SEMESTER REPORTS
4. semester

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PhD Program: Particle and Nuclear Physics

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PhD Thesis Title: Soft QCD and forward physics measurements at the CMS experiment

Introduction

The motivational background and technical details of my main topic (including the concept of the muon puzzle, the calibration of the ZDC and searching for charge exchange reaction, together with what is a random-triggered data and why is it both important and interesting to look at) has been detailed in the previous semester reports; just as the detailed workflow of my other topic (XY factorization analysis) concerning luminosity measurements. Therefore, I only restrict myself to summarize the work done so far in the following sections.

Summary of research work carried out in the previous three semesters

ZDC (Zero Degree Calorimeter) -related works:

1) 2013 data analysis:
   - The aim is to work on p+p data (present), since this was predicted (in my MS studies) to be the most useful geometry for charge-exchange analysis I want to carry out.
   - First, however, detector calibration is needed, for which I used a p+Pb data collected close in time.
   - I examined different pedestal-subtraction techniques, choosing the best method (considering physics expectations and what is computationally advantageous) to obtain the charge value of interest (coming from a neutron hit).
   - Signal-shape studies proved that the read-out system can saturate having an upper threshold for the measured energy. To compensate this effect, I obtained multiplication factors, using which I can get back the "true energy" deposited. I also studied possible ways of improvement for this method by smearing the "true energy" value in accordance with how the distribution looks like under the threshold.
   - Gain factors were obtained for all the channels covered by data via comparison to signals from simulated processes.
   - By plotting the energy deposited in the electromagnetic (EM) section with respect to the one in the hadronic (HAD), the expected neutron peaks (also as tilted ridges towards higher EM energy ranges) can be easily spotted indicating the feasibility of measuring neutrons.
   - I must distinguish between the case in which the neutron deposited all of its energy in the HAD section, or when also the EM section has to be regarded.

- It turned out that ZDC was placed slightly shifted with respect to the parameters in the official simulation in usage.

2) Random-triggered data analysis – already in progress.
3) Validation of the ZDC trigger: I contributed in the data taking during the heavy ion run, checking if the charge measured by the ZDC and monitored by both the trigger and the ZDC groups coincides.
4) Collecting relevant stand-alone codes describing detector geometry for inclusion into the CMS software computing framework.

XY factorization in luminosity measurements:

1) 2022 p+p data analysis – finished. Key results I obtained:
   - Differences in the fits with respect to the main (van der Meer) method were present due to more precisely measured beam position values used in my method.
   - I compensated for additional orbit drift effects happening between two sets of measurement that are handled together during the analysis (therefore they have to have matching position values).
   - I modified 2D fit functions to circumvent oscillation of the simulation between two minima during χ^2-minimalization when calculating the factorization bias.
   - My numerical result was in accordance to the prediction of the beam imaging group (another analysis group within the same working group in CMS), which applies another method to obtain XY factorization serving as cross-check.
   - The observed four-fold periodicity (coming from the filling at pre-accelerator level) of the bunch-crossing pattern was reported and was under discussion with the accelerator division of CERN.
2) 2023 p+p data analysis – already in progress.
3) Being "Beam Radiation, Instrumentation and Luminosity" shifter at CERN: I monitored the performance of the luminometers (luminosity measuring detectors) at CMS.

Description of research work carried out in current semester

ZDC – random-triggered data (from 2023) analysis:

Since the data meanwhile has been written to tapes, working on it got drastically harder. Therefore, I used only one such a file to test its feasibility for further analysis (in order to provide a decent reason for asking for bigger statistics).

It is beneficial to restrict the studies for those events when there was at least one neutron present. Regarding a random-triggered dataset it requires more care with respect to the data from 2013 (where the detector was timed in), because the neutron can arrive at any time with respect to the beginning of the data collection triggered by a random trigger. Therefore, first I restricted the range of the analysis to the vicinity of neutron events (identified as peaks on a plot where the amount of collected signals is shown with respect to the bunch crossing number). Then I got rid of pre-/aftershower events by knowing an approximate signal shape in time.

The bunches were filled far away enough not to cause pile-up effects; and possible saturation phenomena during the read-out did not take place either based on my analysis.

