Scientific Report

regarding the implementation of project PN II, IDEI 56/07.10.2011 with title „Studies of flavor production mechanisms in the pp interaction", spanning January 2014 – December 2014

1. Production of strange particles and correlations studies using LHCb Minimum Bias data.

LHCb Results [1] for various high energy physics analyses had been published in Journals of High Energy Particle community since 2010, when first results of V0-particles production (Lambda baryon and K_{short} meson) were published [2]. Results published till this date are based on LHCb data which contain proton-proton collision events with total a collision energy in the center of mass of the two colliding protons of: 7, 8, 2.76 and 0.9 TeV. For events with a collision energy of 7 and 8 TeV, the LHCb collaboration has available on disk data corresponding to an integrated luminosity of 1 fb^{-1}, and 2 fb^{-1}, respectively – equivalent to number of collisions per year with a magnitude of 10^{14}. In the same time, there are recordings on disks for LHCb events with collisions of proton-Lead, data taken in 2013 for which an LHC-beam of protons has collided with a LHC-beam of Lead nuclei/ions. Beginning with the middle of this year, our group started using these data with proton-ion collisions to study the strangeness production in this class of events. The analyses done on proton-proton collision data continue, as do the studies of single particle production cross-section for baryons Xi, Omega, Lambda and K_{short} mesons. These analyses on proton-proton (pp) data are done for using Minimum Bias data samples, or more exactly the "NoBias" samples, where the "Trigger" used in data recording and selection by LHCb is essentially just an on-switch according to the GPS time of LHC proton bunch-bunch crossing followed by a 25 ns recording time window. This "trigger" involves no selection procedure or requirements on the status of the detector being free of bias in this respect. As the strangeness production is abundant at LHC collision energies, the majority of data analysed by our group is of "NoBias" type, even though the "NoBias" trigger line is generally limited to 100 Hz, meaning the total available integrated luminosity per studied samples fluctuates from few to a maximum of tens of nb^{-1}. The "NoBias" integrated luminosity estimates were completed recently taking into account the decrease with a factor of about 10^{-5} in LHCb integrated luminosities per year. The procedure took into account all the changes in the rate limit during each run and an extra pre-scale
factor of the "NoBias" trigger line which were used in the Luminosity Tool Algorithm. At the moment the exact luminosity numbers for our analyses are not public, and shall be made available soon after publication date.

Following the preselection done by LHCb collaboration – preselection achieved through a software algorithm configured by our group and corresponding to a set of preselected criteria - during mass processing campaigns of the LHCb data. The preselected samples containing the candidates for strange particle pairs (K^+ ,K^-) , (Lambda, K^+) , (anti-Lambda, K^-) and (Lambda, anti-Lambda), where the strange baryons (Lambda) and mesons ($K^{+/-}$) has strangeness number equal. unity. At the present time we have the raw estimates of the production rates for pairs of correlated and uncorrelated strange particles and we implement the detection and selection efficiency correction factors to compute the actual production rates and cross-sections and estimate the strength of correlations. For this we map the Particle IDentity (PID) [3] efficiency in the LHCb-accessible phase space and using a dedicated algorithm we compute the efficiencies of PID tagging directly form the data for charged Kaons. For Lambda baryons the mass constraints on the daughters (p, pion) and the topology of its decay in LHCb is enough to achieve very high level of purity 95% to 99%. The final point in the process of determining the reconstruction and selection efficiencies is to obtain the systematic errors generated by:

- differences in tracking between Monte Carlo (MC) reconstruction and data reconstruction (due to material differences in simulation, calibration differences, etc),
- PID uncertainties,
- mass-fit model limitation,
- selection parameters differences in MC and data,
- strange particle rates and ratios differences in MC and data.

An additional problem is the lack of large samples of inclusive strange particle MC events. As the reconstruction is limited to the fiducial volume of LHCb phase space region and most Lambda particles are lost as they decay outside the vertex locator of LHCb, only a small fraction of baryon pairs and meson-baryon pairs is reconstructed from the few million generated in the MC simulation. To avoid this limit a second mass-generation of samples [4] with an optimized set of generator settings, is currently foreseen to be produced by our group locally and in a second step through a second request to the LHCb collaboration.
Preliminary cross-section estimates are to be expected soon for three collision energies: 2.76, 7 and 8 TeV, though for 2.76 the limit on integrated luminosity (0.5 nb^{-1}) prevents us to obtain enough candidates of baryon pairs (Lambda,Lambda-bar) to extract meaningful cross-section values.

