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PRELIMINARY RESULTS ON PROMPT Ξ^+/Ξ^- PRODUCTION RATIO IN PP COLLISIONS AT $\sqrt{s} = 7$ TEV

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Abstract. *The ratio of prompt Ξ^+/Ξ^- production has been investigated based on a limited data set registered by the LHCb experiment at the CERN Large Hadron Collider in 2010. This ratio has been determined in the rapidity region $1.9 \leq y \leq 4.9$ covered by the LHCb detector. The determination of anti-hyperons to hyperons ratio produced in pp collisions will allow to study the transport of baryons to final state hadrons and to constrain and tune Monte Carlo models.*

I. INTRODUCTION

The study of strangeness production is an important ingredient to understand the nature of strong interactions as it can reveal the particle production mechanism in the collision. The introduction of quark-gluon plasma (QGP) could increase production of strange particles. This is because the threshold which is necessary to produce a strange quark is lower in QGP compared with that of a hadron gas. It is expected that this effect may be enhanced for baryons containing several strange quarks. Thus, measurements of hyperon productions or of the ratio of anti-hyperons to hyperons can serve to constrain theories, particularly the transport of baryon number from *pp* collisions to the final state hadrons, provide input for the tuning of Monte Carlo; at large values of the rapidity, they can be used to probe the fragmentation field and constrain Monte Carlo models.

The LHCb experiment offers a unique opportunity to disentangle these effects as it covers the large rapidity region where differences in the fragmentation models reveal themselves as shown in Figure 1 ([1]).

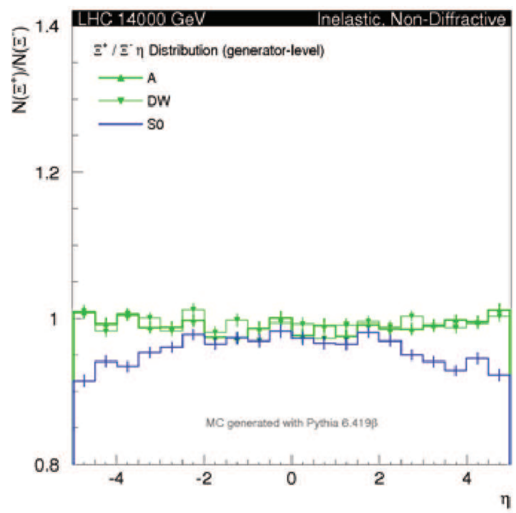


Fig. 1. The ratio Ξ^+/Ξ^- as a function of the pseudo-rapidity; A, DW and S0 refer to particular tuning of P. Skands (ref [1]) to Tevatron data. LHCb covers the domain $1.9 \leq y \leq 4.9$ whereas Tevatron experiments as well as CMS and ATLAS are covering in the central region $|y| \leq 2$.

II. THE LHCB DETECTOR

The LHCb detector is a single arm spectrometer covering 15 to 300 mad in the bending horizontal plane and 15 to 250 mad in the non bending plane. The detector has been described elsewhere [2] and hereafter we shortly discuss the sub-detector which are relevant to measure the prompt $\Xi^-$and Ξ^+.

Figure 2 shows the vertical cross section of the detector which is located at the intersection point number 8 of the LHC. A right angle coordinate system was chosen, with the z axis along the beam line. Protons arrive along $\pm z$ and collide in the middle of the VErtex LOcator.

The tracking system consists of the Vertex Locator (VELO) surrounding the pp interaction region, an upstream tracking station (TT), and three tracking stations downstream the dipole magnet with a mean bending power of 3.7 T.m.

The VELO consists of silicon microstrip modules providing the measurement of the radial r and azimuthal φ coordinates. Each VELO station is made of two halves (left and right) which can be retracted away from the beams during the injection and beam adjustments.

