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SEARCH FOR HBSM DOUBLE CHARGED SCALAR BOSONS IN MULTI-LEPTONS FINAL STATES USING PROTON-PROTON COLLISIONS AT $\sqrt{s}$ = 13 TEV WITH THE ATLAS DETECTOR

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Résumé

The details about the kinetics of the subatomic particles and amalgamation of three fundamentals forces of nature except gravity is precisely furnished by the Standard Model of Particle Physics (SM). The validity of the SM is being estimated through the present experiments specifically through Large Hadron Collider (LHC) experiments which have been providing enough quantification in this regard. The recent uncovering of the Higgs boson by the ATLAS [39] and CMS [40] collaborations at the LHC in the year 2012 accomplished the most recent landmark in the way of triumph of this model.

The SM is more of an estimation of the fundamental hypothesis of nature as being advocated by theoretical and experimental deliberations. The one of the aims of the high energy physics is to discover this theory. Being still deficient in the terms of providing direct discoveries of new matter particles or new force carriers, this model is consistent with the predictions in the field of experimental particle physics.

The Higgs boson is a paramount to evaluate the predictions of the SM and it settles at the core of the model by coupling to various independent parameters. At the same instant, the Higgs boson is intensely connected with the intrinsic theoretical problems of the SM and quite a few trails were executed to extend the SM to furnish the explanation about dark matter that turns into a subsequent transformation of the Higgs boson's properties as compared to the SM speculations [1]. In the wake of that, an accurate ascertainment of all the Higgs boson's properties is crucial that could probe new physics evidently.

The ATLAS and CMS experiments have observed the coupling strengths of the Higgs boson to the other elementary particles as being speculated by the SM. However the coupling of the Higgs boson to fermions of first and second generation is obscure for now. The coupling of the Higgs boson with the third generation fermions have manifested the consistency with the hypotheses of the SM that falls within relative uncertainties of about 20% [2]. Likewise the couplings of the Higgs boson to vector bosons are estimated to be consistent with the SM within relative uncertainties of ∼10% [2].

Besides the computations of the extensive coupling strengths, the evaluation of differential entities for instance the transverse momentum distribution of the Higgs boson i.e. $d\sigma / dp_T^H$ is pertinent. In spite of the fact that collision energy of the LHC is not that sufficient to investigate new physics at the moment but the SM can distinctively be adapted in accordance with required changes at high p_T^H. These substantial fluctuations would not affect the already measured couplings, even though the cross-sections are relatively low in this regime.

The collider with the adequate luminosity and the rather high centre-of-mass energy $\sqrt{s}$ is requisite to yield a sufficient amount of Higgs bosons for such kind of assessments at the LHC, colliding hadrons i.e. protons at $\sqrt{s}$ = 13 TeV. The huge collision data collected by the ATLAS experiment at 139 fb^{-1} during the second operational run of the LHC, is pioneering to great opportunities to execute the measurements in such low cross-sections areas.

This thesis entails the latest measurements on the Higgs boson production in association with heavy vector bosons i.e. W and Z. The experimental signatures with the two leptons together with the

same electric charge or mutli-lepton final states have been employed in the searches for physics beyond the Standard Model (BSM) at LHC. The various models detect heavy BSM particles yielded during proton-proton collisions and then get decayed into multiple massive SM electroweak gauge bosons or top quarks. The signatures with the two leptons of same charge or three or four leptons with various charge combinations have been exploited by the ATLAS and CMS experiments in order to investigate possible SM extensions and phenomenology.

The riveting expansion among the preferred SM extensions is instigating SM sector of the weak gauge triplet of scalar fields along with non-zero vacuum expectation value of the neutral component that leads to the neutrino masses through the type-II seesaw meachanism [138]. The phenomenology of the doubly charged scalar bosons ($H^{\pm\pm}$) that can be produced in pairs and then decay into W bosons with the same charge and singly charged scalar bosons ($H^{\pm}$) decay into W along with Z bosons are taken in consideration.

The structure of thesis is as follows:

Chapter. **2** covers the theoretical background of the Standard Model and its limits are briefly identified. In addition, extensions of the SM that includes Higgs sector beyond SM, SUSY and it extensions are concisely described.