In parallel with the simple pair production studies, we look for jet structures associated to strange particle production (e.g. leading strange particle in a jet, strange particle pairs in jets). The aim is to obtain the for soft particle jets in LHCb, a reasonable amount of strange pair candidates to allow a separate study. Jet structures are formed by particles produced in fragmentation of an initial parton, and the leading particle requirement imposes a strong condition on strange particle production process and origin. An other possibility is to have a soft/hard jet and a distinct strange particle pair. For all these case we implement selection algorithms and we are currently pursuing jet identification techniques and their efficiencies in LHCb case.

Additionally we concluded the feasibility studies in case of production pair of strange particles in LHCb, with at least one particle in pair with strangeness number higher than unity: Xi and Omega in this analysis. It was proven that for 7 and 8 TeV Minimum Bias data there are sufficient number of Xi and Omega candidates reconstructed in conjunction with an other strange particle, and we bagan to map the reconstruction efficiencies in LHCb phase space for the strange baryon Xi/Omega and the other member of the pair. We use only MC efficiency estimates for now, which we extracted from MC samples which were produced by LHCb collaboration at our request and using generator settings configured by us directly in the LHCb simulation software project. The real date obtained through a preselection step, which asks for reconstructed Xi/Omega, are available and are currently used to extract raw production rates. The main problem now is to produce a large MC sample of reconstructed Xi/Omega, together with a second reconstructed strange particle. We work at a generator optimization
by imposing selections criteria for the generated strange particles. This will allow for an increasing efficiency of generating reconstructible Xi and Omega together with associated Lambda or Kaons.
The resulting code is to be implemented in the simulation project after which we intent to ask the

collaboration for a mass production on GRID, in parallel with a local production of MC sample on our cluster. As before, the aim here is to obtain total cross-sections and correlation functions of the pair production, and pursue a similar objective in jet plus strange particle pair case. The large MC sample produced will allow the extraction of reconstructed efficiencies and selection rule optimization, plus a way to estimate the correlation functions for pairs.

In respect to the new proton-Lead collision data, the aim is to make feasibility studies to estimate the overall production of strange particle pairs. The preliminary results are very promising as the production of V0s (K_{short} and Lambda) and Xi/Omega hyperons/baryons follows to the first order of approximation the usual rule A^k, where A is the atomic number of lead, with k power-index close to unity. E.g., the hyperon production rate in proton-Lead events with an integrated luminosity of less than half nb^{-1} is superior to the production rate in proton-proton events at 8 TeV with and integrated luminosity larger than 10 nb^{-1}. The nucleon-nucleon collision energy is about 5 TeV in their center of mass, lower than 7 and 8 TeV for proton-proton collisions.

The results of strange particle pairs will be published next year in LHCb papers on this subjects: e.g.„European Physical Journal C (EPJ C)". Depending on the final results of the jet studies a second article will follow, article with will include correlations between jets and strange particle pairs, jet flavor structure, leading particle effects, and cross-sections. Preliminary results of these analyses are not given explicitly as the LHCb collaboration rules prevents popularization of results before publication. An example is given next for an analysis of restricted data sample, in place of preliminary results on all samples available for a given measurement.

1.1 Example of an analysis which is restricted to a minor LHCb sub-sample of "NoBias" events – correlations between strange particles.

The next conclusions are based on the analysis done on a proton-proton LHCb sample for collision energy of $s= 7^2$ TeV^2, and a constant magnetic field polarization - the sign of the magnetic field does not change/filp within the used sample.

The correlation plots between particles are given usually in the space of three variables: Delta(p_T) = p_T(Lambda) – p_T(anti-Lambda), where p_T is the transverse momentum, Delta(y) is preudo-rapidity difference of baryon and anti—baryon, and Delta(phi) the azimuthal angular difference between the components of the pair.

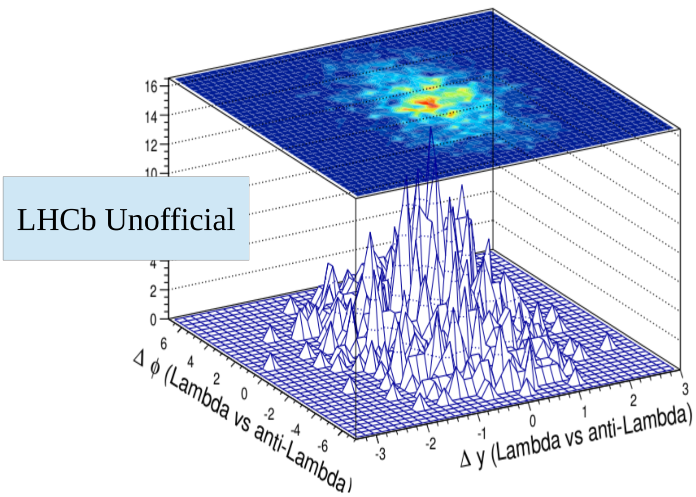

Illustration 1: Correlation between Lambda and Lambda-bar plotted in the phase-space of pseudo-rapidity difference and azimuthal angle difference between the two particles

