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b PHYSICS AT LHC*

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Prospects for b physics study at LHC is described.

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1. Introduction

2008 is a historical year. The first collisions will be observed at the Large Hadron Collider (LHC). Four big experiments will take their first data. ATLAS and CMS are general purpose detectors. ALICE is build to study the heavy ion collisions. LHCb is constructed for precise measurement of CP violation and rare decays of beauty particles. Therefore this experiment is mainly described in this talk even if a possible contribution of ATLAS and CMS to b physics is not neglected.

Excellent results have been already obtained by the BELLE, BABAR, CDF and D0 Collaborations on beauty physics. These measurements gave coherent results as it can be seen in the combination obtained by the CKM-fitter group [1] and presented in Fig. 1. So far, there are no indications for New Physics (NP). However the effects of different NP models have been predicted by many theorists and their non-observation results in strong constraints on the parameters of these models.

The direct measurements of the three angles of CKM triangle are presented in the Table I together with the Standard Model prediction. The Standard Model predictions are obtained by the CKMfitter Group in a fit in which direct measurements of the angles are not used. It can be seen in the Table I that the γ angle is still not measured with significant precision. LHCb with 2 fb^{-1}, which is nominal one year luminosity of LHCb, will measure many parameters used in the CKMfitter compilation with higher precision and, therefore, will give more constraints on NP. Particularly, the three angles of CKM triangle will be measured with precision given in the

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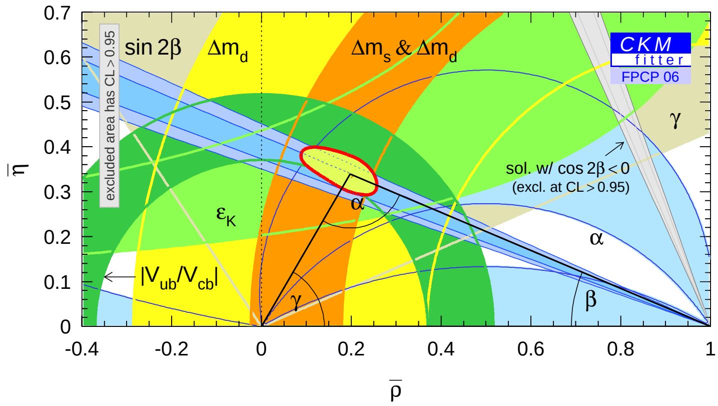

Fig. 1. Combination of measurements obtained by the CKMfitter group.

Table I. The measurement of γ will reach a precision of 5°. This angle will be measured in channels like ($B_s \to D_s K$) where the measurements are not effected by the NP contribution and in channels where they are ($B \to \pi\pi$, $B_s \to KK$, $B \to DK^*, \ldots$). Therefore LHCb will be able to determine contribution of NP to these measurements. Fig. 2 shows how CKMfitter group compilation could look like using LHCb measurements with 2 fb^{-1}.

TABLE I

Current precision of measurements of the three CKM angles and the estimated precision using LHCb measurements with 2 fb^{-1}.

CKM angle	Current value and precision	Standard Model prediction	LHCb 2fb^{-1}
β	$21.5^{\circ}{}^{+1.0}_{-1.0}$	$26.6^{\circ}{}^{+1.0}_{-3.8}$	$\pm 0.5^{\circ}$
α	$87.5^{\circ}{}^{+6.2}_{-5.3}$	$102^{\circ}{}^{+2.9}_{-12.6}$	$\pm 10^{\circ}$
γ	$76.8^{\circ}{}^{+30.4}_{-31.5}$	$67.6^{\circ}{}^{+2.7}_{-4.8}$	$\pm 5^{\circ}$

Rare decays, where Standard Model contributions are suppressed enough to allow potential small NP effects to emerge, are also very interesting to study. These measurements include:

- Very rare leptonic decays: *e.g.* $B_s \to \mu\mu$
- Rare semi-leptonic decays: $b \to sll$
  (*e.g.* $B_d \to K^{0*}\mu\mu$, $B_u \to Kee/B_u \to K\mu\mu$)
- Radiative decays: $b \to s\gamma$
  (*e.g.* $B_d \to K^*\gamma$, $B_s \to \phi\gamma$, $\Lambda_B \to \Lambda\gamma, \ldots$)

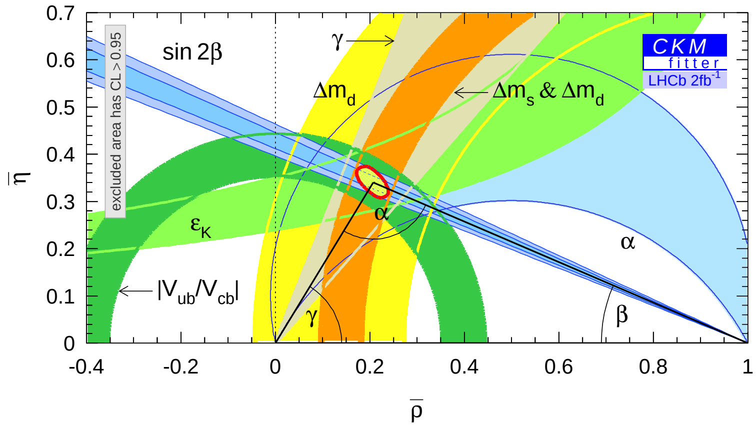

Fig. 2. A possible CKMfitter combination using LHCb measurements with 2 fb^{-1}.

The LHCb spectrometer will measure forward hadron production at the pp collider. At the LHC the $b\bar{b}$ pairs are produced mostly in the forward direction as shown in Fig. 3. As at the Tevatron, different b hadrons are produced: B_d, B_u, B_s, B_c, Λ_b, ... The $b\bar{b}$ cross-section is $\sim 500\ \mu b$ and 10^{12} $b\bar{b}$ pairs/year (10^7s) reach the LHCb spectrometer. The LHCb acceptance is more forward than the one of ATLAS/CMS and the observed $b\bar{b}$ cross-section is higher. The luminosity at the LHCb interaction point is intentionally limited to 2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in order to observe one interaction per bunch crossing on average.

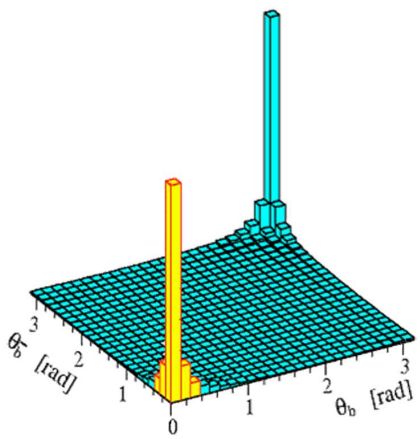

Fig. 3. Angular distribution of $b\bar{b}$ pair production at the LHC.

2. The LHCb detector

For successful measurements of beauty physics the following detector requirements are needed:

- Good triggering, to select interesting events from huge background.
- Good vertexing, to measure decay points and reduce backgrounds.
- Good tracking, to reconstruct tracks and measure well their momenta.
- Good particle identification, to prevent decay products of one decay mode becoming the background to another mode where kinematical separation is not sufficient.
- High speed DAQ coupled to large computing resources for data processing.

The LHCb detector is presented in Fig. 4. The protons collide inside the Vertex Locator. Products of interaction are identified by two RICH detectors located on two sides of the Magnet. The second RICH detector is followed by the calorimeter detectors and muon spectrometer. The tracks are measured by Trigger Tracker (TT) chambers and Tracking (T) stations located before and after the Magnet. There is no material inside the Magnet.