The TT stations also uses the microstrip technology with vertical strips and stereo strips at $\pm 5°$ with respect to the vertical. The three tracking stations behind the magnet have silicon microstrips detectors in the region close to the beam (the Inner Tracker (IT) region) and straw drift tubes in the outer region (the Outer Tracker OT). The momentum resolution increases from $\delta p/p = 0.35\%$ at low momenta to $\delta p/p = 0.55\%$ for 120 GeV/c tracks.

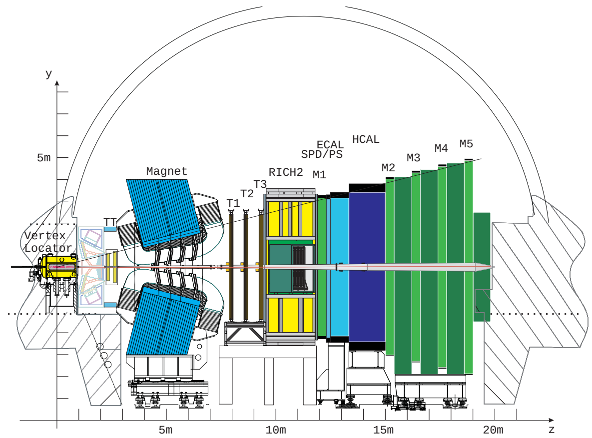


Fig. 2. View of the LHCb detector. The figure is a vertical section along the beam axis.

Non electromagnetic particles are identified using Ring Imaging Cherenkov counters RICH1 and RICH2 : these subdetectors use Silica aerogel ($n\ = 1.03$) for lowest momentum tracks, gaseous C_4F_{10} in the intermediate momentum range and CF_4 for the highest momentum tracks.

Tracks which pass through the whole tracking system (VELO, TT and IT-OT) are called “long tracks”, and tracks which do it only through TT and IT-OT are called “downstream tracks”.

We used a minimum bias trigger based on calorimeter information to select events containing at least one track segment in the downstream tracking stations (TT stations). This trigger also was emulated and applied to the reconstructed Monte Carlo samples.

III. THE DATA SAMPLE

The data sets that we used were recorded in 2010 at a LHC collision energy of $\sqrt{s} = 7$ TeV. The luminosity $\mathcal{L} = 0.0436 \pm 0.0043$ pb^{-1} is enough good for the study in framework of one master thesis. The data were recorded with both polarities of the LHCB dipole magnet and were labeled ”field Up” and ”field Down”. The total number of events is 3.6 10^6.

LHCb simulates the *pp* collisions using PYTHIA 6.4 generator. The emerging particles are then decayed in the EvtGen package and the resulting particles transported through LHCb by GEANT4 where their interactions with the detector material are modeled as are their hits in the sensitive volumes of LHCb. The Monte Carlo sample used in his study consists of 20.54 10^6 events with fields ”Up” and ”Down”. Monte Carlo data are an approximation of the real data steps with the advantage of having the ”truth” information which allows to trace back the real particles.

IV. ANALYSIS METHOD

IV.1. $\Xi \to \Lambda\pi$ selection

Λ and $\overline{\Lambda}$ particles are first reconstructed from their decays $\Lambda \to p\pi^-$ and $\overline{\Lambda} \to \overline{p}\pi^+$. We require the daughters' tracks to be of good quality ($\chi^2_{track}/ndof < 5$) and not to point to the primary vertex: their impact parameter (IP) must satisfy the condition that the χ^2_{IP} with respect to the Primary Vertex is larger than 9 for "long-long" proton and pion tracks and larger than 4 for "down-down" tracks. The reconstructed Λ, $\overline{\Lambda}$ vertex must also be of good quality ($\chi^2_{vtx}(\Lambda, \overline{\Lambda}) < 20$). Some minor requirements on the daughters' momenta and transverse momenta have also been introduced. The mass resolutions obtained for the Λ are $\sigma_\Lambda = 1.114$ MeV/c^2 for "Long-Long" proton and pion tracks and 1.902 MeV/c^2 for "Down-Down" tracks. The ratio of Λ reconstructed from "Long-Long" to "Down-Down" tracks is roughly 1:2.

