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LHCb physics with the first 10 - 20 pb^{-1} of data

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The LHCb experiment, designed for CP violation and rare decay studies in the heavy quark sector, will also give an important contribution to the study of inclusive particle production at LHC energies. Due to the unique pseudorapidity region covered by the LHCb detector, $\eta = (1.8, 4.9)$, which is complementary to the central detectors, the analysis of the first 10 - 20 pb^{-1} of data will already bring an unique insight into strangeness and charm production mechanisms. The excellent vertexing and tracking capabilities allow precise measurements of the inclusive production of K_S, Λ, D^0, and J/ψ. In addition J/ψ polarization and quarkonia can be studied in a kinematical range where QCD models diverge considerably, as they have been extrapolated not only in energy but also in pseudorapidity.

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1. Introduction

LHCb is a dedicated b-physics experiment [1] for high precision studies of CP violation and rare decays. Given the large and correlated $b\bar{b}$ quark production in the forward region, the detector is designed as a single arm spectrometer with a coverage of 15-300 mrad. At the time of this conference, the LHCb detector was fully installed and we were waiting eagerly for the start of data taking. Details on the detector design and its status in Autumn 2009 can be found in [2, 3].

Interesting physics analyses are already envisaged after the collection of the first 100M minimum bias (MB) events, after 2-3 days of running. This assumes stable colliding beams with a centre of mass energy $\geq$ 4 TeV will be available, and that the detector will be fully powered and in stable running conditions. The first 10-20 pb^{-1} of data will allow study of the multiplicity and the kinematic distribution of all charged tracks, strangeness production, first charm signals, J/ψ production and polarization, and the study of charmonia.

The inclusive production studies will not only contribute to QCD physics studies but they will also help to understand and calibrate the detector, and to tune and validate the Monte Carlo (MC) simulations. They can also be used as a stepping stone towards the reconstruction of interesting charm and beauty hadrons that have K_S, Λ, J/ψ, D^0 as daughters. In particular, LHCb can bring very important contributions to charm and beauty baryon studies, since beauty baryons were energetically out of reach for the b-factories. Studies of inclusive distributions with LHCb are particularly interesting given the unique angular coverage. While the tracking and muon systems of ATLAS and CMS cover a pseudorapidity (η) range of $|\eta| < 2.5$ and ALICE $|\eta| < 1.6$ and $2 < \eta < 4$ (muon detector only), LHCb is fully instrumented for $1.8 < \eta < 4.8$, allowing inclusive production studies in a region complementary to the central detectors. The small overlap of the η ranges makes a good case for cross-experiment studies and for a common effort in understanding the first data and tuning and validating the MC simulations for the LHC collision energies.

For the very first analyses proposed here, we plan to rely only on the information provided by the LHCb tracking detectors: the Vertex Locator (VELO) and Inner and Outer Tracker [2, 3]. The same data will also be used for the particle identification (PID) calibration using very clean samples of Λ, K_S, D^*, and later J/ψ. We plan to use only tracks that cross both the VELO and the main tracking stations (Inner or Outer Tracker), i.e. the highest quality tracks with good impact parameter and momentum resolution.

In the first days of running, random triggers or MB triggers will be used rather than the standard LHCb trigger system described in [4]. The MB trigger will use cuts on the Scintillator Pad Detector (SPD) multiplicity if at start-up we have only very low multiplicity events, on the sum over highest E_T 2$\times$2 clusters in the Hadron Calorimeter (HCAL), on the largest E_T hadron, or on information given by the Electromagnetic Calorimeter (ECAL). All these categories of cuts, applied independently or in various combinations, will allow us to keep mostly the non-inelastic, non-diffractive, events. Possible trigger cuts are shown in Figure 1.