Chapter. **3** presents an introduction to the CERN's experiments in general and ATLAS experiment in particular.

Chapter. **4** describes details about object reconstruction at ATLAS experiment. The various objects i.e. electron, photons, muons and jets reconstruction is entailed.

Chapter. **5** concludes my contribution towards efficiency and its uncertainties measurements. The first part entails the measurement methodology used by the ATLAS inner detector to perform the efficiency measurement for the reconstruction algorithm [122]. The brief description of the tag-and-probe method that permits to select an unbiased sample of electrons in data, and estimation of the residual background contributions for the efficiency measurement is provided. Then the results about statistical uncertainties measurements through pseudo-experiments are dispensed. The scale factors measurement for AF2 samples in release 21 with release 21 framework's setup are given. The re-implementation of methodology for electron reconstruction efficiency in release 22 framework and the proof of correctness of that work and comparison of scale factors in either versions of frameworks i.e. Rel21 & Rel22 is also provided.

Chapter. **6** aims at signal searches to extend the scalar sector of the Standard Model with a scalar triplet, directing to a phenomenology which comprehends singly and doubly charged Higgs bosons. This chapter presents the topologies used for the analysis and gives us the details of theoretical framework. The Monte Carlo simulations used for various selection variables are documented and the signal regions used for the different mass hypotheses of $H^{\pm\pm}$ & $H^{\pm}$ are described in order to distinguish signatures of BSM processes from SM backgrounds. The preliminary results obtained for each pre-selection channel i.e. 2L, 3L and 4L are concluded as well.

Chapter. **7** summarizes all the work carried through out for this dissertation.

Chapter 2
Theoretical foundations

The summary of the Standard Model of Particle Physics (SM) is given in the Section. 2.1. The achievements and limitations of the SM are extended in the Section. 2.6. The brief description on Physics Beyond Standard Model stressing Higgs sector, Supersymmetry and encouragement to the extension of the Higgs sector and SUSY is encapsulated in the Section. 2.7. The drawbacks of the BSM Higgs bosons at LHC are furnished in the Section. 2.8.

The information presented in this chapter is based on the following references:

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• Gordon Kane, "Modern Elementary Particle Physics", Second Edition Cited. [4]
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• "Laboratoire National Henri Becquerel" Cited. [31]
• G. Raven, Nikhef and Vrije Universiteit Amsterdam, "CP Violation - The asymmetry between Matter and AntiMatter" Cited. [32]
• G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, "Global Conservation Laws and Massless Particles" Cited. [33]
• T. W. B. Kibble, "Symmetry Breaking in Non-Abelian Gauge Theories" Cited. [34]
• UA1 Collaboration, "Experimental observation of events with large missing transverse energy accompanied by a jet or a photon(s) in pp collisions at $\sqrt{s}$ = 540 GeV, Cited. [35]
• UA2 Collaboration, "Evidence for Z0 $\rightarrow$ e+e− at the CERN pp collider" Cited. [36]
• CDF Collaboration, "Observation of top quark production in pp′ collisions" Cited. [37]
• D0 Collaboration, "Observation of the top quark" Cited. [38]
• CMS Collaboration, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC" Cited. [40]

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• NNPDF Collaboration, "Parton distributions from high-precision collider data" Cited. [42]
• L. Lee, C. Ohm, A. Soffer, and T.T. Yu, "Collider Searches for Long-Lived Particles Beyond the Standard Model" Cited. [44]
• S. Höche, "Introduction to parton-shower event generators" Cited. [45]
• R. Placakyte, "Parton Distribution Functions" Cited. [46]
• R. D. Ball et al., "Parton distributions with LHC data" Cited. [47]
• G. Altarelli and G. Parisi, Asymptotic Freedom in Parton Language" Cited. [48]
• ATLAS Collaboration, "Summary plots from the ATLAS Standard Model physics group" Cited. [49]
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• Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters" Cited. [51]
• Super-Kamiokande Collaboration, "Evidence for an oscillatory signature in atmospheric neutrino oscillation" Cited. [52]
• A. D. Sakharov, "Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe" Cited. [53]
• L. Girardello and M. Grisaru, "Soft breaking of supersymmetry" Cited. [54]

In this chapter, the presented Feynman diagrams are sketched by using TikZ-Feynman LaTeX package [27].

