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Early flavor physics at the LHC

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We discuss here the physics potential of the three LHC experiments ATLAS, CMS and LHCb for early flavor physics measurements.

1. The near future of B physics

After the very successful run of the B factories and of the Tevatron, the goal of heavy flavor physics (HFP) is now shifting from the understanding of the CKM paradigm with the Standard Model to the search for New Physics (NP) appearing in loop processes. The future goals of B physics, and in particular at hadron colliders, are a precise measurement of the γ angle of the unitarity triangle (UT) and the study of loop processes in $b \to s$ transitions such as hadronic penguin processes (e.g. $B_s^0 \to \Phi\Phi$), FCNC decays (e.g $B_s^0 \to \mu^+\mu^-$,$B_d^0 \to K^*\mu^+\mu^-$,$B_s^0 \to \Phi\gamma$) and mixing related observables such as Φ_s,$\Delta\Gamma_s$ (e.g. $B_s^0 \to J\Psi\Phi$).

2. Cross sections and running scenarios

The experiments which will study the b hadron decays at the LHC are ATLAS, CMS and LHCb, with only the third one being really optimised for it. ATLAS and CMS are central detectors covering the rapidity region $-2.5 < \eta < 2.5$ while LHCb is a single arm forward spectrometer covering the region $1.9 < \eta < 4.9$.

Three luminosity scenarios are considered in this paper: a commissioning run at $\sqrt{s} = 900$ GeV of few days, a first data taking period at $\sqrt{s} = 14$ TeV, corresponding to one hundreth of the nominal one year integrated luminosity (i.e. 20 pb^{-1} for LHCb and 100 pb^{-1} for ATLAS and CMS), and another period corresponding to one fourth of the nominal one year integrated luminosity (i.e. 0.5 fb^{-1} for LHCb and 2.5 fb^{-1} for ATLAS and CMS).

The $b\bar{b}$ cross section is large at both energies, i.e. 25 μb at 900 GeV and 500 μb at 14 TeV, but at 900 GeV the $b\bar{b}$ fraction to total inelastic events is a factor of ten smaller than at 14 TeV, where the inelastic cross section is 70 mb. The visible $b\bar{b}$ cross section in the ATLAS/CMS acceptance at 14 TeV is 100 μb while in the LHCb acceptance is 250 μb.

3. B triggers

ATLAS and CMS will dedicate a limited bandwidth to the b trigger, i.e 5 to 10% at low luminosity. ATLAS has two levels of trigger as CMS and LHCb do. The L1 hardware trigger of ATLAS aims at reducing the interaction rate to 100 kHz selecting muon pairs ($p_T > 6$ GeV) or single muons ($p_T > 20$ GeV). The high level trigger (HLT) aims at reducing the rate down to 100 Hz looking inside region of interests (ROI), as given by the L1 trigger, defined around e.m. objects or jets or, at very low luminosity, scanning through the full detector.

LHCb has also two trigger levels. The L0 is a hardware trigger, reduces the rate to 1 MHz and is based on cuts on trasnverse energy (single electrons and photons in the e.m. calorimeter and single hadrons in the hadron calorimeter) and transverse momentum for muons. A pile-up veto is also available, if requested, for rejection of multiple interactions. The HLT reduces the rate to 2 kHz and is based on alleys, i.e. partial reconstuction based on L0 confirmation.

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4. Physics at the commissioning run

At 900 GeV and very low luminosity (probably $10^{29} cm^{-2} s^{-1}$) the interaction rate will be very low (4kHz) and therefore data analysis will use only loose first level trigger cuts and the HLT will be used in pass through mode. Given the very low number of expected B events (a few J/Ψ per day) it likely that the main physics application will be some first tests of mass reconstruction.

5. Physics with one hundreth of the nominal one year integrated luminosity

The collected events will be used for the understanding of the detector, trigger, calibration, alignment, material, B field, reconstruction and particle identification (ID). The possibile physics studies will be:

- beauty production cross sections and $b\bar{b}$ correlations, production asymmetries; this is the subject of another paper at this conference [1]
- J/Ψ production both prompt and from beauty; both LHCb and ATLAS expect a number of events in excess of 10^6 from both sources
- reconstruction of some exclusive channels and measurements of the proper time distributions
- reconstruction of background or control channels for the most important b-physics measurements, some of which are listed in Table 1
- measurements of some branching fracions
- measurements of lifetimes, some of which, together with the expected precision, are listed in Table 2

6. Physics with one fourth of the nominal one year integrated luminosity

Some of the very first measurements will be most probably the reproduction/refinement of the main results from the B factories and the Tevatron:

- B_d^0 mixing phase Φ_d from $B_d^0 \to J\Psi K_S^0$
- B_s^0 mixing frequency Δm_s from $B_s^0 \to D_s \pi$
- B_s^0 mixing phase Φ_s and width difference between the two CP eigenstates $\Delta\Gamma_s$ from the untagged time-dependent measurement of the $B_s^0 \to J\Psi\Phi$ decay
- $\Delta\Gamma_s$ from lifetime measurements of decays to pure CP-even or CP-odd states such as $B_s^0 \to K^+K^-$ (CP even, measures Γ_L) and and to flavor specific decays such as $B_s^0 \to D_s \mu\nu$ (measures $< \Gamma >$)
- indirect CP violation in the semi-leptonic asymmetry A_{SL} with $B_s^0 \to D_s \mu\nu$

Other measurements will be a peculiarity of the LHC experiments due to the high statistics, high energy, good particle identification capabilities and good vertexing. A couple of golden measurements from B_s^0 physics are the search for $B_s^0 \to \mu\mu$ decay and the Φ_s measurement from tagged time-dependent measurements of $B_s^0 \to J\Psi\Phi$ decays, where large, of $\mathcal{O}(1)$ NP effects cannot yet be excluded. The Tevatron will run until 2009 with CDF and D0 being well understood detectors while LHCb can collect b statistics in a fast way.

6.1. Search for $B_s^0 \to \mu\mu$ decay

This is a very rare loop decay, sensitive to NP. The branching ratio (BR) in the Standard Model is expected be around $3.5 \cdot 10^{-9}$ and to be enhanced/suppressed in various extensions of the Standard Model. The current limit at 90% C.L. from CDF+D0 with 1fb^{-1} is now at 20 times the Standard Model expectation.

The main issue in this decay is background rejection; the indication is that at the LHC the background is dominated by random combinations of muons from the semileptonic b-hadron decays. Being the final state made of two leptons, the trigger for this channel will be very effective for the LHC experiments; the flavor tagging will not be necessary but very important for rejecting the combinatorial background are the vertex resolution and the mass resolution. Particle ID capabilities are essential to reject the topologically