# ATLAS calorimeter capabilities for the observation of $B^0\_s, d \rightarrow J/\psi\eta$

F. Ohlsson-Malek

F. Ohlsson-Malek. ATLAS calorimeter capabilities for the observation of $B^0\_s, d \rightarrow J/\psi\eta$. International Conference on Hyperons, Charm and Beauty Hadrons 5 BEACH 2002, Jun 2002, Vancouver, Canada. pp.345-347. in2p3-00012324

## HAL Id: in2p3-00012324

## http://hal.in2p3.fr/in2p3-00012324

Submitted on 7 Feb 2003

# ATLAS Calorimeter capabilities for the observation of $\mathrm{B}^0_{\mathrm{s,d}} \rightarrow \mathrm{J}/\psi\eta$

F. Ohlsson-Malek[a]

[a]Institut des Sciences Nucléaires, IN2P3-CNRS
Université J. Fourier, F-38026 Grenoble, France

The observation potential of the decays $\mathrm{B}^0_{\mathrm{s,d}} \rightarrow \mathrm{J}/\psi\eta$ with the ATLAS detector at the LHC is presented. At present there exist only upper limits for the branching fractions, but at LHC, a clear signal for the decay mode $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta$ is expected. The branching fraction of this decay mode can thus be measured, and other parameters such as the mixing phase can be probed. The CP asymmetry predicted by the Standard Model is very small, and the observation of a sizeable effect would be a signal of physics beyond the Standard Model. The study presented here can also be regarded as an example of the physics prospects with $\eta$-mesons at the LHC [1].

## 1. Physics Interest

The decay $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta$ can be used to measure various parameters in the $\mathrm{B}^0_{\mathrm{s}}$-meson system. Compared to the analogous decay mode $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\phi$, the advantage of this decay mode is that it is a CP eigenstate. CP eigenstates can be separated by means of an angular analysis of the final state, but the a priori unknown strong phases between the eigenstates are extra free parameters in the analysis which have to be sorted out.

At present the upper limit for the branching fraction for $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta$ is $3.8{\cdot}10^{-3}$ at 90% CL [2,3]. The estimate for the branching fraction is (8.3-9.5) $\cdot 10^{-4}$ [4], where the uncertainty is coming from uncertainty in the $\eta - \eta'$ mixing angle.

It can be thus expected with the future LHC experiments that the measurements, of the branching fraction $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta$, of the $\mathrm{B}^0_{\mathrm{s}}$ lifetime and of the $\mathrm{B}^0_{\mathrm{s}}$ mixing phase $\Phi_M \propto \sin\gamma$, will be feasible.

The lifetime and mixing parameter measurements will be performed with other decay channels as well, so the measurements performed with the $\mathrm{J}/\psi\eta$ constitute an important cross-check. Eventually, a high-statistics measurement of the $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta$ branching ratio could allow imposing constraints on the $\eta - \eta'$ mixing angle.

The CP asymmetry in the decays with quark-level transitions $\bar{\mathrm{b}} \rightarrow \bar{\mathrm{c}}\mathrm{c}\bar{\mathrm{s}}$, including decays $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\phi$, $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{J}/\psi\eta^{(\prime)}$ and $\mathrm{B}^0_{\mathrm{s}} \rightarrow \mathrm{D}^+_{\mathrm{s}}\mathrm{D}^-_{\mathrm{s}}$, is predicted to be very small in the Standard Model. The time-dependent CP asymmetry for $\mathrm{B}^0_{\mathrm{s}}$ decay into a final CP eigenstate f is :

$$a_{CP}(t) = \frac{\Gamma(\mathrm{B}^0_{\mathrm{s}}(t) \rightarrow f) - \Gamma(\bar{\mathrm{B}}^0_{\mathrm{s}}(t) \rightarrow f)}{\Gamma(\mathrm{B}^0_{\mathrm{s}}(t) \rightarrow f) + \Gamma(\bar{\mathrm{B}}^0_{\mathrm{s}}(t) \rightarrow f)} \propto few\%$$

These decays are sensitive to processes beyond the Standard Model which typically increase the asymmetry. For example, in a left-right symmetric model with a spontaneous CP violation [5], the CP asymmetry may be as large as $\mathcal{O}(40)\%$, while the model predicts for the 'golden decay mode' $\mathrm{B}^0_{\mathrm{d}} \rightarrow \mathrm{J}/\psi\mathrm{K}^0_{\mathrm{S}}$ a 10% CP asymmetry.

## 2. Event reconstruction

The decays $\mathrm{B}^0_{\mathrm{s,d}} \rightarrow \mathrm{J}/\psi\eta$ were implemented in the Monte Carlo program PYTHIA 5.7 [6] in order to generate the signal sample. In the event generation, b-quark pairs were produced in pp-collisions at $\sqrt{s} = 14$ TeV either directly via the lowest order process, or via gluon splitting or flavour excitation.