Chapter 3
The ATLAS Experiment at LHC

The information presented in this chapter is based on the given citations:

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- CERN Accelerating Science, "Large Electron-Positron" Cited. [59]
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- The LHCB Collaboration et.al, "The LHCb Detector at the LHC" Cited. [67]
- The LHCf Collaboration et.al, "The LHCf detector at the CERN Large Hadron Collider" Cited. [68]
- The TOTEM Collaboration et.al, "The TOTEM Experiment at the CERN Large Hadron Collider" Cited. [69]
- V. A Mitsou and on behalf of the MoEDAL Collaboration, "The MoEDAL experiment at the LHC: status and results" Cited. [70]
- The ATLAS Collaboration, G. Aad, T. Abajyan, et. al, "Improved luminosity determination in pp collisions at $\sqrt{(s)} = 7$ TeV using the ATLAS detector at the LHC" Cited. [71]
- M. Aaboud, G. Aad et al., "Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC" Cited. [72]
- M. Aaboud, G. Aad et al., "Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC" Cited. [73]
- CERN Accelerating Science, "CERN’s Accelerator Complex" Cited. [74]
- R. Bailey and P. Collier, "Standard Filling Schemes for Various LHC Operation Modes" Cited. [75]
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• J.J. Goodson, "Search for Supersymmetry in States with Large Missing Transverse Momentum and Three Leptons including a Z-Boson" Cited. [84]
• ATLAS Collaboration, "ATLAS Magnet System" Cited. [85]
• G. Aad et. al, "ATLAS Pixel Detector Electronics and Sensors" Cited. [87]
• J R. Pater, "The ATLAS SemiConductor Tracker operation and performance" Cited. [88]
• A. Vogel, "ATLAS Transition Radiation Tracker (TRT): Straw Tube Gaseous Detectors at High Rates" Cited. [89]
• J. Pequenao, P. Schaffner, "How ATLAS detects particles: diagram of particle paths in the detector" Cited. [90]
• M. Capeans et. al, "ATLAS Insertable B-Layer Technical Design Report" Cited. [91]
• A. Salzburger, "The ATLAS Track Extrapolation Package" Cited. [92]
• ATLAS Collaboration, "Performance of the ATLAS Transition Radiation Tracker in Run 1 of the LHC: tracker properties" Cited. [93]

Chapter 4
Object Reconstruction in the ATLAS detector

This chapter explains the reconstruction, identification and measurement performance of the final state objects used for different physics analyses at ATLAS experiment. The objects reconstructed, identified and measured by the inner subsystem of the detector are electrons, photons, muons, jets, tau leptons and missing transverse energy.

The chapter contains information from the following citations:

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- ATLAS Collaboration, "Performance of the ATLAS Track Reconstruction Algorithms in Dense Environments in LHC Run2" Cited. [95]
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- ATLAS Collaboration, "Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton-proton collision data" Cited. [97]
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- ATLAS Collaboration, "auxiliary material attached to JINST 14 (2019) P12006" Cited. [106]
- ATLAS Collaboration, Aad, G., Abbott, B. et al., "Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s}$ = 13TeV"

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• ATLAS Collaboration., Aad, G., Abbott, B. et al. "Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data" Cited. [114]
• Oreglia, M., "A Study of the Reactions $\psi' \rightarrow \gamma\gamma\psi$" Cited. [115]
• "Electroweak Model and Constraints on New Physics" Cited. [116]
• "Status of Higgs Boson Physics" Cited. [117]
• L. Evans and P. Bryant, "LHC Machine" Cited. [118]
• ATLAS Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider" Cited. [119]
• CMS Collaboration, "The CMS experiment at the CERN LHC" Cited. [120]
• ATLAS Collaboration, "Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton-proton collision data at $\sqrt{s}=13$ TeV" Cited. [121]