In

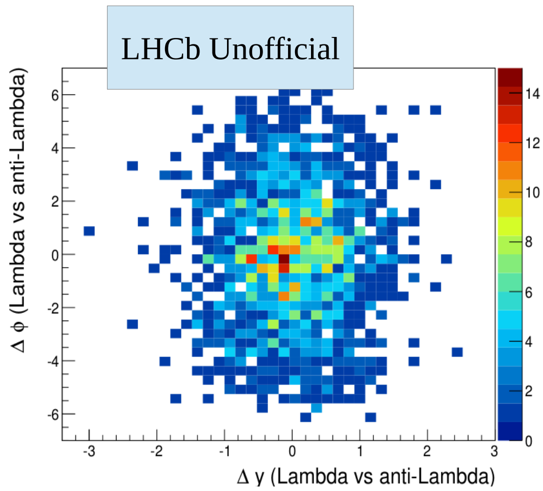

Illustration 2: Correlation between Lambda and Lambda-bar plotted in the phase-space of pseudo-rapidity difference and azimuthal angle difference between the two particles (same as before)

plots 1-2 it is evident the reduced number of events with reconstructed baryons Lambda and Lambda-bar. Not the same it can be said in the kaon plots where the production rate of (K^+,K^-) pairs is much larger and is doubled by a better reconstruction efficiency and larger acceptance - i.e. the charged Kaon does not have to decay in flight within the vertex locator as does Lambda. This is evident in the 3-4 plots.

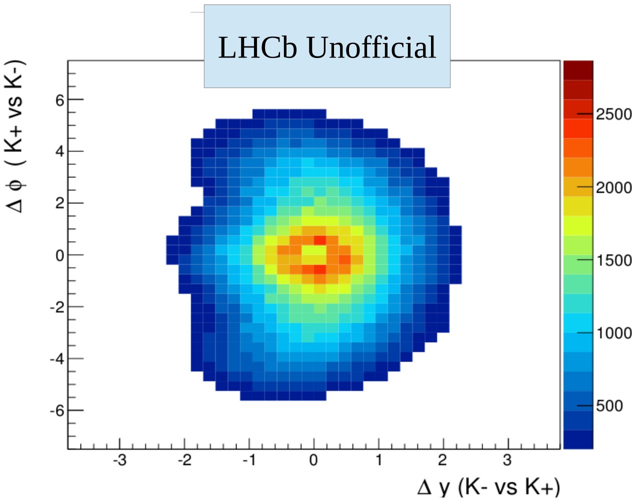

Illustration 3: Correlation between strange particles : (K+,K-), in phi-azimuth and pseudorapidity. Raw distributions without correcting for detector effects.

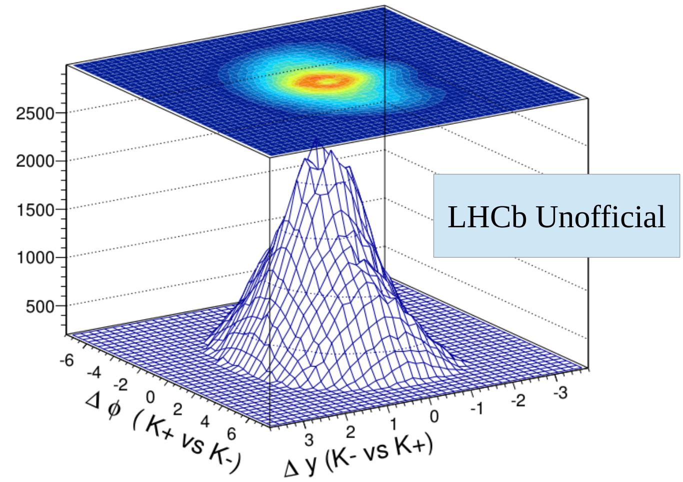

Illustration 4: A different representation of the same plot as the precedent

Precedent plots and results display the correlations between strange particles. If we compare the results obtained with the charge kaons correlations for daughters of the phi meson phi -> (K+,K-), the qualitative features are present in both cases, though phi meson induces a stronger correlations made extreme by the comparable mass of phi and the sum of daughter masses, plot 5.