2. Charged particle kinematic distributions

Most of the theoretical models describing pp interactions were tuned on Tevatron data. In some cases LEP and SPS data were also used, or extrapolations to STAR data performed. The

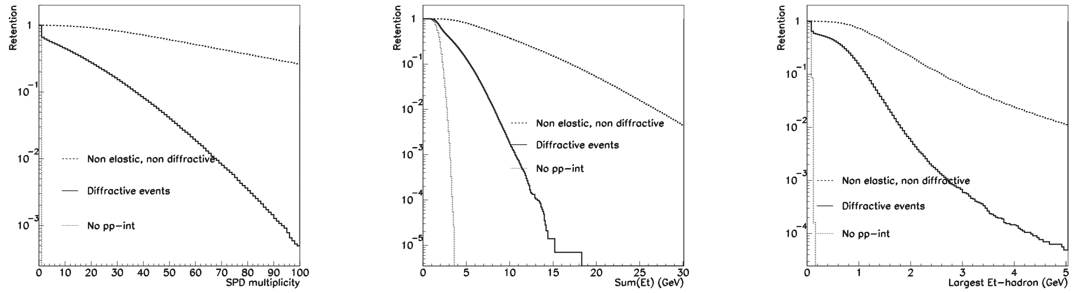

Figure 1: Possible trigger cuts used to discriminate between different types of interactions, Left: SPD multiplicity, Centre: sum over highest E_T 2×2 clusters in HCAL, Right: largest E_T hadron in HCAL.

agreement between models is broken at the LHC due to different energy extrapolations. The models disagree even more in the LHCb kinematical region after additional η extrapolation. Even the measurement at LHCb of basic distributions such as charged particle multiplicity can help towards understanding of charge asymmetries or to discriminate between different QCD models [5]. Measurements will also help to tune the MC simulation both at the generator and at the detector level.

Given that the LHCb detector will take data at a completely new energy and in a unique rapidity range, single and double differential kinematic distributions and their ratios, measured for all charged particles, or separately for positive and negative charged particles, will provide interesting information. Measurements include:

$$\frac{dn}{dX}, \quad \frac{dn^+/dX}{dn^-/dX}, \quad \frac{dn^+/dY}{dn^-/dY}, \quad \frac{d^2n}{dX\,dY} \tag{2.1}$$

where X,Y = transverse momentum p_T, η, azimuthal angle ϕ in the laboratory system etc. Such measurements can be performed with very low integrated luminosity.

3. Strangeness production

The rules of fragmentation/hadronization are so far not fully understood, only phenomenological models being available. In the framework of PYTHIA - the most frequently used simulation program in particle physics [6] - there are several models/tunings available [5]. Studies of strangeness production at the LHC will provide an invaluable input for QCD studies, as the absence of valence strange quarks in the initial state makes strangeness production an excellent probe of the fragmentation field. Different fragmentation models, tuned on Tevatron data, agree on the total amount of strangeness produced but disagree on its distribution over phase space and on the ratios of the strange hadrons produced. LHCb is particularly interesting for model-dependent QCD studies since one can measure the production of strange quarks in an η range where models are expected to diverge more than for central pseudorapidities. Interesting distributions are the ratio of K_S to the total charged particle multiplicity vs. η, the strange meson/baryon ratio vs. p_T and the antibaryon/baryon ratio vs. η. We refer in first data mainly to ratios since most systematic uncertainties cancel and no luminosity measurement is needed. In what follows we shall use the $\bar{\Lambda}/\Lambda$

ratio as a function of η as a case example, see Figure 2. Here such ratios for prompt baryons (i.e. produced at the primary vertex or originating from electromagnetic or strong decays of particles produced at the primary vertex) from non-diffractive events are represented. The different distributions were obtained by consistently varying PYTHIA parameters related to parton distribution functions, initial state radiation, final state radiation, beam remnants, hadronization, underlying event, color reconnection (see [5]), in addition to the LHCb tuning and simulation framework. It can be seen that LHCb will discriminate between the models due to the up to 5% differences in the LHCb kinematic region as opposed to only 1% for the region covered by the central detectors.

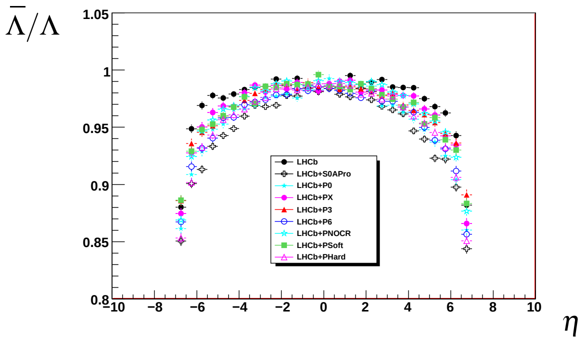

Figure 2: The $\bar{\Lambda}/\Lambda$ ratio as a function of η, for promptly produced baryons coming from non-diffractive events. The different distributions have been obtained by consistently varying PYTHIA parameters in addition to the LHCb tuning.