For the Ξ's, we first require that a pion whose track $\chi^2_{track}/ndof$ is less than 5 encounters the Λ direction with a closest distance of approach less than 0.8 mm. For Λ from "Long-Long" tracks, the pion must also have a long track, whereas "Down-Down" Λ's are combined with either a "Long" or "Down" pion, thus allowing for a certain flight path of the Λ. We then reconstruct the Ξ and require that his mass should be in a domain of $\pm$ 100 MeV/c^2 compared to the mass of the $\Lambda - \pi$ pair.

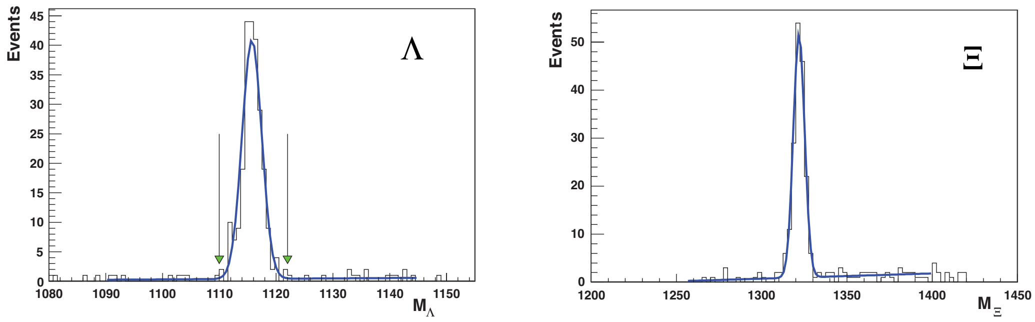
In the final selection, the $\Xi^\pm \to \Lambda(\overline{\Lambda})\pi^\pm$ must pass the following selection criteria :

- the reconstructed mass of the $\Lambda/\overline{\Lambda}$ must be within $\pm$ 6 MeV/c^2 from its PDG value,
- the $\pi^\pm$ (from the Ξ decay) must not point to the target : its χ^2_{IP}, which corresponds to the square root of its IP significance, must be greater than 12,
- the directions of the Ξ and of the Λ are quite close so that the cosine of the angle created by their directions is larger than 0.9996,
- the Ξ should point to the target : its χ^2_{IP} must be lower than 9 and the cosine of the angle between its momentum and its flight direction must be greater than 0.9999,
- the separation between the Λ vertex and theprimary vertex must be greater than 10σ,
- separation between the Ξ vertex and the primary vertex must be larger 2σ.

Finally, combinatorial background can be more reduced using a Fisher discriminant based on the impact parameters of the Ξ daughters and of the Ξ :

$$\nu = \ln \frac{IP_\Lambda \cdot IP_\pi}{IP_\Xi \cdot 1} > 1$$

Figure 3 shows the mass peaks resulting from this selection. The mass resolution that we obtained for the $\Lambda\,(\overline{\Lambda})$ is compatible with the resolution ($\sigma_\Lambda = 1.23 \pm 0.46$ MeV/c^2) obtained by LHCb at $\sqrt{s} = 0.9$ TeV [3]. This value is definitively better than the resolution obtained by the CMS collaboration ($\sigma_\Lambda = 3.4$ MeV/c^2) and our Ξ mass resolution compared to the CMS one [4] ($\sigma_\Xi = 4.1$ MeV/c^2). This shows the higher performances of LHCb regarding particle momentum resolutions.



(a) (b)

Fig. 3. The $\Lambda\,(\overline{\Lambda})$ mass peak used in the Ξ reconstruction; the arrows show the mass domain accepted in the selection; the resolution is $\sigma_\Lambda = (1.722 \pm 0.137)$ MeV/c^2 (a). The prompt $\Xi^\pm$ mass peak; the resolution is $\sigma_\Xi = (3.235 \pm 0.235)$ MeV/c^2 (b).

