Frascati Physics Series Vol. VVVVVV (xxxx), pp. 000-000
Frontier Science – Frascati, Oct. 6-11 , 2002
Invited Talk in Plenary Session

B PHYSICS AT THE LHC

Neville Harnew.
University of Oxford, Oxford OX1 3RH, UK.

ABSTRACT

The CP-reach of the LHCb, ATLAS and CMS experiments is reviewed. A summary is given of the measurement of the unitarity triangle angle γ in a number of complimentary channels.

1 Introduction

Prior to 2007, BaBar, Belle, CDF and D0, will make first measurements of the parameters of the unitarity triangle. The quantity $\sin(2\beta)$ will be well measured in the "gold plated" $\mathrm{B_d^0} \to \mathrm{J}/\psi \mathrm{K_s^0}$ channel, perhaps to a world precision exceeding $\sim$0.02. The sides $|V_{td}/V_{ts}|$ and $|V_{ub}/V_{cb}|$ will be known from $\mathrm{B_s^0} - \overline{\mathrm{B}}_\mathrm{s}^0$ mixing and from $b \to u$ decays, respectively, but limited by theory to between 5–10%. The quantity $\sin(2\alpha)$ will be measured but with poor statis-

Table 1: Comparison of the LHC experiment parameters.

	LHC	
Energy / collision mode	14 TeV pp	
$b\bar{b}$ cross section	$\sim$500 μb	
Inelastic cross section	80 mb	
Ratio $b\bar{b}$ / inelastic	0.6%	
Bunch spacing	25 ns	
	LHCb	ATLAS / CMS
Detector configuration	Single-arm forward	Central detector
Running luminosity	2×10^{32}cm^{-2}s^{-1}	$\leq1\times10^{33}$cm^{-2}s^{-1}
$b\bar{b}$ events per 10^7 sec	$1\times10^{12}\times$ accept.	$\leq5\times10^{12}\times$ accept.
<Interactions/crossings>	0.5 ($\sim$30% single int.)	$\sim$2.3

tical precision, perhaps to $\sim$0.1. There will be no significant measurement of the angle γ.

The LHC will provide an unprecedented source of B hadrons, delivering of the order of 10^{12} $b\bar{b}$ pairs per year (10^7s). Precision measurements can be made of CP violation in many rare decay channels, including the B_s^0 sector. This will enable several redundant measurements of the angle γ to be made. A comparison of the LHC experiment parameters is given in Table 1.

2 The LHC Experiments

2.1 The LHCb Experiment

The LHCb detector [1] is a single-arm dipole spectrometer, which exploits the sharply peaked forward-backward $b\bar{b}$ production cross section. It runs at a tuned LHC luminosity of 2×10^{32}cm^{-2}s^{-1}, which maximizes the number of single interactions per beam-crossing. The detector covers a forward angular aperture between approximately 10 and 250 mrad (300 mrad) in the non-bending (bending) plane. Experimental attributes of LHCb include efficient K/π identification, excellent decay time and mass resolutions, and photon detection.

The detector has recently been reoptimized, resulting in less material and improved performance. The new layout of the LHCb experiment, the so-called "LHCb-Light" geometry, is shown in Fig. 1.