The first 100M MB events of LHCb data will be exploited for strangeness production studies. A procedure has been designed to select prompt V^0s produced in non-diffractive pp interactions. We reconstruct the decays $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$ and $K_S \to \pi^-\pi^+$ with protons and pions which give well defined tracks, i.e. tracks that cross all tracking detectors. Our main discriminating variable is v_1[1] defined as:

$$v_1 = \ln \frac{IP_p IP_\pi}{IP_\Lambda} \ \text{ for } \ \Lambda, \qquad v_1 = \ln \frac{IP_{\pi^+} IP_{\pi^-}}{IP_{K_S}} \ \text{ for } \ K_s, \tag{3.1}$$

where IP_p, IP_π are the impact parameters of the daughter particles and IP_Λ, IP_{K_S} are the impact parameters of the V^0 candidates, all with respect to the primary vertex. As one can see in Figure 3, this variable separates very well the V^0 signals from the background in $\sqrt{s}$=10 TeV pp collisions. The cut values of 2 ln(mm) for K_S and 2.5 ln(mm) for Λ were chosen to maximize the significance in five equal η bins between 2.5 and 5.0. The range of p_T and η covered by our selected V^0 samples is also shown in Figure 3, and in Table 1 the candidate sample composition is shown[2]. For the Λ, the background is almost equally distributed between candidates not matched to a true MC particle (combinatorial background, clones, ghosts) and K_S decays misidentified as Λ or $\bar{\Lambda}$'s. For the K_S the main background contribution comes from candidates not matched to a true MC particle (combinatorial background, clones, ghosts). The K_S contamination in the Λ candidate sample can be reduced by attributing to both particles the pion mass and removing all the combinations that peak at the K_S mass, or by the use of Armenteros-Podolanski diagrams [7]. From fits of the mass

[1] An alternative selection using a multivariate analysis is also available.

[2] The diffraction contamination was evaluated using PYTHIA 6.

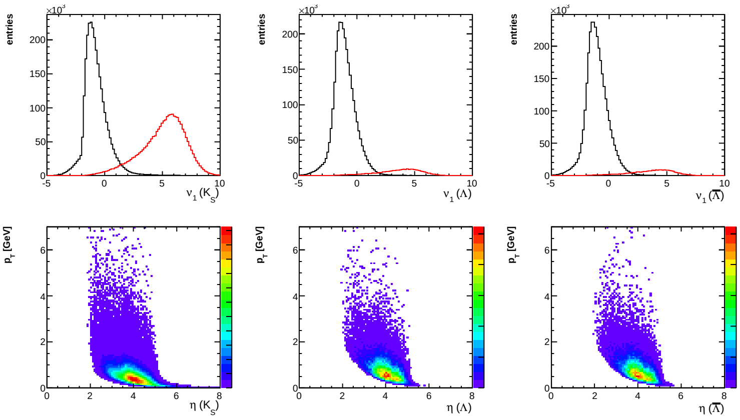

Figure 3: Top: v_1 as a discriminating variable: red - true V^0 candidates (multiplied by seven), black - background. Bottom: η and p_T coverage for the selected V^0, for simulated $\sqrt{s}$=10TeV pp collisions.

Candidates	Λ and $\bar{\Lambda}$	K_S
Mass window	$\pm$ 7MeV	$\pm$ 15 MeV
V^0 prompt non-diff.	73%	84.6%
V^0 non-prompt non-diff.	2.4%	1.4%
V^0 diff.	2.8%	4.5%
V^0 detector interaction	0.03%	0.23%
Background	21.7%	10%

Table 1: Relative contributions within selected V^0 candidate mass windows.

