understand the concept of Tag and Probe and applied the Tag-and-Probe method to study both simulated and measured track reconstruction efficiency of Tracker Detector.

Motivation

CMS has a comprehensive Data Quality Monitoring (DQM) system. When a subdetector behaves abnormally, it is reflected in measured or reconstructed properties. However, if a small parts of a particular subdetector went defective, a quick and simple estimate of how the faulty parts may affect the quality of data taking. Hence, this is how the aim of this project, “automatic measurements” arise.

The overall muon efficiency is dependent on several factors, as shown in Equation 1 (Collaboration, 2012).

$$\varepsilon_{\mu} = \varepsilon_{track} \cdot \varepsilon_{rec} \cdot \varepsilon_{iso} \cdot \varepsilon_{trig} \quad (1)$$

The project studied ε_{track} , the track reconstruction efficiency alone.

This project used the “Tag-and-Probe” (T&P) method to study the track reconstruction efficiency of the Tracker Detector in the CMS detector. A T&P method is a data-driven method to measure the efficiency without relying much on simulation. For this project, the $Z \rightarrow \mu\mu$ process was selected as the mass resonance of Z boson is well known and its decay product as di-muons leaves clean signals.

Methods

Global muons and stand-alone muons are used as “tag” and “probe” respectively (Chatrchyan, et al., 2014). The definitions of global muons and stand-alone muons are depicted in Figure 1. The global muons are the muons constructed *outside-in*, by associate the hits in the Tracker to the tracks in the Muon Chamber, by comparing parameters of the two tracks. The stand-alone tracks are the muon tracks found in the Muon Chamber, and the tracker tracks are hits left on the Tracker Detector by muons. Hence a well-combined tracker track with stand-alone track will give a global muon (CMS Collaboration, 2012).

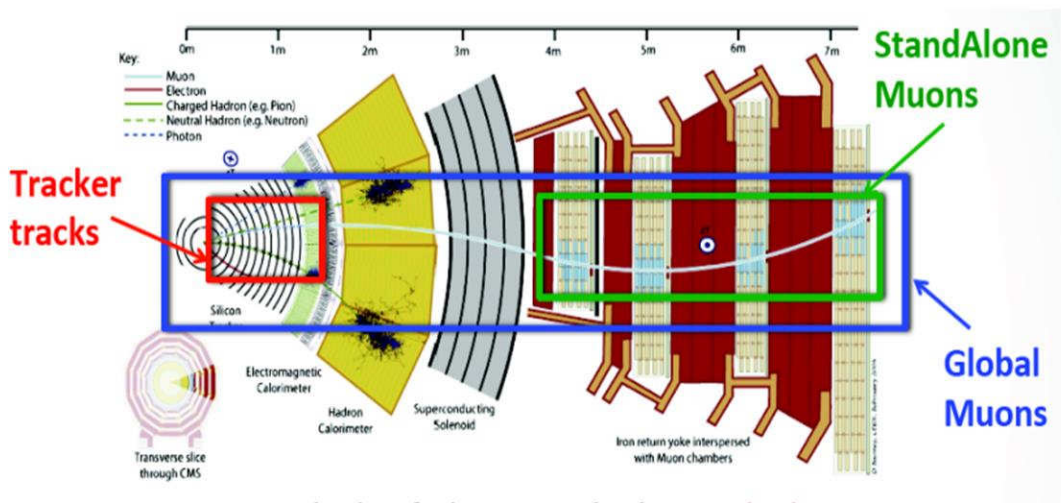


Figure 1: Pictorial definitions of global muons, stand-alone muons and tracker tracks. [citation]

A simplified version of T&P for this project is as follows:

- Select the highest p_T global muon from each event and this is the TAG.
- Select a stand-alone muon and associate with the TAG. If the reconstructed Z boson invariant mass falls within the mass windows of $86 < Z_{inv} < 101$, we called it a PROBE.
- Associate the PROBE with a tracker track, and require the $\Delta R < 0.1$, where ΔR is the angular separation between PROBE and tracker track, defined by $\Delta R = \sqrt{\eta^2 + \varphi^2}$. If satisfied, the passed PROBE is referred as PASSED PROBE.
- The track reconstruction efficiency is defined as the ratio of PASSED PROBE to PROBE.
- The procedure is repeated in bins of different kinematic/geometric variables such as p_T, η, φ .