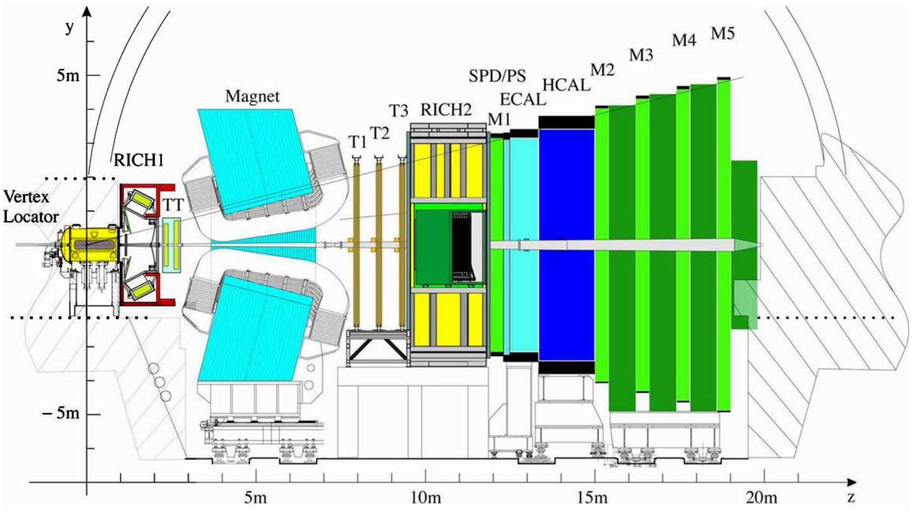

Fig. 4. The LHCb detector.

Importance of material absence inside the Magnet is best seen on the example of electrons, particles which would be mostly affected by its presence. In LHCb electrons radiate photons either before or after the Magnet as shown in Fig. 5 (left). The clusters from the photons emitted by the electrons after the Magnet are merged with those from electrons. Electrons are identified by comparing energy measured in the electromagnetic calorimeter ECAL with track momentum measured in the magnetic field. The position of clusters from photons radiated by electrons before the Magnet is precisely known by extrapolating the direction of the corresponding electron tracks. $J/\psi \to e^+e^-$ reconstruction is obtained by adding radiated photons to electrons and is shown in Fig. 5 (right).

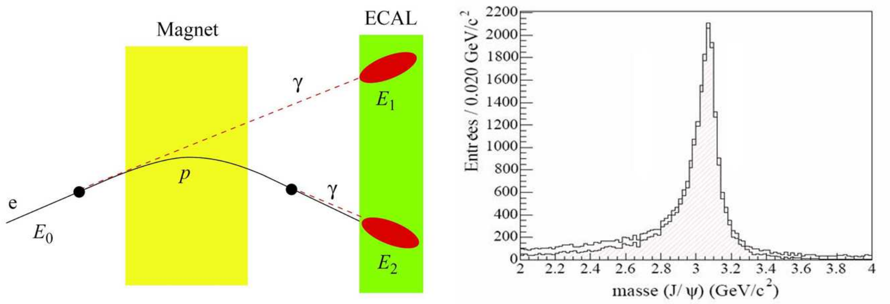

Fig. 5. Photon radiation by electrons in LHCb (left) and the J/ψ reconstruction after adding radiated photons to electrons (right).

Vertexing and tracking is assured by 21 Vertex Locator silicon stations and by TT and T chamber stations. The track density is high, therefore TT station and inner part (IT) of T stations is made in silicon technology, the outer part (OT) is made in straw tube technology. The excellent track reconstruction efficiency $> 95\%$, momentum resolution $\Delta p/p \sim 0.4\%$, impact parameter resolution ~ 20 μm and proper time resolution ~ 40 fs are obtained. The fraction of false tracks "invented" by the reconstruction program is low $\sim 4\%$.

The particles are identified by two RICH detectors. RICH1 identifies low momentum tracks using two radiators, Aerogel and C_4F_{10}. CF_4 allows to identify high momentum tracks in RICH2. The kaons are identified with 88% efficiency and a corresponding misidentification rate of pions as kaons is 3%. There is better than 3σ separation between pions and kaons with momenta between 3 and 80 GeV.