Finding out that the most recent gain and calibration values are from years ago (the newer measurements are under analysis), I used only the official (recent) pedestal values on the ADC-level together with an older energy calibration (until newer results can be included).

I studied the correlation matrix of individual channels (per EM/HAD section per positive/negative side wrt. the interaction point) to find out if some mislabeling took place.

Now, getting to know that in another type of dataset (which is easier to access than the tapes) the data needed for my analysis might be available, I am currently trying to train the codes to be able to handle that kind of dataset in order to work on larger data set gaining in statistics.

XY factorization – analysis on 2023 p+p data (finished):
After another wave of code refactorization I carried out the XY factorization analysis on the 2023 p+p data as well. This year I had to face a different type of problem, having the 2D fitting functions all converging to the same minimum (up to uncertainties).
The data taking was split into two in 2023, and even working on the right data (having all the corrections needed correctly), for the first part I obtained a huge value that was never observed so far and it also contradicted the preliminary results of the beam imaging group who are using partially a subset of the same data I got my result from. Furthermore, it is notable that for the second part of measurements, I got the value around the expected one (which was in accordance with what the beam imaging group found).
Therefore, I included first all data the beam imaging group uses, but the results obtained from that in my method were in accordance with my previous results, giving the high value.
Then I suspected after further elaborations that the shape to be fitted is more square-like in these data which turned out (from discussions with the accelerator department) to be not unphysical as it was regarded previously. Thus, I introduced and examined new 2D fit functions that can reproduce such shapes as well, but their prediction was still in correspondence to the high value.
It also turned out meanwhile that the beam imaging group suffers from huge systematic uncertainties coming from their closure test, therefore I suggested to use a time-dependent correction based on my analysis (connecting the high value from the early part with the expected value in the second part), which time-dependence idea was approved by the luminous region studies of another colleague (using data also from the gap between the two parts I used, fitting perfectly to the line of the time-dependent correction).
These results will be soon published in an Analysis Note and I will prepare publicly available plots (these activities are both in progress).
I also organized the analysis code to be available for the working group, and I presented XY factorization analysis based on my method comparing it to other techniques on the BRIL and lumiPOG workshop at CERN.

Publications

Already published:

- Fehérkuti, G. I. Veres, R. Ulrich, T. Pierog, Feasibility studies of Charge Exchange Measurements in pp Collisions at the LHC, *Entropy*, **2022**, *24*, 9, 1188, DOI:10.3390/e24091188 (proceedings – special issue)
- Fehérkuti, Diffraction and elastic scattering at the LHC, *Proceedings of Science*, **2024**, *450*, 034, DOI:10.22323/1.450.0034 (proceedings)
- The CMS Collaboration, Luminosity measurement in proton-proton collisions at 13.6 TeV in 2022 at CMS, Physics Analysis Summary, **2024** (public note)
    - I am author and contributor in the corresponding analysis note AN-22-148 (internal note)
    - I prepared publicly available plots (public summary website)

In preparation:

- Manuscript about "XY factorization bias in luminosity measurements" in the *International Journal of Modern Physics A.* (grey area between article and proceedings)
- Analysis Note and publicly available plots from the results of the XY factorization analysis on 2023 pp data. (internal note and public summary website)
- ZDC Analysis Note. (internal note)

Planned:

- Joint luminosity paper from the 2022-2023 pp data, containing my XY factorization analysis. (article)

Studies in current semester

I took my last course in this semester: Standard Model (FIZ/2/002E), of which I was not graded before handing in this semester report.

Conferences participations during the doctoral studies

Conferences, workshops, schools, meetings:

- LUM-POG / DPG meetings, online, 07. 03. 2023., 04. 04. 2023., 13. 06. 2023., 05. 09. 2023., 14. 11. 2023. [approval], 13. 02. 2024., 19. 03. 2024., 02. 04. 2024. - Status report on XY factorization (English)
- BRIL and lumiPOG workshop, CERN (Chateau de Bossey), 28. 02. 2024. - 01. 03. 2024. - Transverse factorization: offset and diagonal scans (English)
- LLCMWG meeting, online, 11. 12. 2023. - Non-factorization studies in CMS (English)
- Wigner Particle Physics Seminar, Budapest, 18. 12. 2023. - Diffraction, elastic scattering at LHC (English)
- 23rd Zimányi School Winter Workshop on Heavy Ion Physics, Budapest, 08. 12. 2023. - XY factorization bias in luminosity measurements (English)
- Forward meeting, online, 30. 11. 2023. - Forward ppRef menu discussion (English)
- Theory Meets Experiments - The high intensity frontier of particle physics, GGI, 20. 11. 2023. - 24. 11. 2023.
- ZDC meetings, online, 10. 11. 2023. - Status report on ZDC studies (English)
- Large Hadron Collider Physics Conference, Belgrade, 25. 05. 2023. - Diffraction, elastic scattering at LHC (English)
- CMS Week & Upgrade Days, CERN, 30. 01. 2023. - 03. 02. 2023.
- Wigner Particle Physics Seminar, Budaest, 24. 10. 2022. - Study of the K+ decay with the NA62 Experiment (Hungarian)
- 22nd Zimányi School Winter Workshop on Heavy Ion Physics, Budapest, 09. 12. 2022. - Study of the K+ decay with the NA62 Experiment (English)

Outreach:

- EC Természettudományi Tábor (Wigner): "Részecskefizika bevezető" presentation (07. 24. 2024.)
- Részecskefizikai Diákműhely (Wigner): "Szemezgetések a sokszínű fizika területeiből egy PhD-hallgató szemével" presentation (08. 03. 2024.)
- Masterclass (ELTE): HPGe laboratory demonstration (06. 03. 2024.)
- EC Természettudományi Tábor (Wigner): "Szemezgetések a sokszínű fizika területeiből egy PhD-hallgató szemével" presentation (02. 08. 2023.)

- The Higgs boson is 10 years old! (ELTE): interviewee in the "Ask the researcher!" session, moderator of the scientific escape room (19. 11. 2022.)
- Researchers' Night (ELTE): demonstrator at the cloud chamber, helper at the registration (30. 09. 2022.)

Teaching activity

During the semester I taught in the laboratory: „Vizek tríciumtartalmának meghatározása [TRI] (Környezetfizikai Laboratóriumi Gyakorlat 2. - III. éves környezettan szakos hallgatóknak)".

Bibliography

[1] O. A. Grachov, M. J. Murray, Status of Zero Degree Calorimeter for CMS Experiment, *Inspire HEP*, **2006**, arxiv:nucl-ex/0608052

[2] O. Surányi, Study of Very Forward Neutrons with the CMS Zero Degree Calorimeter, *Universe*, **2019**, *5*, 210. [3-4], DOI:10.3390/universe5100210

[3] O. Surányi, A. Al-Bataineh, J. Bowen, S. Cooper, M. Csanád, V. Hagopian, D. Ingram, C. Ferraioli, T. Grassi, R. Kellogg, E. Laird, G. Martinez, W. McBrayer, A. Mestvirishvili, A. Mignerey, M. Murray, M. Nagy, Y. Onel, F. Siklér, M. Toms, G. Veres, Q. Wang, Performance of the CMS Zero Degree Calorimeters in pPb collisions at the LHC, *JINST*, **2021**, *16*, P05008, arxiv:2102.06640

[4] S. Baur, H. Dembinski, M. Perlin, T. Pierog, R. Ulrich and K. Werner, Core-corona effect in hadron collisions and muon production in air showers, *Inspire HEP*, **2020**, arxiv:1902.09265v2

[5] A. Aab, P. Abreu, M. Aglietta et al., Direct measurement of the muonic content of extensive air showers between $2 \cdot 10^{17}$ and $2 \cdot 10^{18}$ eV at the Pierre Auger Observatory, *European Physical Journal C*, **2020**, *80*, 751, DOI:10.1140/epjc/s10052-020-8055-y

[6] J. Albrecht, L. Cazon, H. Dembinski, A. Fedynitch, K.-H. Kampert, T. Pierog, W. Rhode, D. Soldin, B. Spaan, R. Ulrich, M. Unger, The Muon Puzzle in cosmic-ray induced air showers and its connection to the Large Hadron Collider, *Astrophysics and Space Science*, **2022**, *367*, 3, 27, arxiv:2105.06148v1