ANALYSIS

The kinematics and geometrical variables of global muon, stand-alone muons and track hits are shown in Figure 2. From the plot of p_T , the excess hits at lower p_T bins of Tracker hits are from non-muon particle. To ensure reasonable muon sample purity, for this project the cut for p_T for analysis is at 25 GeV.

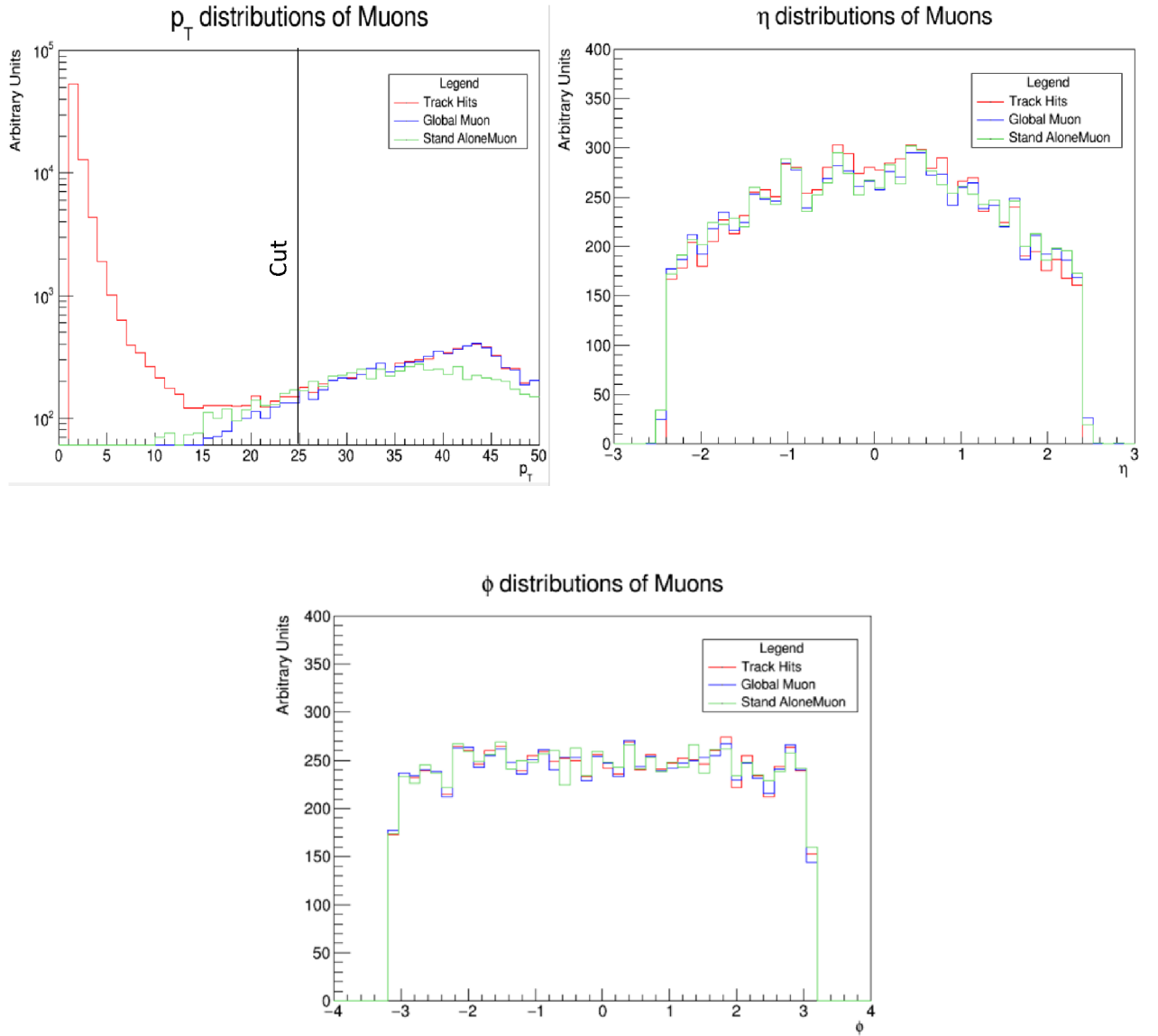


Figure 2: Plots of kinematic and geometrical variables of global muons, stand-alone muons and track hits.