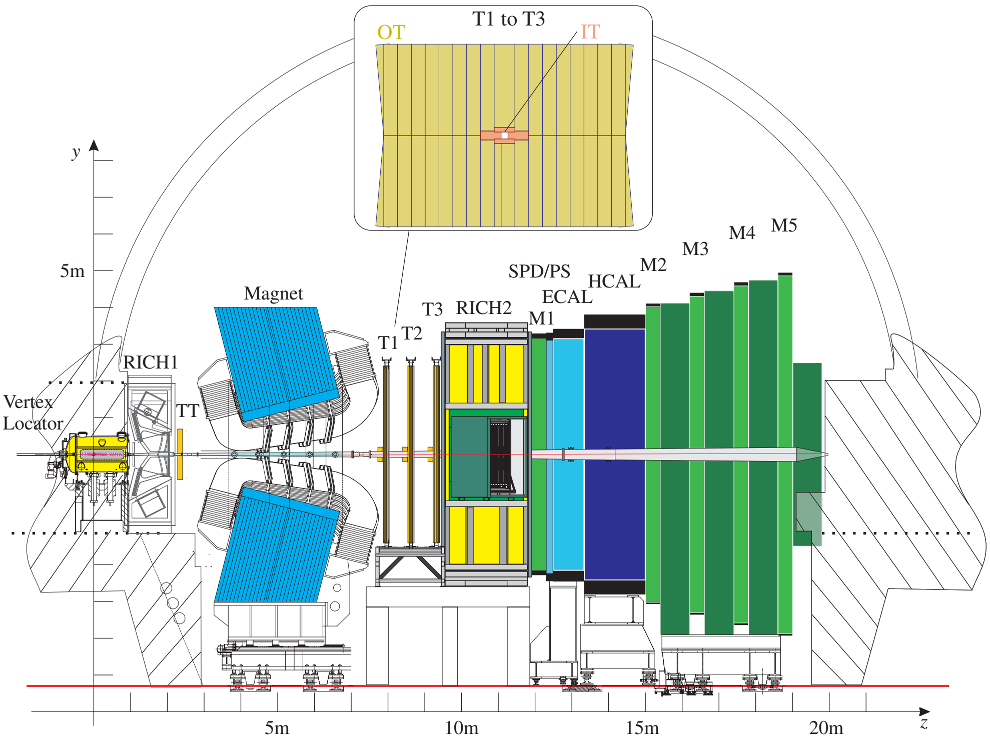

Figure 1: The optimized "LHCb-Light" spectrometer. The layout of the inner and outer regions of the T1–T3 chambers is highlighted.

- The Tracking System has undergone major revision. Nine tracking stations have been reduced to four, resulting in a reduction of the material budget from 0.27 X_0 (0.11 λ_0) to 0.12 X_0.

- The removal of shielding plates in front of the magnet gives ~0.1 T of fringe field in the region of RICH-1, which necessitates a new "vertical" RICH-1 layout with a two-mirror reflective geometry.

- The fringe field in the region between the Vertex Locator (VELO) and the magnet allows a momentum measurement at the Level-1 trigger. This gives a more efficient rejection of fake vertices which result from secondary interactions. At a 40 kHz output rate, the new Level-1 design gives a preliminary efficiency for $B_d^0 \to \pi^+\pi^-$ events better than 85%.

2.2 The ATLAS/CMS Experiments

The ATLAS [2] and CMS detectors [3] have tracking coverage in the central rapidity region, $|\eta|$ <2.5 and include pixel microvertex layers at a radius of ~5 cm. Specialist B triggers which can operate up to luminosities of typically 1×10^{33} cm^{-2}s^{-1}, appropriate for the first 30 fb^{-1} of running (~3 years). However, there is current uncertainty on whether the data acquisition systems of the experiments will need to be staged and, if so, this would have a detrimental effect on the B physics capabilities.

The detectors have no dedicated hadronic particle identification capabilities. However the ATLAS TRD provides a dE/dx measurement giving limited K/π separation (~0.8σ). An event-by-event maximum likelihood technique can be made to identify B decays using the proper time, reconstructed mass and the K/π separation variable. Nevertheless, complete event analysis of B decay channels which require particle identification will be very challenging.

3 B physics performance

The CP physics reach of the LHC experiments in specific benchmark channels after a year of operation, together with the unitarity triangle parameters which they measure, is summarised in Table 2. The LHCb performance figures are prior to detector optimation, and are currently being re-evaluated for the new LHCb-Light geometry and the improved trigger.

3.1 Measurements of the angle γ with LHCb

A major strength of the LHC is that it provides a copious number of B_s^0 mesons. This allows the angle γ to be measured in a variety of complementary ways. Since particle identification and good mass resolution are essential, rigorous measurements of γ at the LHC are only possible with the LHCb experiment.

- The measurements of four time-dependent decay rates in the channels $B_s^0 \to D_s^{\pm}K^{\mp}$ and the charge conjugate states provide a theoretically clean measurement of the angle $(\gamma - 2\delta\gamma)$ [4]. LHCb will record ~2400 events per one year of running, giving a sensitivity of 3°–16° in $(\gamma - 2\delta\gamma)$.

Table 2: Performance summary of the LHC experiments in a selection of benchmark channels for one year of operation. The quoted numbers are the errors on the parameter in question, unless specified otherwise. A dash for an entry means that no significant measurement can be made.