Chapter 5
Electron reconstruction efficiency measurements

The information identified in this chapter is partly taken from the following citations:

• ATLAS Collaboration, "Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton-proton collision data" Cited. [122]
• CMS Collaboration, "Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC" Cited. [123]

• ATLAS Collaboration, "Electron efficiency measurements with the ATLAS detector using 2012 LHC proton–proton collision data" Cited. [124]
• ATLAS Collaboration, "auxiliary material attached to Eur. Phys. J. C 79 (2019) 639" Cited. [125]
• C. Hensel and K. Kröninger, "Data Analysis in High Energy Physics" Cited. [126]
• G. Tarna, "Studies of the Higgs boson properties and search for new physics beyond the standard model in the top sector with the ATLAS detector" Cited. [127]
• Di C. Lucia et al., "Support Note for Electron ID: efficiency measurements" Cited. [129]
• Ehrke, Lukas Fabian, "Electron Identification using Deep Neural Networks" Cited. [130]
• ATLAS, EGAM, "TagAndProbeFrame Framework" Cited. [133]
• ATLAS, EGAM, "TagAndProbe Framework" Cited. [134]
• Y. Sulman, "Reconstruction Efficiency Module" Cited. [135]
• A. Christos et al., "Support Note for Electron ID: electron reconstruction and identification" Cited. [137]

The results presented in this chapter is my own contribution towards the analysis. The results for statistical uncertainties through pseudo-experiments were already published in a journal [163] whereas the measurements for electron reconstruction efficiency, scale factors and associated uncertainties were already documented in an ATLAS internal note [128].

The analysis is based on reconstructed electrons from electromagnetic energy deposits which has to match the tracks in the inner detector. A reconstructed electron is defined as an object consisting of a cluster built from energy deposits from calorimeter (super-cluster) and a matched track (or tracks). For the electron candidates to be distinguished from other particles, identification and isolation criteria are applied with background rejection and signal efficiency. These candidates are categorized as signal electrons which are coming from Z decay while backgrounds consist of misidentified hadrons, photon conversions and heavy flavour decays. Therefore, it is crucial to measure how well those candidates are reconstructed in the detector. To see a good agreement of data and MC, efficiencies are computed based on tag-and-probe method using Z resonances.

In the first part of this chapter (Section **5.2**), the measurement methodology used by the ATLAS experiment to perform the efficiency measurement for the reconstruction algorithm [122] is reviewed. Here we describe how the tag-and-probe method allows to select an unbiased sample of electrons in data for this measurement, and how the residual background contribution is estimated.

The Section **5.4** is dedicated to the measurement of statistical uncertainties through pseudoexperiments. Since statistical uncertainties in published results are estimated using first-order approximations only, the Sections **5.4** and **5.4.2** are devoted to study the accuracy of those approximations by comparing them to the dispersion of repeated pseudo-experiments.

Results are presented in Section **5.4.2** for various representative choices of the available number of events for the measurement and the level and shape of the residual background. Concluding remarks are provided in Section **5.7**.
The scale factors measurement for AF2 samples in release 21 with old framework and the results are shown in Section **5.5**. Then, the methodology for electron reconstruction efficiency is re-implemented in new framework and the proof of correctness of that work and comparison of scale factors in either versions of frameworks i.e. Rel21 & Rel22 is provided in Section **5.6**.

The results presented in this chapter represents my own contribution towards the analysis. The methodology of the electron reconstruction efficiency measurement is briefly explained in Section **5.2**. The approximation formula being used for the statistical uncertainties in the measurements published by the ATLAS collaboration was explained explicitly in Section **5.4**. In Section **5.4.1**, the principle of the assessment of their accuracy through pseudo experiments was briefly explained. The studies were performed with different assumed target efficiencies, number of events available for the measurement, and level and shape of the background. This novel studies of uncertainties measurements through pseudo experiments was described in Section **5.4.2**.