Events containing a $\mathrm{B}^0_{\mathrm{s,d}}$ meson were selected, and then the $\mathrm{B}^0_{\mathrm{s,d}}$ was forced to decay into a $\mathrm{J}/\psi\eta$ final state. The $\mathrm{J}/\psi$ meson was forced to decay into $\mu^+\mu^-$, and only events passing the ATLAS level-1 trigger requirements for B hadrons (a muon with a $p_{\mathrm{T}} > 6$ GeV and $|\eta| < 2.4$) and the

$\eta$ meson decaying into $\gamma\gamma$ were retained[1]. Events were further selected to satisfy the ATLAS second level trigger: the presence of a second muon with $p_{\mathrm{T}} > 3$ GeV and $|\eta| < 2.5$.

The background considered was a sample of $\mathrm{B} \to \mathrm{J}/\psi\mathrm{X}$ decays, processed and selected in the same way as the signal events. The background from fake J/$\psi$'s is expected to be small when reconstructing B-mesons including J/$\psi$'s, and the background from primary J/$\psi$'s has been shown to be small when applying a cut on the decay vertex of the J/$\psi$ [7].

A full GEANT-based simulation was used to simulate the response of the ATLAS inner detector and the electromagnetic calorimeter. The muon chambers were not included in the reconstruction, but only real muons were included in the analysis. The muon identification efficiencies were assumed to be 85% and 78% for the first muon (the muon with a $p_{\mathrm{T}} > 6$ GeV) and the second muon (the muon with a $p_{\mathrm{T}} > 3$ GeV), respectively.

Electronic noise and pile-up corresponding to $\mathcal{L} = 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ were added to the electromagnetic calorimeter raw data at the reconstruction level as described in Ref. [8].

The ATLAS electromagnetic calorimeter (ECAL) is a LAr sampling calorimeter with three sampling layers [9]. The energy resolution is about $\sigma(E)/E = 10\%/\sqrt{E} \oplus 1\%$ ($E$ in GeV). The high-granular part of the ECAL extends up to $|\eta| < 2.5$, *i.e.* it has the same coverage as the Inner Detector. The basic cell is 0.025 in $\Delta\eta$ and 0.025 in $\Delta\phi$ in the second sampling layer. At the clusterization level, the algorithm uses a cell clusterization sliding window of 3x3 and a cell clustering energy threshold of 1 GeV. A cluster is defined as the shower sampling inside a window of 3x5 cells in the second ECAL layer.

An algorithm based on the selection of two highest transverse energy clusters was applied to reconstruct the $\eta$. Clusters originating from hadrons, background photons and noise were suppressed by special requirements [10].

After the cuts, the obtained mass distribution was fitted with two Gaussians, with widths 39 MeV and 227 MeV, see Fig. 1. The $\eta$-reconstruction efficiency was 2.3% within two standard deviations (±78 MeV) of the nominal mass, and the background was 24%.

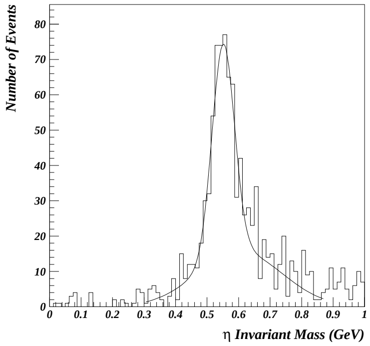

Figure 1. Invariant mass distribution of $\eta$-mesons in signal events after all the cuts.

## 3. Results and conclusion

The signal reconstruction efficiency was found to be 0.011 for the $\mathrm{B}^0_{\mathrm{s}}$ and 0.010 for the $\mathrm{B}^0_{\mathrm{d}}$. Taking an integrated luminosity of 30 fb$^{-1}$, the J/$\psi$ and $\eta$ branching fractions from Ref. [2], and the production cross-section and the kinematical acceptances from the Pythia event generator, the numbers of events as a function of the branching ratios calculated in Ref. [4] are given in Table 1.

| | $\theta_P = -10^o$ | $\theta_P = -20^o$ |
|---|---|---|
| $\mathcal{B}\mathrm{r}(\mathrm{B}^0_{\mathrm{s}} \to \mathrm{J}/\psi\eta)$ | $8.3 \cdot 10^{-4}$ | $9.5 \cdot 10^{-4}$ |
| $N^{\mathrm{obs}}_{\mathrm{Bs}}$ | 8 500 | 9 700 |
| $\mathcal{B}\mathrm{r}(\mathrm{B}^0_{\mathrm{d}} \to \mathrm{J}/\psi\eta)$ | $4.1 \cdot 10^{-6}$ | $1.6 \cdot 10^{-6}$ |
| $N^{\mathrm{obs}}_{\mathrm{Bd}}$ | 200 | 80 |
| $N^{\mathrm{obs}}_{\mathrm{back}}$ | 10 800 | 10 800 |

Table 1
Estimated branching ratios for $\mathrm{B}^0_{\mathrm{s,d}} \to \mathrm{J}/\psi\eta$, and the numbers of signal and background events for an integrated luminosity of 30 fb$^{-1}$. $\theta_P$ is the $\eta - \eta'$ mixing angle, as estimated in Ref. [11].