The importance of good particle identification in b physics is shown in an example of $B_s \to KK$ and $B_d \to \pi\pi$ selection presented in Fig. 6. Without RICH identification the two selections are strongly contaminated by background. The RICH detectors allow a very clean selection of these two decays. This is a unique feature at hadron colliders.

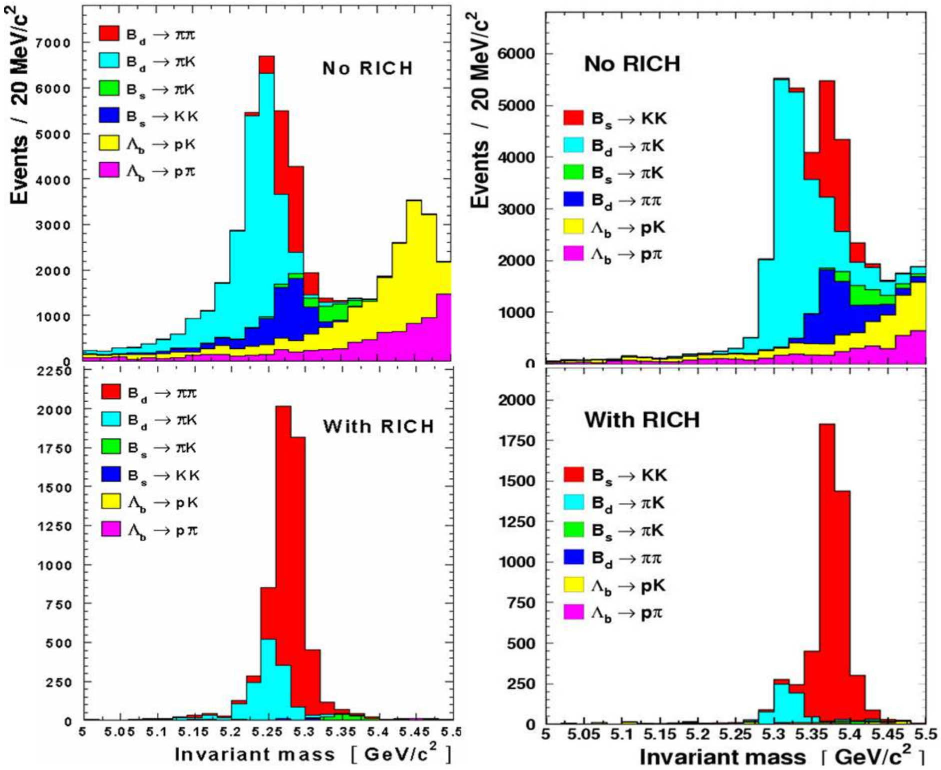

Fig. 6. $B_d \to \pi\pi$ and $B_s \to KK$ selection with and without RICH identification.

Fig. 7 shows the LHCb detector construction status in spring 2006. The interaction point is located inside the LHC tunnel on the right hand side of the figure. The particles produced at the interaction traverse then, from the right to the left hand side, the RICH1 and the Magnet. The three tracking chamber stations are installed in the empty space after the Magnet as can be seen in Fig. 8. RICH2 detector installed after tracking chambers followed by the Calorimeter detectors. ECAL and HCAL detectors are seen in Fig. 7 as well as the thin wall of lead converter. On both sides of the lead the thin scintillator pad SPD and PRS detectors are installed, in order to measure the beginning of shower development and distinguish between e's and γ's. The ECAL and the HCAL detectors are placed on the chariots and can be open and closed in any possible configuration. The SPD, PRS and lead wall are fixed from above and similarly can be opened and closed in any possible configuration. The muon detector wall is seen on the left hand side of Fig. 7.

The detector is now being commissioned.

Fig. 7. LHCb detector in spring 2006.