We conclude through this studies that, the first-order approximation is very accurate for low level of background for instance 5% or large number of events e.g. $10^{4,}$ 10^{5}, 10^{6}. Even for more difficult scenarios with small available statistics or large background, the approximation remains acceptable: differences rather exceed 30%, and furthermore the approximated uncertainty is always larger than the one determined though pseudo-experiments. The usage of the approximation is therefore conservative and largely justified. The results of electron reconstruction efficiency, scale factors measured with AF2 release 21 samples and the comparison with previous recommendations were precisely explained and shown in Sections **5.5**, **5.5.1**. The methodology is re-implemented in the TagAnd-Probe framework for release 22 setup.

The comparison between measurements performed in Rel22 and Rel21 frameworks was done, by computing the efficiencies once in Rel22 setup and then comparing them with results measured in Rel21 setup. The results are shown in Section **5.6.2**. All results of efficiencies and scale factors in central values, statistical, systematic & total uncertainties are validated. They match exactly with old values measured in TagAndProbeFrame framework, and fall within the numerical precision (10^{-8}) of float data type.

Chapter 6
The searches for associated production of BSM Higgs boson in the $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ and $H^{\pm} \rightarrow W^{\pm}Z$ channels

The analysis presented here is aimed to search the signals of Type − II SeeSaw model [139] that extends the scalar sector of the Standard Model with a scalar triplet, directing to a phenomenology which comprehends singly and doubly charged Higgs bosons. The associated production of doubly charged $H^{\pm\pm}$ and singly charged $H^{\pm}$ bosons are investigated through the analysis.

Section **6.1** presents the topologies used for the analysis and Section **6.2** gives us the details of theoretical framework. The Monte Carlo simulations used for various selection variables are listed in Section **6.3.2**. In Section **6.4.4** the signal regions used for the different mass hypotheses of $H^{\pm\pm}$ & $H^{\pm}$ are described in order to distinguish signatures of BSM processes from SM backgrounds. The results for associated production of charged Higgs's signal are concluded in Section **6.7** and the validation plots are given in Section **6.6**.

The general introduction of chapter is compiled on the information available in following citations;

• A. Melfo et al., "Type II neutrino seesaw mechanism at the LHC: The roadmap" Cited. [139]
• P. Fileviez Perez, T. Han, G.- y. Huang, T. Li and K. Wang, "Neutrino masses and the CERN LHC: Testing the type II seesaw mechanism" Cited. [140]
• A. Arhrib, R. Benbrik et al., "Higgs potential in the type II seesaw model" Cited. [141]
• S. Kanemura, M. Kikuchi, K. Yagyu and H. Yokoya, "Bounds on the mass of doubly charged Higgs bosons in the same-sign diboson decay scenario" Cited. [142]
• T.P. Cheng and L.-F. Li, "Neutrino masses, mixings, and oscillations in SU (2) × U (1) models of electroweak interactions" Cited. [143]
• ATLAS Collaboration, "Monte Carlo Generators for the Production of a W or Z/γ * Boson in Association with Jets at ATLAS in Run2" Cited. [144]

• ATLAS Collaboration, "Multi-Boson Simulation for 13 TeV ATLAS Analyses" Cited. [145]
• J. Alwall et al., "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations" Cited. [146]
• The NNPDF collaboration., "Parton distributions for the LHC Run II" Cited. [147]
• T. Sjöstrand et al., "An Introduction to PYTHIA 8.2" Cited. [148]
• ATLAS Collaboration, "ATLAS Pythia 8 tunes to 7 TeV data" Cited. [149]
• ATLAS Collaboration, " Measurement of W ±Z production cross sections and gauge boson polarisation in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector" Cited. [150]
• ATLAS collaboration., Aad, G., Abbott, B. et al., "Search for doubly and singly charged Higgs bosons decaying into vector bosons in multi-lepton final states with the ATLAS detector using proton-proton collisions at $\sqrt{s}$ = 13 TeV" Cited. [152]
• ATLAS collaboration, "Search for doubly charged scalar bosons decaying into same-sign W boson pairs with the ATLAS detector" Cited. [162]

The results presented in this chapter are my own finding.

The results for the validation of background are concluded in Section. **6.6** on the basis of the selections given in Table.6.5 and the specified regions for the WZ production mentioned in the Section. **6.4.5**.