Efficiency contributions	Λ and $\bar{\Lambda}$	K_S
Decay mode	63.9%	69.2%
Two tracks in acceptance	20.3%	21.7%
Two reco. tracks	3.7%	8.0%
Selection	72.0%	89.0%
Total	0.3%	1.2%

Table 2: Efficiency contributions with respect to 4π acceptance.

plots in each η bin, we determine the yield and consequently the efficiency, shown in Figure 4. The contributions to the total efficiency are given by the branching fraction, the finite acceptance of the detector, the reconstruction efficiency, the requirement for high-quality daughter tracks crossing all the tracking detectors and the kinematic selection. The efficiency is estimated as 1.2% for K_S and 0.3% for Λ and $\bar{\Lambda}$ and given in Table 2[3]. The average efficiency between $2.5 < \eta < 5$, is 2.76% for

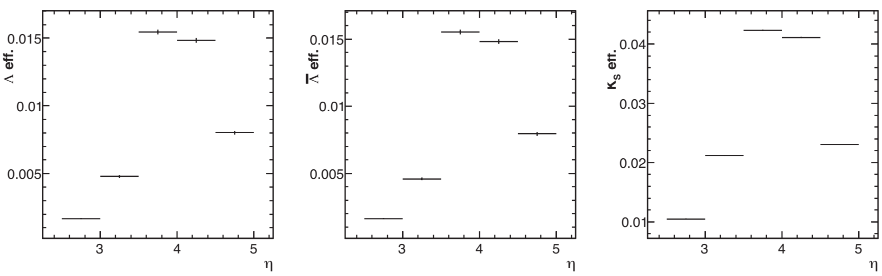

Figure 4: From left to right: Λ, $\bar{\Lambda}$ and K_S efficiency as a function of η.

[3]From Monte Carlo simulation, the efficiency is found to be approximately the same for Λ $\bar{\Lambda}$ when the protons/anti-protons from the baryons are energetic, $>$ 10 GeV/c.

η bin	stat. errors
(2.5, 3.0)	1.4%
(3.0, 3.5)	0.8%
(3.5, 4.0)	0.5%
(4.0, 4.5)	0.5%
(4.5, 5.0)	1.1%

Table 3: The expected statistical error on the $\overline{\Lambda}/\Lambda$ ratio, for each bin considered in η.

K_S and 0.89% for Λ and $\overline{\Lambda}$. The expected statistical error (corrected for efficiency) is presented for the $\overline{\Lambda}/\Lambda$ ratio, extrapolated to 100M events - corresponding to first data. In Table 3 one can see that LHCb, with 100M events, can discriminate between models [5] corresponding to the distributions in Figure 2. Systematics and methods to correct for small contaminations of non-prompt V^0s and V^0s coming from diffractive events are under study.

4. D-meson production

We plan to look for charm signals in the first MB events, by reconstructing $D^0 \to K^-\pi^+$ and $D^\pm \to K^\mp\pi^\pm\pi^\pm$ decays. The analysis methodology is similar to the one for the V^0 analysis: minimal detector requirements (VELO and Tracker), no particle identification and geometry and kinematic variables for the selection. Again, particle ratios will be considered since systematics cancel. Alternatively a multivariate analysis method can be used to reduce the background. About 2k particles for each studied charm species are expected to be reconstructed in 100M MB events. The mass distributions of D^0, D^+ and D^- are shown in Figure 5. Overall efficiencies for D signals

ratio	selection	value	stat error 100 M events
$\bar{D}^0/D^0$	cut-based	1.19 ± 0.26	7 %
$\bar{D}^0/D^0$	multivariate analysis	1.35 ± 0.20	5 %
D^-/D^+	cut-based	1.38 ± 0.23	6 %

Table 4: Ratios of the reconstructed charm mesons.

are about 0.1%. The ratios not efficiency corrected can be found in Table 4.