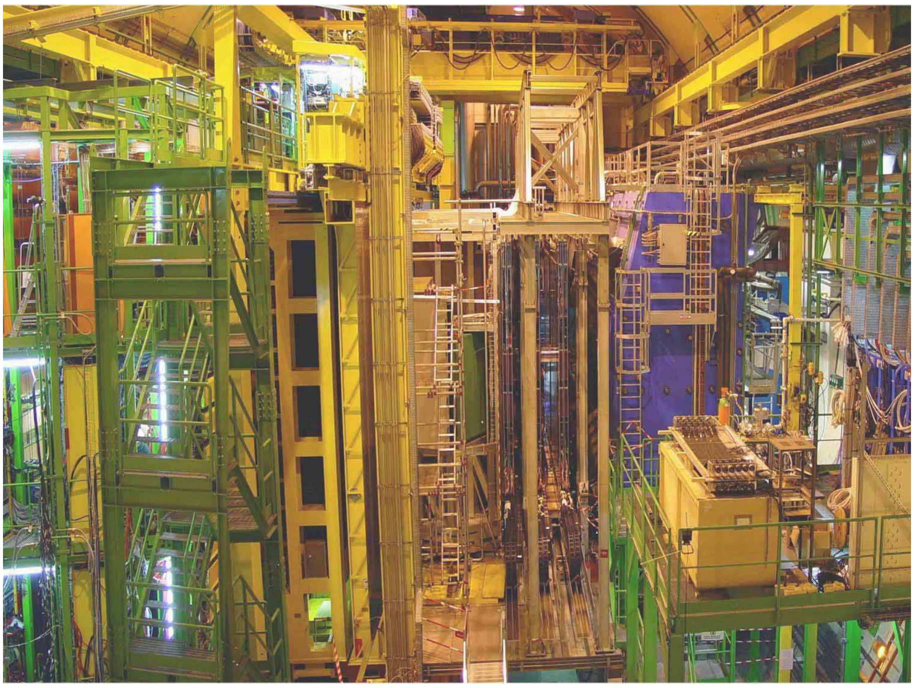

Fig. 8. LHCb detector in January 2008.

The Trigger plays a very important role at hadron collider. The Hardware Trigger at LHCb is reducing the 40 MHz bunch crossing rate into 1 MHz rate transmitted to the software trigger. High p_{T} electrons, photons and hadrons measured by the Calorimetry and high p_{T} muons and muon pairs measured by the Muon Spectrometer are selected. Multiple interactions are rejected by the Pile-up system located near the Vertex Locator.

The Software Trigger is using the data sent from different subdetectors through the Readout Network to CPU processors. Full detector information is therefore available at 1 MHz. The hardware trigger is confirmed or not and then more information is used step-by-step and uninteresting events are rejected. Ultimately, data are stored at a rate of 2 kHz.

The hardware trigger (LVL1) of ATLAS [3] uses the coarse granularity calorimeter and muon information. The Regions of Interests (RoI) are identified for further processing in the Software Triggers LVL2 and the Event Filter. The LVL2 trigger is using full granularity within RoI. The LVL1 trigger is verified there and information from the different detectors in RoI around LVL1 are combined. The Event Filter refines the LVL2 selection using the "offline-like" algorithms and better alignment and calibration. Different strategies for b physics are used. At high luminosity above $2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ di-muons with $P_{\mathrm{T}} > 6$ GeV/c are selected. At lower luminosity single muons with $P_{\mathrm{T}} > 6$ GeV/c are added. In addition the objects around muon are investigated, like the second muon with lower threshold, single e/γ, e^+e^- pair and/or hadronic b decay products. Finally 10–15 events for b physics, among a total number of 200 events/second, are stored.

The hardware trigger of CMS [4] selects di-muons with $P_{\mathrm{T}} > 3$ GeV/c each or single muons with $P_{\mathrm{T}} > 14$ GeV/c. The software trigger restricts the B reconstruction to RoI around muon or uses a reduced number of hits/track. Finally about 5 events for b physics, among a total number of 100 events/second, are stored.

3. Final remarks

The construction and commissioning of LHC detectors is progressing efficiently. They will be ready in 2008 to observe first collisions at LHC and soon after to get first physics results.