The angular separation, ΔR , is used to study how well the three variables “combined”. As shown in Figure 3, most of the stand-alone muons are matched with the global muons in track reconstructions, and the small peak at $\Delta R \approx \pi$ is due to the back-to-back muon pair production. Thus, the analysis in this project selected $\Delta R < 0.1$ to ensure good matches of variables which are of interest to study.

By taking dot product of the four-momentums of di-muons process, we can identify what particle decays to the given muon pair. Figure 4 depicts the mass spectrum, where two global muons originated from the same event were combined and peaked at the mass of Z boson,

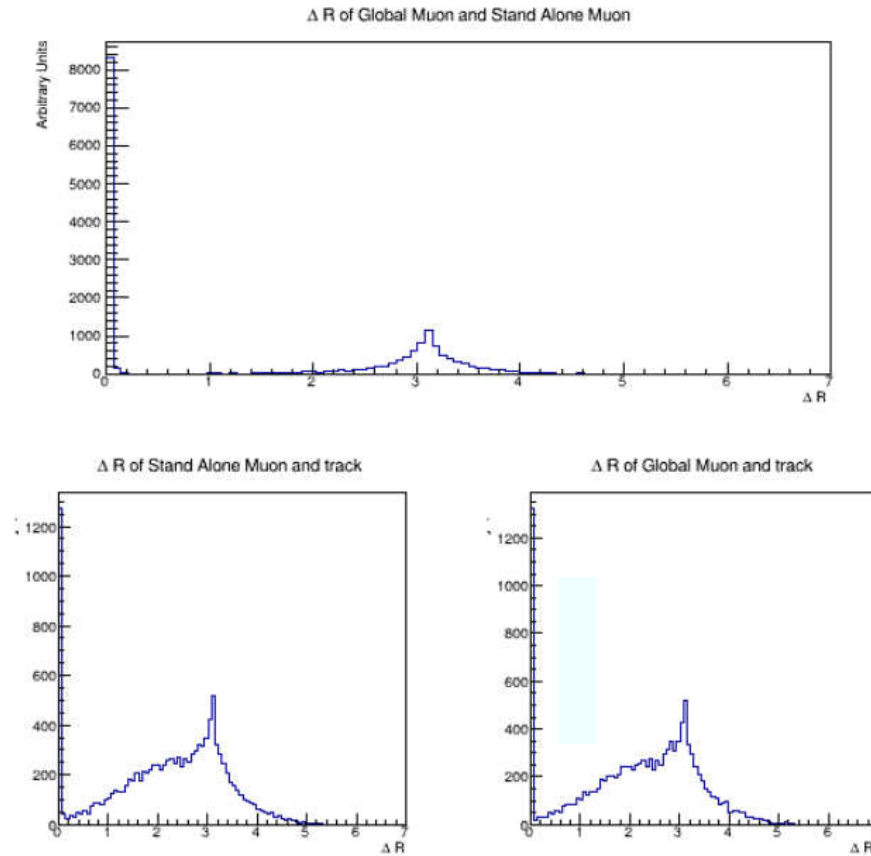


Figure 3: ΔR plots between the variables to be studied.