5. J/ψ production

Given the large cross-section for J/ψ production, a significant data sample will be available in the first days of LHC running. We plan to use the J/ψ sample to measure the cross section for both the prompt J/ψ and $b\bar{b}$ production. These cross-sections are important for later analysis

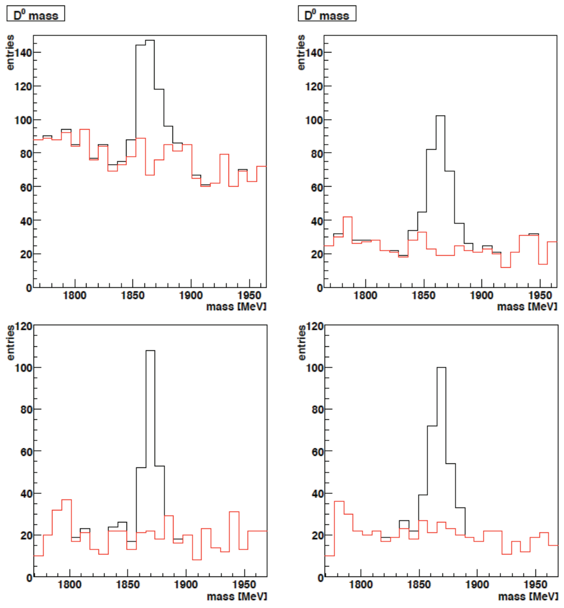

Figure 5: Reconstructed D mesons in 9.5M MB events with 2<rapidity<4.5 and p_t <12 GeV; red background, black signal. Top left $D^0 \to K^-\pi^+$, cut based analysis; Top right multivariate analysis; Bottom left $D^+ \to K^{\mp}\pi^{\pm}\pi^{\pm}$ cut based analysis; right: $D^- \to K^{\pm}\pi^{\mp}\pi^{\mp}$, cut based analysis.

steps to assess the event yields, understand muon trigger rates and constitute a necessary input for branching fraction measurements.

The study of prompt J/ψ production is interesting as the process is not yet completely understood. Non-relativistic QCD, if colour octet terms are taken into account [8], reproduces the p_T spectrum and the cross section measured at the Tevatron [9, 10]. However it does not reproduce the production polarization where the increase of the transverse polarization with p_T is not observed. Other models also predict correctly the p_T spectrum but not the polarization. Further cross-section and polarization measurements are necessary to discriminate between the models and hence to understand charmonium production, especially in LHCb which covers the not-yet-investigated forward region. With an integrated luminosity of 5 pb^{-1} at $\sqrt{s} = 8$ TeV, we expect to reconstruct about 3M J/ψ mesons. Figure 6 (left) shows the J/ψ signal obtained from 19M MB events. To separate the prompt J/ψ and the J/ψ originating from b decays, we will use the discriminant variable t defined as:

$$t = \frac{dz}{p_z^{J/\psi}} m^{J/\psi}, \tag{5.1}$$

where dz is the distance from the primary interaction vertex to the J/ψ decay vertex projected on the beam direction, $p_z^{J/\psi}$ is the projection of the J/ψ momentum onto the same direction, and $m^{J/\psi}$ is the reconstructed J/ψ mass. Figure 6 (right) shows the t distributions for both the prompt J/ψ and J/ψ originating from b quark decay.

The large statistics available means that measurement errors will be dominated by systematic uncertainties. Toy MC studies have been made to check how the presence of J/ψ polarization in

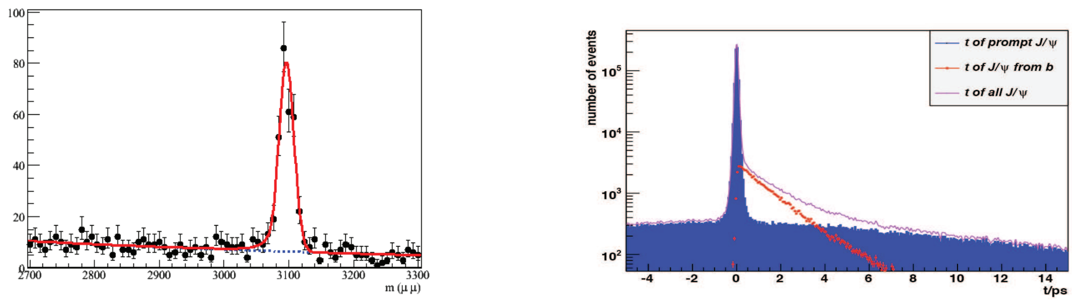

Figure 6: Left: J/ψ mass distribution for 19 M MB events. The mass resolution is about 11 MeV/c^2. Right: the distribution of the discriminant variable t for prompt J/ψ and J/ψ from b decays.