The distributions for the variables describing signal features for each pre-selection channel i.e. 2L, 3L & 4L were delineated in Figs. 6.5, 6.7, 6.8, 6.9 & 6.10. A good agreement is seen between data and MC background extrapolations from SM processes which favours to precised estimates for background contributions in the shapes. The variables were obtained for 2L, 3L & 4L channels after applying pre-selection criteria given in Table. 6.5.

The results for the signal production of charged Higgs (associated production mode) for the various object collection are delineated in the Figs. 6.11, 6.12, 6.14 & 6.15. The variables were obtained after applying the object selection on them as given in Table. 6.4. In each variable case, five different curves representing signal mass point for singly ($H^{\pm}$) and doubly charged ($H^{\pm\pm}$) Higgs boson. The corresponding signal mass points 200, 300, 400, 500 & 600 GeV for associated production of charged higgs in all three channels are shown inclusively.

The results indicates masses of singly ($H^{\pm}$) and doubly charged ($H^{\pm\pm}$) Higgs bosons and the measurements were done correctly as depicted in the Fig. 6.16. The mass of all the W bosons and Z boson involved in the associated production mode of the Higgs as depicted in Fig. 6.1 & 6.2 were precisely measured and the results for their masses are given

in Fig. 6.17. The signal is not included in validations plots for the background comprehensively as the request for the signal production is in progress. But the preliminary results for the request of the signal production are shown. The contribution from fake leptons or non-prompt electrons is also not considered but this is supposedly to be done for the future studies. Overall, the preliminary results are included in this chapter.

Chapter 7
Concluding remarks

In this dissertation I have presented my own work on the ATLAS reconstruction efficiency measurement for full Run 2 data using two different release version of TagAndProbe framework and search for HBSM double and singly charged scalar bosons decaying into multi-leptons. The work is performed with proton proton collision datasets recorded by the ATLAS experiment in the LHC Run 2 correspond to years 2015-2018. Additionally, the checks for the Run 3 pre-production MC21 samples are done within ATLAS Egamma group and the results for the variables based on LH discriminant are also presented.

This thesis presents an overview of the Standard Model and physics beyond standard model i.e. Higgs physics within chapter **2**. An introduction to the CERN's experiments in general and ATLAS experiment in particular is given in chapter **3**. The details about object reconstruction at ATLAS experiment are given in chapter **4**. The chapter **5** and **6** contain my contribution towards different measurements and performances towards ATLAS physics analyses. The major work about electron reconstruction efficiency measurements and singly and doubly charged Higgs searches at ATLAS experiment is done under groups i.e. Electron and Photon Performance Group (EGAMMA) and Higgs and Diboson Searches (HDBS).

The first part of the chapter **5** describes the measurement methodology used by the ATLAS experiment to perform the efficiency measurement for the reconstruction algorithm. I have briefly described the tag-and-probe method that permits to select an unbiased sample of electrons in data, and estimation of the residual background contributions for the efficiency measurement. The section is also dedicated to measure statistical uncertainties through pseudo-experiments. Since statistical uncertainties in published results are estimated using first-order approximations only, there are detailed results are provided to the accuracy of those approximations by comparing them to the dispersion of repeated pseudo-experiments.

The scale factors measurement for AF2 samples in release 21 with release 21 framework and the results are shown. The re-implementation of methodology for electron reconstruction efficiency in release 22 framework and the proof of correctness of that work and comparison of scale factors in either versions of frameworks i.e. Rel21 & Rel22 is provided.

Aiming at signal searches to extend the scalar sector of the Standard Model with a scalar triplet, directing to a phenomenology which comprehends singly and doubly charged Higgs bosons, the analysis is presented in chapter **6**. The associated production of doubly charged and singly charged Higgs bosons are investigated through the analysis. The topologies used for the analysis and the details of theoretical framework is also entailed. The Monte Carlo simulations used for various selection variables are documented and the signal regions used for the different mass hypotheses of charged Higges are described in order to distinguish signatures of BSM processes from SM backgrounds. The results obtained for the background validation and the MC signal are concluded as well.

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