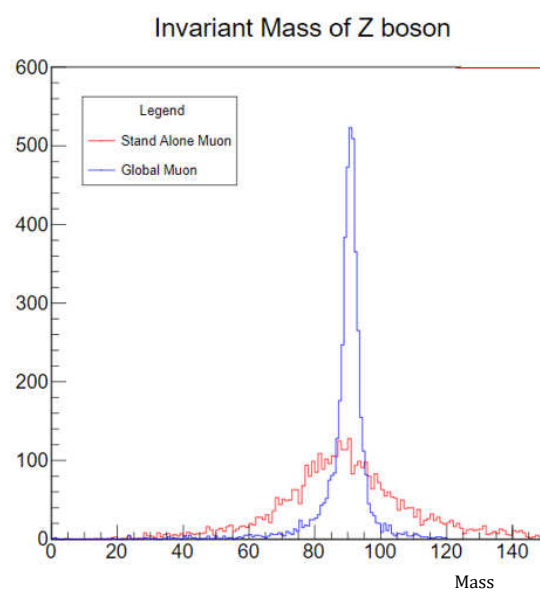


Figure 4 : Plot of invariant mass of Z boson using stand-alone muon and global muon.

which is around $91 \text{ GeV}/c^2$. This is a condition that was implemented in this analysis to ensure that the muons of interest originated from the decay of Z boson. Note that the spectrum generated from stand-alone muon has a wider width due to the fact that Muon Chamber has relatively lower resolution than the Tracker Detector, making the determination of transverse momentum of muons relatively inferior to

The analysis began with selecting the proper “TAG” as described in the section above, and identifying the corresponding “PROBE” around the mass windows of $86 < Z_{inv} < 101$, as shown in Figure 5.

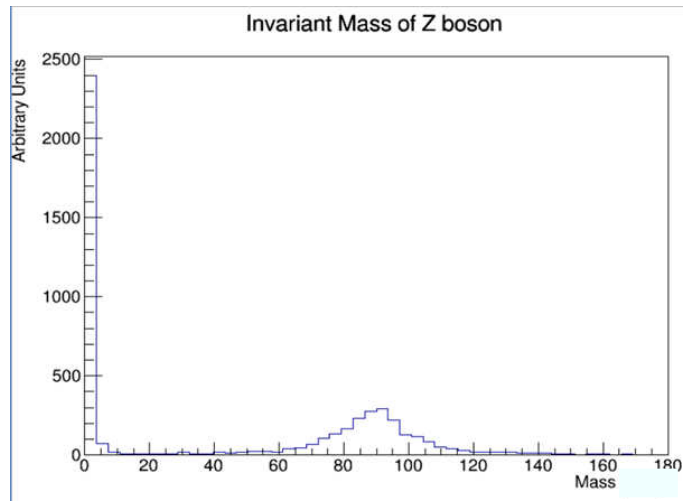


Figure 5: Selection of “PROBE” from the mass spectrum after combining all stand-alone muons with “TAGS”.

The peak about 0 GeV is due to process such as the Drell-Yan process, in which muons are the possible scattering products. Finding the number of stand-alone muons fell under the Z mass windows, we obtained the number of PROBES. The PROBES were then associate to all the tracks by requiring the ΔR between stand-alone muon tracks and tracker tracks to be lesser than 0.1. Figure 6 shows the result obtained.

The peak around 0 are the PASSED PROBES which were used to calculate the efficiency. The efficiency calculation can be modelled as a binomial process, with the efficiency, ε , as the probability of “success”. Its uncertainty can be estimate by the following formula (Paterno, 2004):

$$\delta\varepsilon = \frac{1}{N} \sqrt{k(1 - \frac{k}{N})} \quad (2)$$

where $\delta\varepsilon$ is the uncertainty of efficiency, N is the total number of events and k is the number of events that passes a certain cuts.

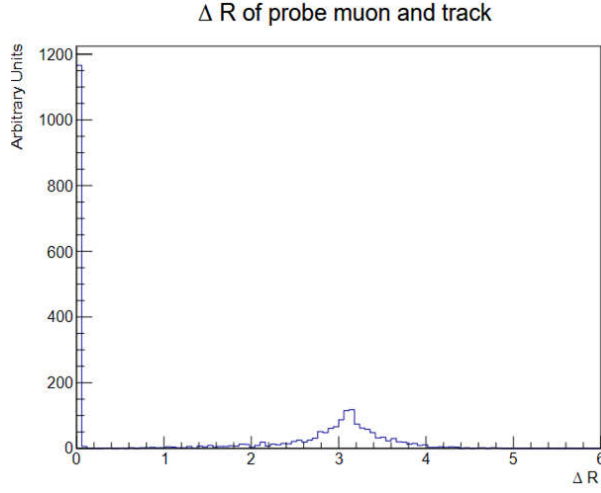


Figure 6: The stand-alone muon tracks were associated with the tracker tracks.