Measurement	Channel	LHCb	ATLAS	CMS
$\sin(2\beta)$	$B_d^0 \to J/\psi K_s^0$	$0.3° - 0.5°$	$0.6°$	$0.7°$
$\sin(2\alpha)$	$B_d^0 \to \pi^+\pi^-$	$2° - 10°$	$3°$	$5°$
$\sin(2\alpha)$, $\cos(2\alpha)$	$B_d^0 \to \rho\pi$	$5° - 15°$	–	–
$2\beta + \gamma$	$B_d^0 \to D^\star\pi$, 3π	down to $7°$	–	–
$\gamma - 2\delta\gamma$	$B_s^0 \to D_s K$	$3° - 16°$	–	–
γ	$B_d^0 \to \overline{D}^0 K^{\star 0}$	$4° - 18°$	–	–
$\delta\gamma$	$B_s^0 \to J/\psi\phi$	$0.6°$	$0.9°$	
x_s	$B_s^0 \to D_s^-\pi^+$	< 90	< 46	< 48
Rare decay	$B_s^0 \to \mu^+\mu^-$	4.4σ S.M.	4.3σ S.M.	10σ S.M.

- The channels $B_d^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ provide a measurement of the angle γ via two time-dependent decay asymmetries [5]. The importance of particle identification and good mass resolution is demonstrated in Fig. 2. Approximately 5000 events are expected per year in each channel. The angle γ can be measured to a precision of 5°–10° after one year of running, limited by theoretical uncertainty.

- The channels $B_d^0 \to D^{\star\pm}\pi^\mp$ and the charge conjugate states provide a measurement of the angle $(2\beta+\gamma)$ via four time-dependent decay rates [6], with an expectation of ∼500 k events per year. The angle γ can be measured to a precision better than 5° after five years of running, assuming β is measured from $B_d^0 \to J/\psi K_s^0$ decays.

- The channel $B_d^0 \to \overline{D}^0 K^{\star 0}$ and the charge conjugate states provide a determination of the angle γ via a measurement of six time-integrated decay rates [7]. Since visible branching ratios are very small (10^{-8} – 10^{-7}), an annual yield of only 1700 events in all six channels is expected.

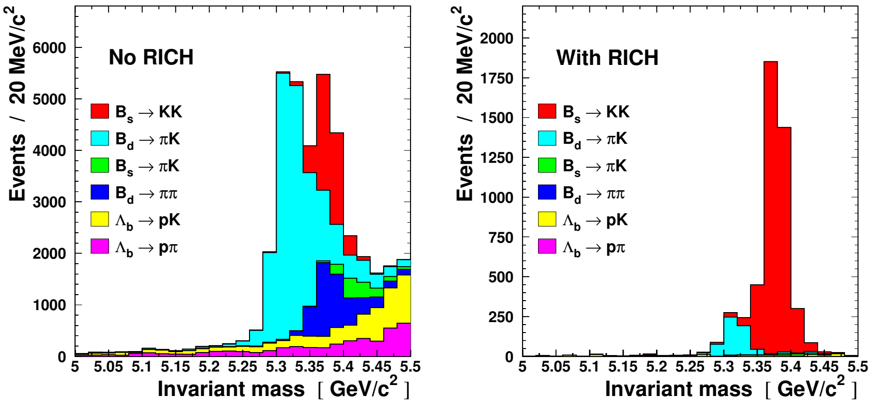

Figure 2: The B_s^0 mass peak from $B_s^0 \to K^+K^-$ combinations before and after particle identification criteria have been applied.

A measurement of the angle γ is possible to a precision of $\sim 10°$ after one year of running.

3.2 The $B_s^0 \to \mu^+\mu^-$ rare decay

The $B_s^0 \to \mu^+\mu^-$ channel is an example of a Standard Model rare decay process, with an expected branching ratio of $\sim 3.5\times 10^{-9}$ [8]. Here the high p_T di-muon triggers running at high luminosity (1×10^{34} cm^{-2}s^{-1}) give the general-purpose detectors a distinct advantage over the forward detector. With its excellent muon detection capability, CMS can observe an estimated 26 signal events with 6.4 events background for 100 fb^{-1} of running.

4 Summary

The LHC experiments will perform a study of CP violation with unprecedented precision in many different and complimentary channels. The LHCb detector provides good particle identification, vertexing, and has an efficient and flexible trigger. K/π particle identification will be essential for the measurement of B final states involving hadrons. ATLAS/CMS measure leptonic channels very well, but are not so competitive in hadronic modes. Construction of the detectors is progressing well and the LHC will be ready for data-taking in 2007.

Acknowledgments

I am very grateful to the following people who provided material for this review : Paula Eerola and Nick Ellis (ATLAS), Fabrizio Palla and Samim Erhan (CMS), and Tatsuya Nakada and Guy Wilkinson (LHCb). I also extend my thanks to the Symposium organizers, in particular to Franco Fabbri and Paolo Valente.

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