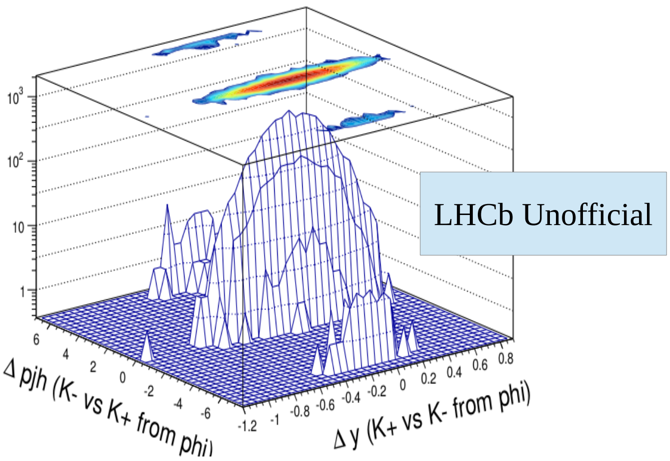

Illustration 5: . Correlations between kaons with oposite charge and strangeness, daughters of phi meson.

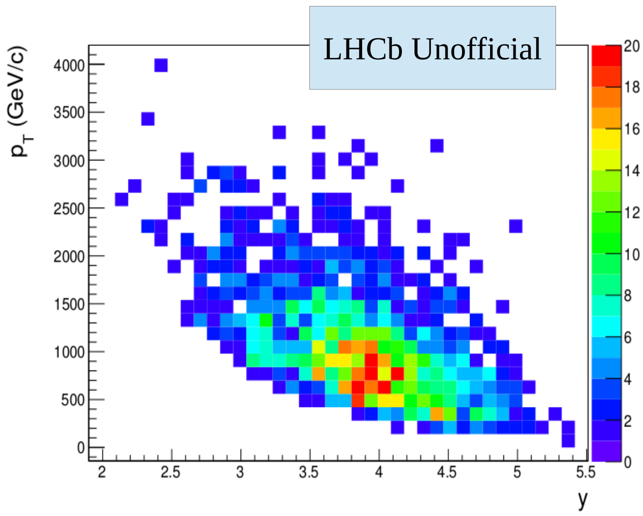

Illustration 6: Lambda baryons reconstructed in the LHCb acceptance, the phase space occupancy is display in pseudo-rapidity and transverse momentum.

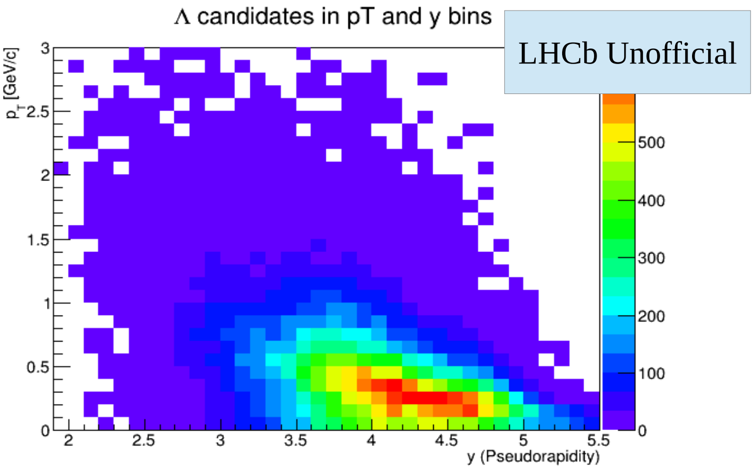

Illustration 7: Compared with the plot 6 here it is given the number of reconstructed Lambdas which are not part of a strange particle pair, and which are reconstructed in LHCb acceptance.

Comparison between single-particle Lambda distributions (plot 7) and the Lambda from strange particle pairs distributions in plot 6 show generally larger transverse momentum for correlated particles than for single-particle. It would be consistent with the effects induced by a common production process as the difference is consistent with the mass difference between Lambda and Kaon,

In conclusion:

Additionally to obtaining the production cross-section values for pairs of strange particles - main objective of the flavor analysis – it will be pursued an analysis of correlation and the disentanglement of distinct contributions from each production step – i.e., hadronization, showering and parton-parton collision. In a separate analysis it is studied the production of strange particles in conjunctions with jets of particles reconstructed in LHCb. The latter study is done in parallel at simulation level and in a data analysis. It remains to be seen if we have enough NoBias data to allow for a sizable sample of reconstructed jets.

Bibliography.