From Figure 7, the efficiency is obtained by calculating the ratio of area of the histograms. The overall track reconstruction efficiency from the data is $\varepsilon_{data} = 0.991563 \pm 0.002038$ and $\varepsilon_{simulation} = 0.99575 \pm 0.00079$.

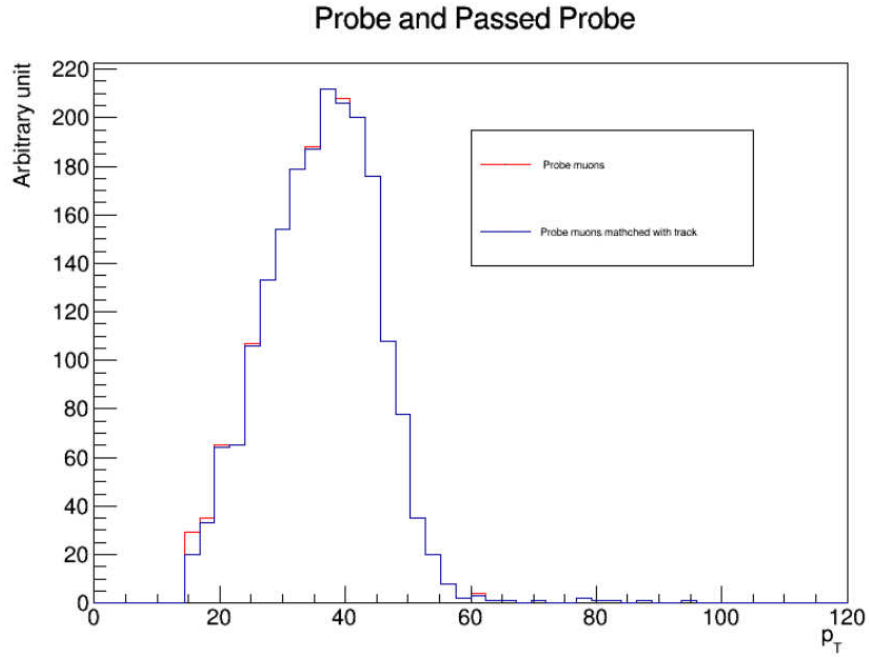


Figure 7: Histograms of Probe muons and Probe muons that matched with tracks.

The track reconstruction efficiency for both simulation and data, computed bin-by-bin as variables of p_T and η are shown in Figure 8 and Figure 9. The efficiencies were high because the nTuples generated for this project have the background eliminated, thus having high purity of Z-events, which simplifies the analysis. This result is consistent with the results

published in 2010 (Collaborations, 2010), where the pile up for each run is lower before compare to more recent data. In reality, we should expect the efficiency to be lower.

A rough estimate of expected number of Z boson for each run is calculated to be 2.55×10^5 per run, by taking the cross section, σ of 1928 pb and the luminosity, $\mathcal{L}$ to be 400 pb^{-1} .

