SEMESTER REPORTS

1. semester

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

Introduction

In high energy proton-proton or proton-nucleus collisions a so-called *charge exchange* reaction may take place. In this process a final state neutron appears after a virtual pion exchange, the neutron carrying nearly the total beam energy. This neutron can be detected with the Zero Degree Calorimeter (ZDC) [1-3] of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) of the European Council for Nuclear Research (CERN).
Features of events tagged with these forward neutrons, considered to be pion-proton or pion-nucleus interactions, can be measured with the central part of the CMS detector. Pion production yield in such reactions is related to the number of muons in the analogous cosmic ray air showers. Therefore, studying such reactions could lead to a better understanding of cosmic ray air showers, in which collisions of charged pions with nuclei (of atoms in the air molecules) play a very important role.
Recent studies (e.g. [4-6]) show a serious discrepancy between the predicted and measured yield of arriving cosmic muons, referred to as the *muon puzzle* (or *muon mystery*). Therefore, studying such processes at LHC energies and comparing the data to models is necessary to clarify this part of cosmic ray physics and extended air showers.

For high-precision physics results it is inevitable to know luminosity as accurately as possible, for which multiple corrections are used. One of them comes from the measured fact that the shape of the beam (bunches) in *X* direction differs from that of in the *Y* direction, however treated in calculations as if they were the same. The task of the so-called *XY correlation analyses* is to give a quantitative measure of this non-factorizability of the directions to enhance the knowledge on the precision of luminosity measurements.

Description of research work carried out in current semester

I continued my analyses related to charge exchange on measured proton-proton, proton-lead and lead-proton collisions from 2013 (Run 1). The ZDC detector was already there at the data taking, but it was not calibrated at that time. Therefore I had to find a heavy-ion run nearby the chosen proton-proton run (that is the collision geometry of interest on the basis of my previous analyses) as well.

On the basis of that early data I can calibrate the ZDC using the neutron energy peaks produced by the approximately mono-energetic neutrons coming from the disintegration of the lead nucleus (just as it was carried out in [2]). With this calibration I can verify the feasibility of utilizing the proton-proton data set.
The read-out of the channels of the detector is happening in so-called (25 ns wide) *timeslices* (TSs). I found out that in an event within a TS the channels can experience overflow (they cannot measure the true signal, but only a truncated one due to saturation). To avoid this mismeasurement I examined the signal shape in time (for all channels) and obtained multiplication factors with which I can determine the would-be true charges in a TS on the basis of the next TS(s).
To obtain proper signals one has to eliminate the pedestal of the recorded signal. For this I have chosen the charge value in TS3 (for each event accordingly), since our expectation is to get the on-time signal in TS4. This is also proven from data.
Regarding the calibration from the lead-proton data (I did not use the proton-lead one, because that produces the neutron peaks in the ZDC of the negative side, whose gain was so low, I could not use), one can compare the charge measured by the electromagnetic (EM) and hadronic (HAD) sections. The neutron peaks (also as tilted ridges towards higher EM energy ranges) can be easily spotted indicating the feasibility of measuring neutrons.
Concerning the calibration of the neutron peaks one has to consider two distinct cases. One of them is to regard the distribution measured by the HAD section if there was no signal in the EM one (technically obeying the constrain of having less than 2000 fC in total). This refers to the situation in which the neutron begins to deposit its energy only in the HAD section. Another possible case is when the shower begins already in the EM section, thus a contribution to the total charge has to be assumed (for instance $HAD + 0.1 \cdot EM$).

I also had the opportunity of carrying out my obligatory service work in CMS (which is mandatory for me as a PhD student to qualify for authorship of the CMS publications) in an additional topic. Service works usually involve software or hardware development and maintenance of a detector. I have chosen it to be related to system operation and I joined a luminosity work on XY correlation. My actual project after code refactoring is working on newly measured (2022) data besides further analyses on data from 2018.

Publications

Already published:
A. 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

Results of the analyses on the topic related to the ZDC I am going to publish in an Analysis Note what I has begun to write.

Studies in current semester

After coming back in the end of September from CERN where I was a Summer Student at the NA62 experiment, I took three courses at ELTE this semester:

- The Phase Diagram of Strongly-Interacting Matter (FIZ/2/024E)
- Astroparticle Physics (FIZ/2/132)
- Quantum Chromodynamics (FIZ/2/083E)

I scored grade 5 from each.

I also took part of the 22nd Zimányi School Winter Workshop on Heavy Ion Physics, where I could attend many interesting lectures of recent studies, also at the Poster Session.

Conferences in current semester

I have presented my Summer Student work (*Study of the K+ decay with the NA62 Experiment*) on the following conferences, seminars:

- Wigner Particle Physics Seminar, 24. 10. 2022. (Hungarian)
- 22nd Zimányi School Winter Workshop on Heavy Ion Physics, 09. 12. 2022. (English)

Professional activities

Given my particular concern for outreach I took part in multiple such programs at ELTE.
On the *Researchers' Night* I was both at the registration station and as a demonstrator at the cloud chamber.
I also helped in the organization and in the operation of a scientific escape room on *The Higgs boson is 10 years old!* program, where I was also an interviewee in the *Ask a researcher!* session.

Bibliography

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[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

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[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