1. Alves, A.Augusto, Jr. et al. LHCb Collaboration, “The LHCb Detector at the LHC”, JINST 3 (2008) S08005, LHCb-DP-2008-001 ; CERN-LHCb-DP-2008-001, http://iopscience.iop.org/1748-0221/3/08/S08005/;

2. Alves, A.Augusto, Jr. et al. LHCb Collaboration, “Prompt K0S production in pp collisions at sqrt(s) = 0.9 TeV”, arXiv:1008.3105; CERN-PH-EP-2010-027; LHCb-PAPER-2010-001.- Geneva : CERN, 2010 - 24 p. - Published in : Phys. Lett. B 693 (2010) 69-80

3. Adinolfi, M et al. LHCb RICH Collaboration,“Performance of the LHCb RICH detector at the LHC”, Eur. Phys. J. C 73 (2013) 2431, arXiv:1211.6759 ; CERN-LHCb-DP-2012-003 ; LHCb-DP-2012-003, http://link.springer.com/article/10.1140%2Fepjc%2Fs10052-013-2431-9;

4. „PYTHIA 6.4 Physics and Manual”, T. Sjöstrand, S. Mrenna and P. Skands, JHEP05 (2006) 026, plus „An Introduction to PYTHIA 8.2”, T. Sjöstrand et al, arXiv:1410.3012 [hep-ph].

2. Analysis of the Monte Carlo data generated with PYTHIA – RIVET software packages

PYTHIA is the main simulator used by LHCb for describing the proton-proton collision. At present its implementation uses a phenomenological model as well as results from perturbative QCD. Due to the complexity of the description it has a large number of phenomenological parameters and special configurations of these parameters called "tunes" are used by different groups of specialists to reproduce sets of measurements. LHCb has its own configuration of the parameters/tune which is is used in the LHCb's version of the PYTHIA. Our group is involved in the task force which plans for the re-optimization of the LHCb tune such that the new results resulted from the first run of the LHC experiments to be better reproduce in the simulator. Among the observables interesting for the tuning process are the production of strange particles, their multiplicities, correlated production, jets etc which constrain the phenomenological parameters of PYTHIA. The involvement in these studies has the benefit that it gives you a profound view of the details of PYTHIA+LHCb software (including simulation, digitization, the trigger, offline reconstruction) and the representation of physical systems involved (the mechanism of particle production and the description of the LHCb detector). These expertise is further use in interpreting the LHCb data, discriminating the signal from the background, correcting the production rates from detector inefficiencies. In the next sections we will give some examples of correlations studies for strange particles using simulated data produced by PYTHIA interfaced by RIVET [3] and the way they are used for LHCb tune. The RIVET interface gives one an exceptional flexibility in defining the desired observable of the production/correlation process as well as choosing the phenomenological model and defining the setup environment. In the following we are using Minimum Bias type of events corresponding to proton-proton collisions at sqrt{s} = 7 TeV.

PYTHIA implements the Lund model of string fragmentation. In the next plots we make distinction between strange particles coming from the fragmentation of a string from those when particles appears from other processes. One more source of strange particles is associated with the decaying of charm and beauty quarks, but these processes can be neglected in the Minimum Bias samples, the only relevant process of this type is the decay of phi meson in a pair of (K-,K+).

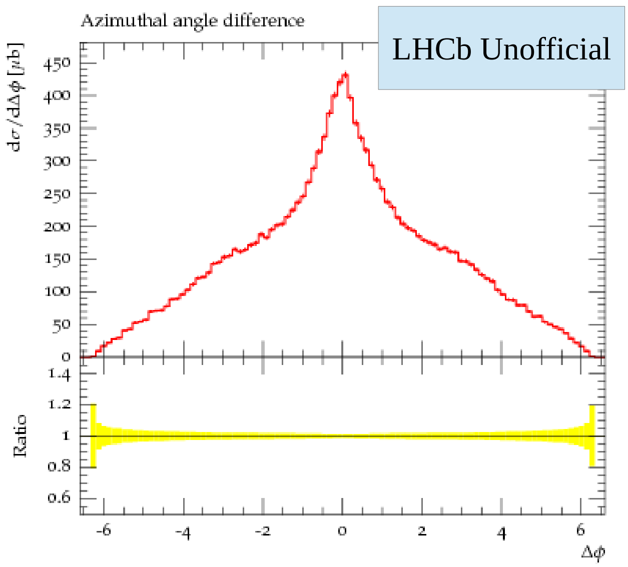

Illustration 8: Correlation of the Lambda and anti-Lambda particles as a functionof the difference between the azimuthal angles