IV.2. Efficiency and corrections

We apply this selection to the minimum bias Monte Carlo (MC) data in order to correct for the reconstruction efficiency for the Ξ of both charges and for the two polarities of the magnetic field; this efficiency is defined as :

$$\epsilon_i = \frac{N_i(\Xi^\pm \to \Lambda\,(\overline{\Lambda})\pi^\pm)_{reconstructed}}{N_i(pp \to \Xi^\pm X)_{generated}}$$

The "efficiency" does therefore include the acceptance; the subscript "i" refers here to the rapidity bin that we are considering. We did not observe any dependence of the efficiencies upon the direction of the magnetic field. The ratio of these efficiencies will be used to correct the raw ratio Ξ^+/Ξ^-.

A final correction that can be applied to the results is the efficiency of selecting prompt Ξ from LHC collisions, i.e. not coming from decays. A cumulative lifetime cut on their ancestors $\sum c\tau < 10^{-9}$ m has been applied to remove almost the Ξ coming from weak decays. Only the decay which can affect the prompt Ξ selection is $\Xi^\star(1530) \to \Xi\,\pi$; fortunately, the decay of these hyperons will give as much Ξ^+ as Ξ^-, thus do not affect the production ratio of anti-hyperons to hyperons. We can therefore conclude that the non promt fraction of Ξ hyperons in our selection is less than 1% (Table 1).

In LHCb, the two protons beam collide with an angle meant to compensate for the influence of LHCb's magnetic field. The absolute value of the crossing angle depends on the beam energy : $\theta = 270\ \mu$rad in the x-z (horizontal) plane for 7 TeV collision energy. The Center of Mass (CM) rapidity of a particle is then calculated as

$$y^\star = \frac{1}{2} \ln \frac{E^\star + p_L^\star}{E^\star - p_L^\star}$$

Table 1. *Ancestors of the* $\Xi^{\pm}$*. The requirement* $\sum c\tau < 10^{-9}$ *m do select the prompt hyperons, leaving decays of* $\Xi^{\star}(1530)$ *which give the same amount of* Ξ^{+} *and* Ξ^{-} *and thus do not affect the production ratio* Ξ^{+}/Ξ^{-}*.*

Mother particle	$c\tau$ (m)	Fraction in acceptance (%)
Primary vertex	0	89.3
$\Xi^{\star}(1530) \to \Xi\,\pi$	10^{-14}	10.3
$\Xi_c^0 \to \Xi\,\pi$	$3.36\ 10^{-7}$	0.245
$\Omega \to \Xi\,\pi^0$	$2.46\ 10^{-2}$	0.115
$\Omega_c \to \Xi^-\,K^-\,\pi^+\,\pi^+$	$2.1\ 10^{-7}$	0

where $E^{\star}$ and $p_L^{\star}$ are the CM energy and longitudinal momentum of the particle; the colliding beam having a crossing angle, their CM values are $E^{\star} = E - \theta p_z$ and $p_L^{\star} = p_z - \theta E$.

IV.3. Systematics

Our analysis relies upon LHCb Monte Carlo; therefore, the corrections discussed in the previous section may be biased by the choice of the generator tuning and of the interaction models for the created particles. However, extensive studies done for the determination of the prompt $\overline{\Lambda}/\Lambda$ ratio have shown that the ratio of these anti-hyperons to hyperons is affected by the choice of the generator tuning to less than 0.01 and to 2% the systematics relative to the particle interactions with the material [3]. For the Ξ^{+}/Ξ^{-} ratio, we put the same upper limits to the systematics affecting this ratio.