Using the branching ratios with $\theta_P = -20^o$, the number of observed signal events would be

---

[1] Throughout this paper, the symbol $p_{\mathrm{T}}$ is used for the transverse momentum with respect to the beam direction, and $\eta$ for the pseudorapidity.

9 700 and 80 for $\mathrm{B_s^0}$ and $\mathrm{B_d^0}$, respectively. With $\theta_P = -10^o$, the numbers of observed signal events would be 8 500 and 200. In both cases, it is clear that the $\mathrm{B_d^0}$ signal cannot be observed. Using the estimates obtained from Pythia, the number of observed background events was 10 800. A signal-to-background ratio of about 1 :1 can be thus achieved for the $\mathrm{B_s^0}$ signal.

The mass distribution of the reconstructed $\mathrm{B_s^0}$-mesons and the background is shown in Fig. 2.

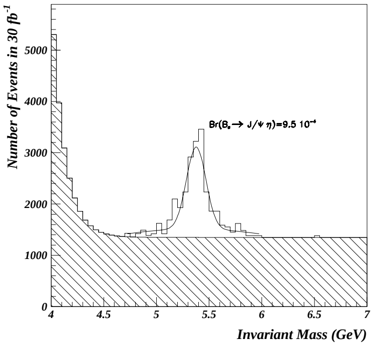

Figure 2. Invariant mass distribution of the reconstructed $\mathrm{B_s^0}$-signal and background (white histrogram) and the background (shaded) after all the cuts apart from the final mass cut. The background mass distribution has been smoothed due to the insufficient simulation statistics.

The observable asymmetry is $a_{\mathrm{obs}}(t) = Da_{CP}(t)$ where $D$ combines all the experimental dilution factors due to mistagging, decay time resolution, fit statistics and background. The asymmetry was then fitted. The error on the CP asymmetry can be approximated as :

$$\delta(\sin\phi_M) = \frac{1}{D_{\mathrm{tag}} D_{\mathrm{res}} D_{\mathrm{fit}} \sqrt{D_{\mathrm{back}}} \sqrt{N_{\mathrm{tag}}^{\mathrm{obs}}}},$$

and the values obtained are $\delta(\sin\phi_M) = 0.17$ for $x_s = 19$ and $\delta(\sin\phi_M) = 0.33$ for $x_s = 30$.

While the experimental resolution is not sensitive to the CP asymmetry of a few per cent, which is the case of the asymmetry predicted by the Standard Model, an asymmetry of 40%, as predicted by some models beyond the Standard Model, could be observed with a favourable combination of the $\mathrm{B_s^0}$ mixing parameter and the branching ratio.

ATLAS expects to carry out B-physics studies mainly in the first years of LHC operation, running at low luminosity $(1 - 2 \cdot 10^{33}\mathrm{cm^{-2}s^{-1}})$. A peak luminosity of $2 \cdot 10^{33}\mathrm{cm^{-2}s^{-1}}$ may be achieved in this period, which is a factor of two higher than previously assumed. The increase in pile-up, from about two to four events per bunch crossing, is not expected to have a major impact on B physics analysis in general and on our decay mode in particular. However, there are implications for the trigger which could be compounded by funding limitations for the initial system. In view of this, revised trigger algorithms or selection criteria (e.g. LVL2 trigger with $p_{\mathrm{T}}(2^{\mathrm{nd}}\mathrm{muon}) > 5$ GeV instead of 3 GeV) might have to be used causing some loss of efficiency.

The LHCb experiment will eventually be able to collect more statistics, since the forward spectrometer geometry with a long lever arm is more favourable for $\eta \rightarrow \gamma\gamma$ reconstruction. During five years of LHC operation, the LHCb is expected to collect an integrated luminosity of 10 $\mathrm{fb}^{-1}$, giving about 260 000 signal events in the $\mathrm{B_s^0}$ channel. The combined potential of the LHC experiments is thus very promising.

## REFERENCES

1. C.Driouichi et al., EPJdirect C N2 (2002) 1.
2. D.E.Groom et al., Eur. Phys. J. C15 (2000) 1.
3. M.Acciarri et al., L3 Coll., Phys. Lett. B 391 (1997) 481.
4. P.Z.Skands, JHEP 1 (2001) 8.
5. P.Ball and R.Fleischer, Phys. Lett. B475 (2000) 111.
6. T.Sjöstrand, Comp. Phys. Commun. 82 (1994) 74.
7. ATLAS Technical Design Report Vol II, CERN/LHCC/99–15 (1999).
8. S.Simion, ATL-SOFT-99-001 (1999).
9. ATLAS Calorimeter Performance Technical Design Report, CERN/LHCC/96–40 (1996).
10. F.Ohlsson-Malek and M.Melcher, ATLAS-PHYS-2001-023.
11. T.Feldman, Int.J. Mod. Phys. A15(2000)159.