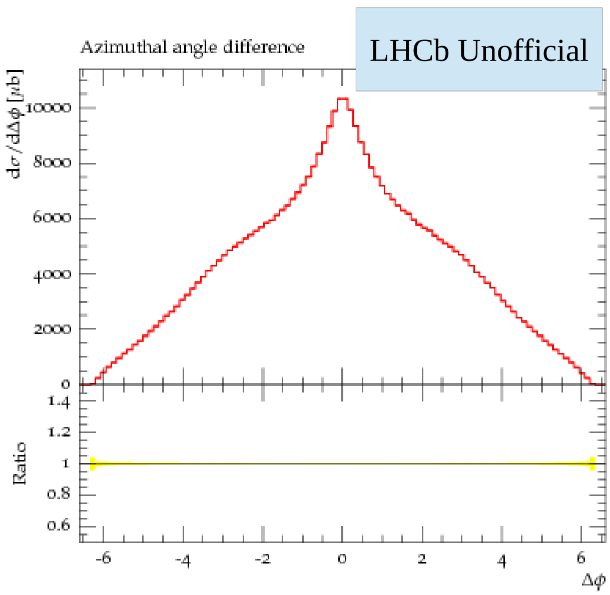

Illustration 9: Correlation between the kaon particles with different electrical charge. The anti-correlation component is observed at values of π and -π in the difference of the azimuthal angles.

In the next subsection we will discuss the particle production in Z0 decays for which the relevant process are the hard-QCD processes. In the Minimum Bias case most of the events are produced in soft-QCD interactions well below the threshold of Z0 production.

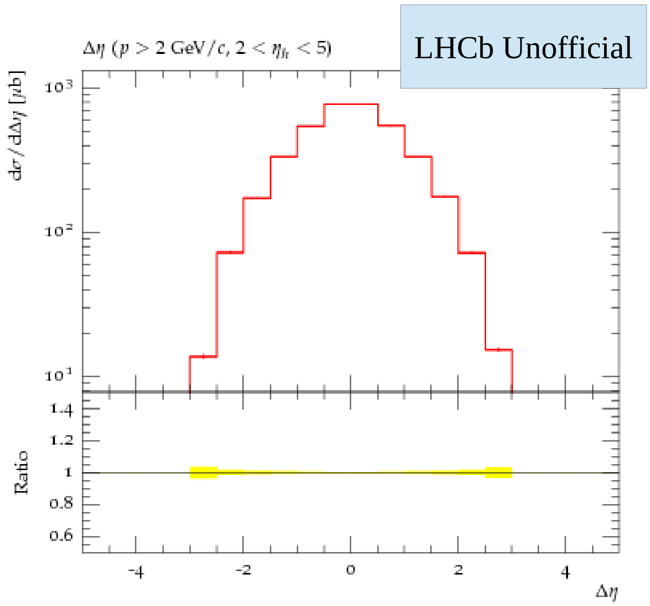

Illustration 10: Correlation of the Lambda and anti-Lambda particles as a function of the pseudorapidity differences.

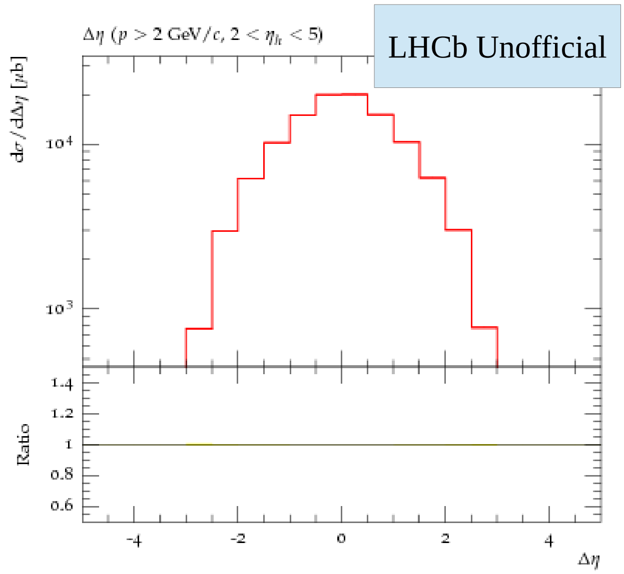

Illustration 11: Correlation of the K+ and K- as a function of the pseudorapidity differences.

The conclusions from the plots 8-11 are in agreement with the one from the LHCb measurements at a qualitative level. Some aspects that appears in the plots are still to be observed in the real data. Additionally there are a set of new observables which plan to produce with the RIVET+PYTHIA software. The intention is to use these results and finalize a study based on the MC data which will be published in a international journal. These results will form the base for understanding the data from LHCb experiment.

An obvious continuation of these studies are the studies of the production correlations for strange particles produced not in soft-QCD interactions, but in hard-QCD interactions as in the case where the pairs of the strange particles come form the electroweak decay of Z0 boson at the on-shell energies. As our goal is to separate the process of strange pairs production from the fragmentation processes we have started these studies with the case of the more popular Z → e+ e-. In the next step the Z → s s-bar channel will be studied. The RIVET 'plugin' developed for the Z → e+ e- case will also allow the LHCb collaboration to publish more of its results.