The diffractive events are obviously not favored by the LHCb reconstruction, due to a low efficiency in detecting diffractive primary vertices with fewer tracks. Diffractive events account for about 25% of the MC generated collisions but only about 3% are seen in the reconstructed events. This indeed depends on the diffractive model used in the MC, but for the anti-hyperons to hyperons ratio the uncertainty on the correction should not exceed 2% [3].

Particle interactions with the LHCb detector material are simulated using the GEANT package, where interaction cross-sections for each particle as described in the LHEP physics list (see for example [5], [6] and references therein). We do not expect that material interactions have a large effect on the anti-hyperon to hyperon ratio as particle absorptions and interactions cross sections have been carefully tested. An upper limit for the uncertainty on the ratio can be put at 2%.

Summing up all these uncertainties gives an upper limit of the systematic error of 3.5%.

V. RESULTS

As no difference in the selection efficiencies is observed between B field up and B field down MC samples, the data sets corresponding to the two magnetic polarities are merged and the Ξ^{+}/Ξ^{-} ratio is calculated and corrected for the acceptance and efficiency and for the tiny non-promt contamination. Due to the size limit of our data sample, we present the Ξ^+/Ξ^- ratio in three bins in y, where integration was take over possible p_T range covering the domain 1 GeV/c $\leq p_T \leq$ 3 GeV/c.

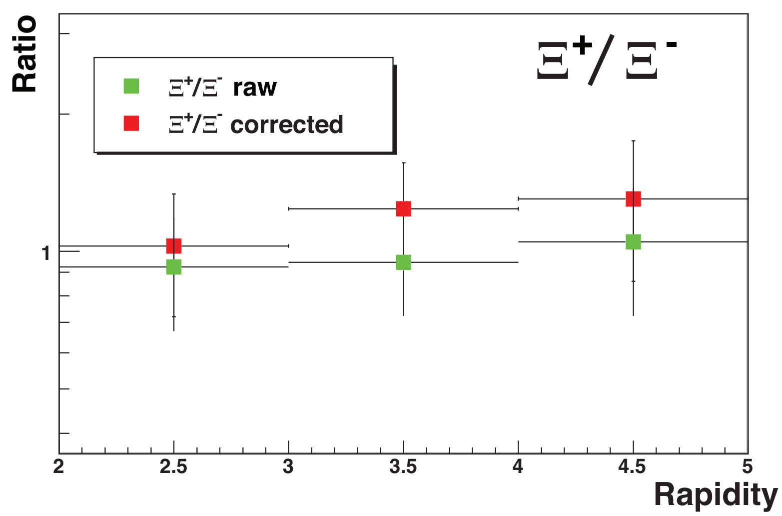


Fig. 4. Ξ^+/Ξ^- *ratio before and after the efficiency and acceptance correction as a function of the CM rapidity.*

Our results are shown in Table 2 and in Figure 4. Our results lie in the domain 0.8 - 1.0 within the errors and are mainly dominated by the statistical errors, both in the number of selected events and in the determination of the efficiency. From this data sample, we cannot show any trend on the anti-hyperons Ξ^+ to hyperons Ξ^- ratio as a function of the CM rapidity.

Table 2. Ξ^+/Ξ^- *ratio in three CM rapidity bins. The results are integrated over our* p_T *domain. The value of the efficiency and acceptance correction is also given.*

	1.9< y < 3	3< y < 3.5	3.5< y < 4.9
Ξ^+/Ξ^- raw	0.9259 ± 0.2569	0.9459 ± 0.223	1.05 ± 0.328
Ξ^+/Ξ^- corrected	1.028± 0.3076	1.24± 0.3239	1.305± 0.444
correction (ϵ^-/ϵ^+)	1.111 ± 0.1242	1.319± 0.1483	1.243± 0.1686

An enough statistics is therefore necessary to study the anti-hyperons to hyperons ratio not only as a function of y, but also as a function of p_T; this will be our next goal. An extension of this study to Ω hyperons is also foreseen as the statistics will not be a limiting factor in LHCb.

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