the $J/\psi \rightarrow \mu^+\mu^-$ decay, defined as:

$$\frac{dN}{dcos\theta} \propto 1 + \alpha \cos^2\theta, \tag{5.2}$$

influences the results of the cross-section measurement. Here θ is defined as the angle between the momentum of μ^+ in the J/ψ centre of mass system $p_{\mu^+}^{CM}$ and the direction of the momentum of the J/ψ in the laboratory system, boosted to the centre of mass system of the J/ψ. It has been demonstrated that the LHCb geometry will induce a fake J/ψ polarization, as can be seen in Figure 7. Here is shown the $\cos\theta$ distribution obtained in four different cases, where muons from J/ψ are emitted in 4π, or the geometrical acceptance of the two μ is restricted. Also, if the

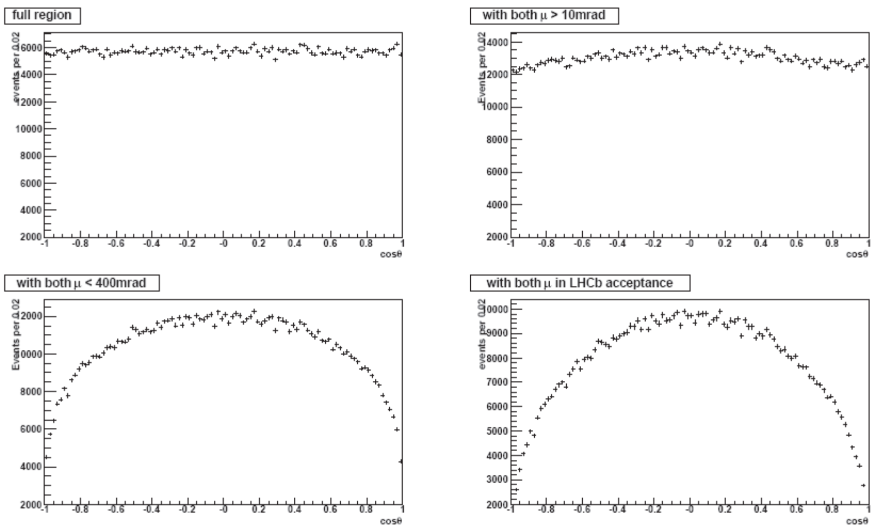

Figure 7: Fake polarisation introduced by the LHCb acceptance. The four plots show the $\cos\theta$ distributions, in different conditions. Muons from J/ψ are emitted in 4π, or where the geometrical acceptance for the muons is restricted.

polarization α is assumed to have an incorrect value, this introduces a systematic error up to 25 % in the cross-section calculation, demonstrated in Table 5.

input α	input $\sigma(nb)$	$\sigma(nb)$ measured assuming α=0
0	4340	4337.3 $\pm$ 7.7
+1	4909	4305.4 $\pm$ 7.7
-1	3518	4383.0 $\pm$ 7.9

Table 5: Systematic error introduced if the polarization is not taken into account. α=+1 transverse polarisation, α=-1 longitudinal polarization and α=0, no polarization.

Finally, a number of other studies can be performed with the first 10-20 pb^{-1} of data. These include measurements of the production and polarization of $\psi(2S)$ using the decay mode $\psi(2S) \rightarrow \mu^+\mu^-$, a study of the $\psi(2S)$ to J/ψ production ratio, measurement of χ_c production in $\chi_c \rightarrow J/\psi\gamma$, bottomonium production and spectroscopy, $\Upsilon(1S,2S,3P) \rightarrow \mu^+\mu^-$, $\chi_b \rightarrow \Upsilon\gamma$ and study of exotic X, Y, Z states. More details on the J/ψ cross-section measurements and quarkonia studies at LHCb can be found in [11].

6. Summary

The LHCb experiment is ready to exploit the first minimum bias data. Very interesting physics studies are planned including preliminary tests of future charm and beauty benchmark channels, strangeness production, D-meson production ratios, J/ψ production and polarization and quarkonia studies. LHCb will take advantage of the experiment's unique kinematical range, complementary to the central LHC detectors.

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