2.1 Introduction in particle - antiparticle production at Z resonance: Z → e+e-

The electroweak processes are currently used for rigorous checks of the Standard Model of the elementary particles. These processes are mediated at high energy by the charged currents, W± bosons and at low energies moreover by the neutral currents, Z0 bosons and γ, the mediators of the interactions being the γ* virtual photons, which are gradually replaced by the Z0 bosons as the interaction energy get closer to the invariant mass of the Z0 boson. This last process, mediated by the neutral bosons, is described by the Drell-Yan [1] model which reproduces well the experimental distributions, the anomalous effects being explained in quantum chromodynamics.

In the context of the particle-antiparticle production, the decay modes of the Z0 bosons are highly interesting topics due to the clean signals obtained in data. Thus we distinguish the leptonic modes electron-positron, miu- miu+ and tau- tau+ each one appearing with a probability of 10%. In the rest of the cases (approximately 69%, see reference [2]) the decays are hadronic modes producing pairs of quark - antiquark which hadonize in pairs of strongly correlated hadrons.

During this stage of the project we studied at the generator level the production of electron-positron pairs due to the decay of Z0 bosons originating from the proton-proton interaction. This channel was chosen also due to the kinematic similarities with the hadronic channel we plan to measure. This study allowed us to introduce a new tool useful in the assessment of different theoretical models used by different generators, i.e a RIVET library [3] - component of the Professor framework [4] used for the optimization of the generators. This step also helped the LHCb community which thus has an easy access to compare the predictions of different theoretical models with the experiment. Results proving the utility of this tool were presented in the ``14th International Balkan Workshop on Applied Physics", IBWAP-2014, 2-4 July, 2014, Constanţa, România and a submitted proceeding paper will appear in 2015 [6].

The expertise in using the RIVET software will be readily used in studies at generator level of pair hadron production originating from the same parton (i.e. highly correlated) and which are in the acceptance of LHCb detector. These studies are well underway and make the connection with the study of the s-sbar production studies the main goal of the project.

[1] S.D. Drell, T.-M. Yan, ``Massive Lepton-Pair Production in Hadron-Hadron Collisions at High Energies", Phys. Rev. Lett. 25 (5), 316–320 (1970).
[2] K. A. Olive et al. (Particle Data Group), Chin. Phys. C 38, 090001 (2014).
[3] http://rivet.hepforge.org.
[4] A. Buckley, H. Hoeth, H. Lacker, H. Schulz, J.E. von Seggern, ``Systematic event generator tuning for the LHC", Eur. Phys. J. C 65, 331--357 (2010).
[5] R. Aaij et al. (LHCb Collab.), ``Measurement of the cross-section for Z0 \to e+ e- production in pp collisions at sqrt{s}=7 TeV", J. High Energy Phys. 02, 106 (2013); doi: {10.1007/JHEP02(2013)106}.
[6] Ana Elena Dumitriu, A. T. Grecu, ``RIVET Plug-in for Z0 \to e+ e- Production Cross-Section Measurement in pp Collisions at sqrt{s}=7 TeV", accepted for publication in Rom. J. Phys. 60, (2015).

3. Correlation and production studies of the „beauty” hadrons

3.1 LHCb results on b-quarks pairs production

Studies of the b quark production at LHCb are an important goal for understanding the of quantum chromodynamics (QCD) and for the development of future physics programs and hadron accelerators at higher energies. The interest is both theoretical and from experimental perspective. On one side the perturbation computations have a limited accuracy and depend strongly on assumptions such as the renormalization scale, factorization scale or of the value for mass of the b considered, such that there is an interest in understanding the physics in this energy regime and in developing new computational techniques. On the pragmatic side, the understanding of the production distributions of the b quark is necessary for the estimation of the backgrounds of this source which appears in direct searches of new particles as Higgs bosons, supersymmetric particles etc. More the study of production asymmetry of b and anti-b quark has acquired a lot of attention form the community, due to the claims from the Tevatron that an asymmetry beyond the Standard Model predictions has been found in the case of top, anti-top production.

In the following are mentioned two LHCb results on the production of b- anti-b quark pair and on the production asymmetry of the two. These two results of the Collaboration were presented publicly in a note conference LHCb-CONF-2013-002 [1] and an published article [2]. Although our group was not directly involved in the above mentioned analyzes the studies performed in the s-quark case will be continued also for the case of the "beauty" hadrons integrating thus the above results. The observables that we plan to measure has not been measured by the HEP community yet and there is the possibility to apply the results of an existing feasibility study on the correlations of beauty quark production starting with next data taking period from 2015 and continuing with the data from the upgrade runs. We plan to introduce in the LHCb software new lines for triggers and preselections. The opportunity in publishing even preliminary results is still open, especially if these will be associated with the studies on the correlations of the strangeness production.