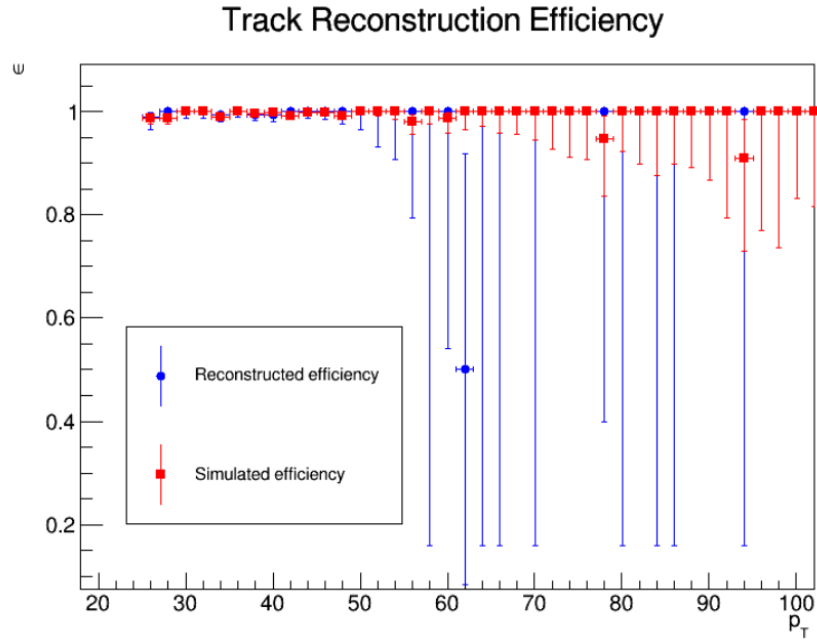


Figure 8: Track Reconstruction Efficiency with p_T bins.

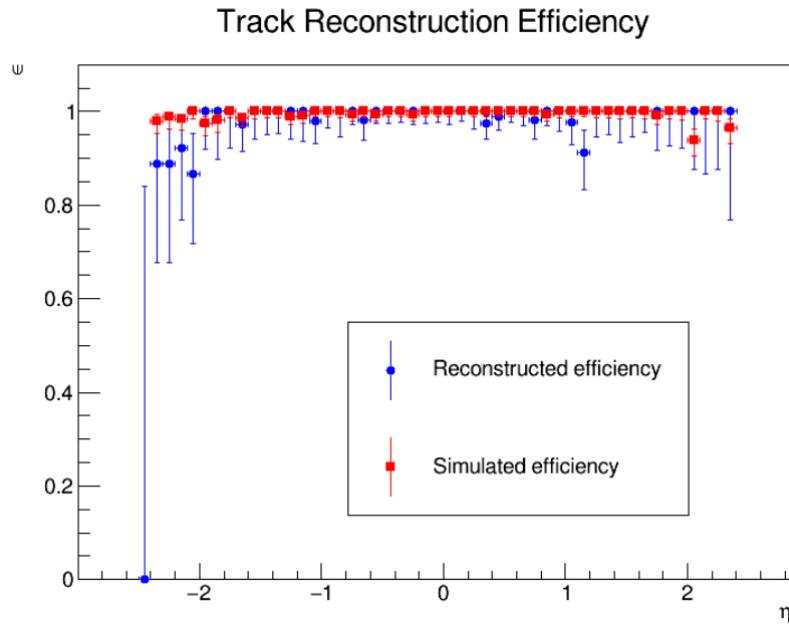


Figure 9 : Track Reconstruction Efficiency with η bins.

Conclusion

From this project, I learnt about the concept of Tag-and-Probe and how it was implemented to study the track reconstruction efficiency in both data and simulation. The computed overall efficiencies for data and simulation are $\varepsilon_{data} = 0.991563 \pm 0.002038$ and $\varepsilon_{simulation} = 0.99575 \pm 0.00079$ respectively. The efficiencies with respect to p_T and η are high due to the removal of background signals.

References

- [1] CMS Collaboration, T. C. (2012). Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7\text{TeV}$. Journal of Instrumentation, 7(10). doi:10.1088/1748-0221/7/10/p10002
- [2] Paterno, M. (2004). Calculating efficiencies and their uncertainties. doi:10.2172/15017262
- [3] CMS Collaboration (2010). Measurement of Tracking Efficiency (Rep. No. CMS-PAS-TRK-10-002). Retrieved <http://cds.cern.ch/record/1279139>
- [4] Held, A. (2017, February 15). Tagging and probing. Retrieved from <https://amva4newphysics.wordpress.com/2017/02/15/tagging-and-probing/>
- [5] Tag and Probe. (2014). Retrieved from <https://twiki.cern.ch/twiki/bin/view/CMSPublic/TagAndProbe>
- [6] Chatrchyan, S., Khachatryan, V., Sirunyan, A. M., Tumasyan, et.al., (2014). Description and performance of track and primary-vertex reconstruction with the CMS tracker. Journal of Instrumentation, 9(10), 34. doi: 10.1088/1748-0221/9/10/p10009