4. Bonus: Light Higgs search

At LHC a significant fraction ($\sim 30\%$) of the light Higgs bosons, currently being searched for at the Tevatron, are emitted forward within the acceptance of the excellent LHCb spectrometer and the light Higgs bosons decay predominantly into $b\bar{b}$ pair. LHCb has very good b-quark identification and its spectrometer will be very well calibrated with the large number of B mesons. The LHCb Collaboration is investigating a possibility of Higgs discovery by measuring Higgs decay into $b\bar{b}$ jets associated with high p_{T} lepton in order to reduce high $t\bar{t}$ production background. A typical light Higgs production event is shown in Fig. 9. The sensitivity to such light Higgs events is currently under study.

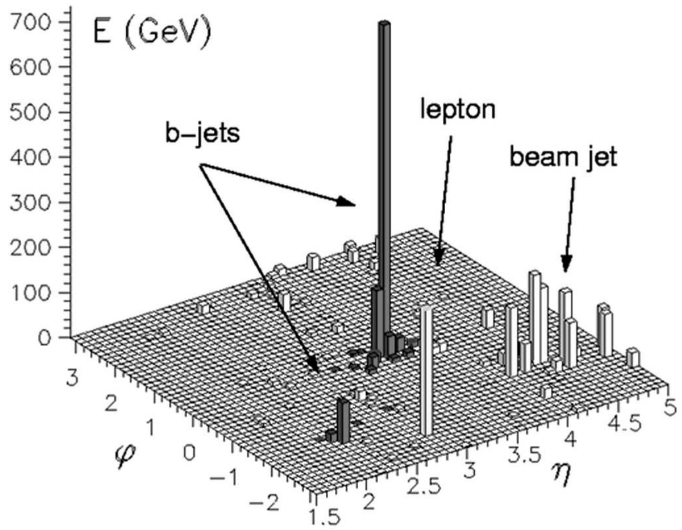

Fig. 9. A possible signature of light Higgs event in LHCb.

This study is encouraged by the fact that the precision electroweak measurements [5] tell us that the mass of the Standard Model Higgs boson is lower than about 160 GeV and the most probable value is 86^{+36}_{-27} GeV. Here in Cracow it is important to remind that the Z line-shape measurements at LEP shown in Fig. 10 make an important contribution to this prediction. The solid line fitted to the experimental points shows the experimentally measured line-shape. The dashed line shows the Standard Model line-shape which parametrization is used in the Standard Model fits. The Higgs mass prediction is obtained in a fit of electroweak radiative corrections to parameters of the line-shape and other measurements, which size is about few $\times10^{-3}$. The difference between the solid and dashed line-shape had to be known with much higher prediction, and, in fact, has been calculated by the group of Staszek Jadach with a precision of few $\times10^{-4}$ [6] allowing therefore significant prediction of the Higgs mass.

Staszek Jadach and his group — thank you.

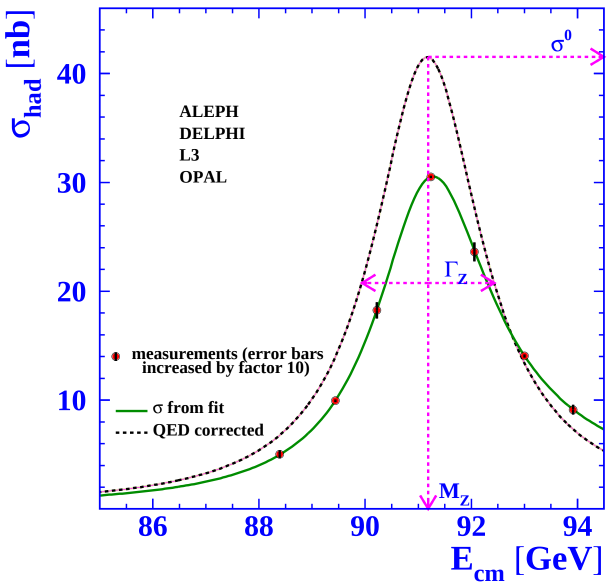

Fig. 10. The Z line-shape.

I would like to thank the organizers of the Epiphany Conference for the excellent organization.

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