[1] LHCb Collaboration, L. Collaboration, Measurement of σ(bb-bar) with inclusive final states, LHCb-CONF-2013-002
[2] LHCb collaboration, L. Collaboration, First measurement of the charge asymmetry in beauty quark
pair production, Phys. Rev. Lett. 113 (2014) 082003. 16 p.
[3] P. Nason, S. Dawson, and R. K. Ellis, The Total Cross-Section for the Production of Heavy Quarks in Hadronic Collisions, Nucl. Phys. B303 (1988) 607.

4. Results and contributions in international conferences, workshops and publications in 2014

I. Ana Elena Dumitriu, A. T. Grecu, "RIVET Plug-in for Z0→e+e− Production Cross-Section Measurement in pp Collisions at sqrt(s)=7 TeV", accepted for publication in Rom. J. Phys. Vol. 60, (2015).

Preparation and submission of a proceeding paper ("14th International Balkan Workshop on Applied Physics", IBWAP-2014, 2-4 July, 2014, Constanta, Romania).

II. Official web page of LHCb Collaboration:
http://lhcb-sb.web.cern.ch/lhcb-sb/public/sb_talks.php

Florin Maciuc	Bucharest-IFIN-HH	2014-10-20	LHCb workshop on quantum interference effects	Cern	Switzerland	Workshop	50	Soft QCD measurements in LHCb

Organizing an LHCb workshop on the topics: LHCb workshop on quantum interference effects, QCD measurements and generator tuning. http://indico.cern.ch/event/329946/

Presentations during the event:
1. LHCb and Introduction to Tuning and QCD Measurements at LHCb
Speaker: Florin MACIUC
2. Soft QCD measurements in LHCb
Speaker: Florin MACIUC
3. Generator Tuning with Professor/RIVET at LHCb. Status of PYTHIA8 Optimization
Speaker: Alex GRECU, LHCB GENERATOR TUNING GROUP
4. Two sessions of the workshop were presided by Florin MACIUC.
5. LHCb results in pA,
Speaker: Florin MACIUC for M. SCHMELLING and „pA Physics Group”.

At Workshop on Heavy Quark Baryons at LHCb (24 July 2014)
https://indico.cern.ch/event/317758/
6. QEE speaker: Florin MACIUC

At Particles and Nuclei International Conference PANIC 2014 http://panic14.desy.de/
7. "Soft QCD measurements at LHCb", speaker A. Grecu

La LHCb Week, https://indico.cern.ch/event/352359/
8. „HepData : LHCb perspective” speaker A. Grecu

9. „MC generators tuning” speaker A. Grecu

III. Presentations during the working sessions of the Collaboration
Summary of Workshop on quantum interference effects, QCD and generators tuning
Speaker: Florin MACIUC
Xi and Omega production in pA collisions,
Speaker: Florin MACIUC
Xi/Omega production studies in pp collisions
Speaker: Florin MACIUC

5. Planned contribution for 2015

1. LHCb paper in „European Physical Journal C (EPJ C)” - „Production of Strange Particle pairs in LHCb proton-proton collisions at sqrt(s)=7, 8 and 2.76 TeV”.

2. Article in Rom. J. Phys. „Correlation and Production mechanisms of Strange Particles in Proton-Proton”.

3. Article LHCb in „European Physical Journal C (EPJ C)” -„Hyperon Production in LHCb Proton-Proton Colisions at sqrt(s)=7, 8 and 2.76 TeV”.

4. Organizing an Workshop „Generators and Tuning” Bucharest (or Krakow).

5. International Conferences and Workshop talks.

6. LHCb events: talks and organization activity,

possible contribution: 7. LHCb-Romania group paper in Rom. J. Phys. „Correlation of Beauty Particles in Proton-Proton collisions”

Project manager, Dr. Florin MACIUC

Date: 2.12.2013

The material included in this document corresponds to an on-going analysis.
Plots, numbers and qualitative results which were obtained using LHCb data or LHCb proprietary software can not yet be made public unless already published. The preliminary conclusions outlined in the present document reflect only the results and opinions of the LHCb-Romania group and are not yet approved by LHCb collaboration. Except for the example included in Chapter 1, where a small sample was taken as prof of concept and the signal was displayed in raw uncorrected form, the plots and values included here are public LHC data (already published in HEP journals or part of public HEP databases) or were obtained base on MC simulations with generators publicly available under GNU-licence, e.g. generator „PYTHIA 8 is licensed under the GNU General Public Licence version 2”.