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LHCb: From the detector to the first physics results

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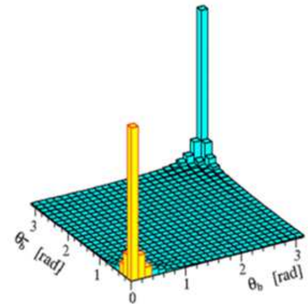
On behalf of the **LHCb collaboration**

In this talk the LHCb detector is presented, with emphasis on its main features and performance. The event selection is described, from the hardware trigger to the physics analysis. Last, some recent physics results are presented.

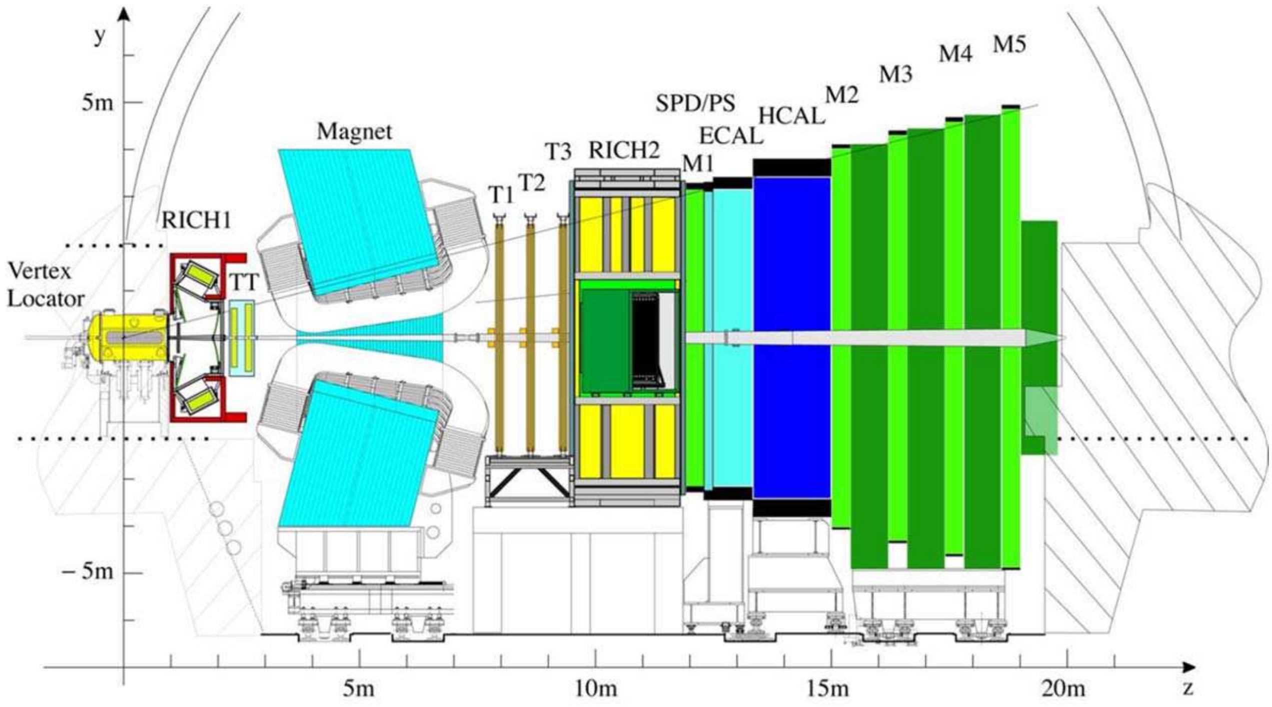
The LHCb detector



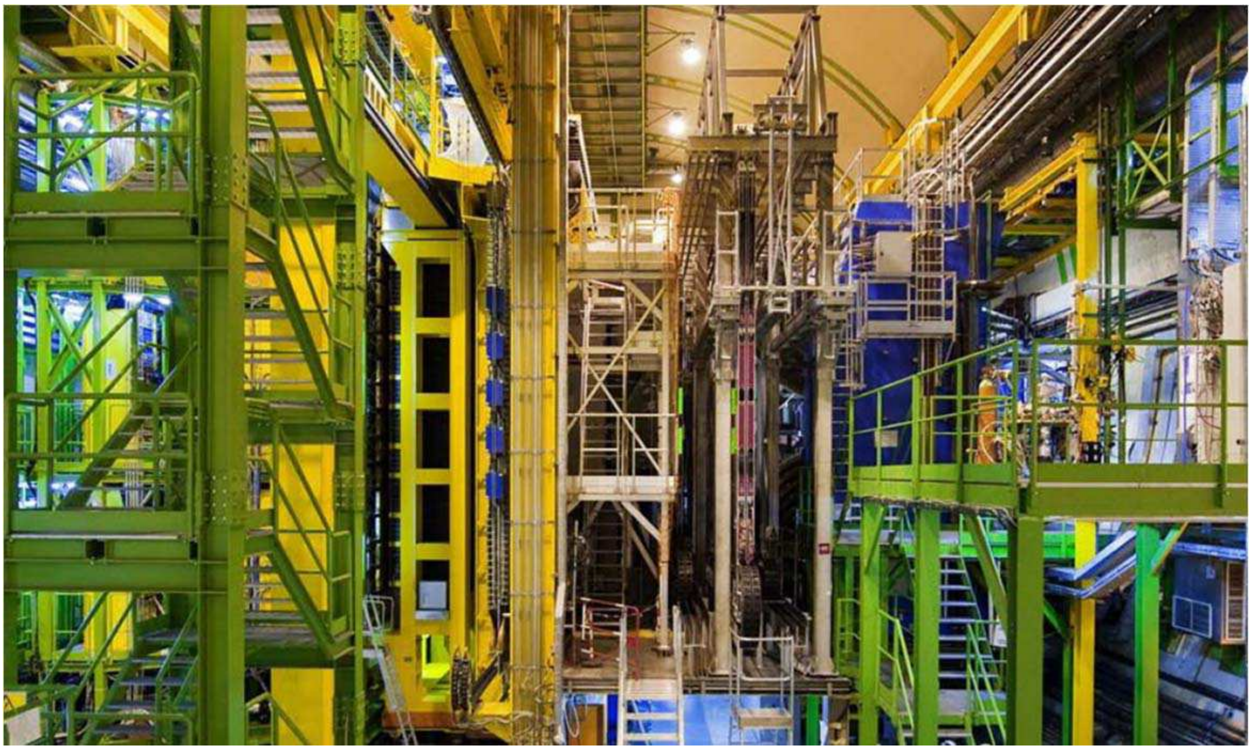
The pp interactions are producing B and D hadrons mainly in the forward (and backward) directions, as the two interacting partons have different *x*. The $b\bar{b}$ pair is then in the same hemisphere, as shown on the nearby figure and a single arm spectrometer allows measuring both signal and tagging hadrons. The main components of the detectors are:

- A very accurate vertex detector.
- A dipole magnet with precisely known field for high precision momentum measurement
- Particle identification in a wide momentum range for π, K, p, μ and electrons.

The detector is shown on the next figure.

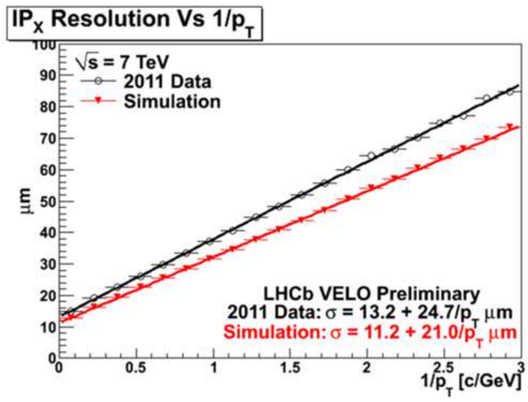


In real life, the view of the detector is more crowded, and is in fact oriented from right to left…



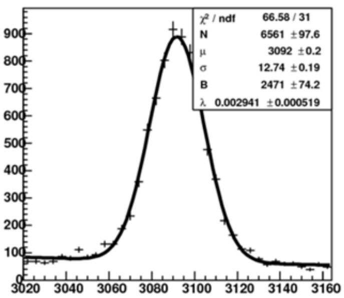
The vertex detector

Surrounding the interaction point, it should measure the primary vertex (in average 40 particles) and identify a secondary vertex where de B has decayed after flying typically a centimetre. The detector is placed as close as possible from the interaction point: sensors are at 7.5 mm from the beam. This is possible only during "Stable Beam" and the detector opens by ± 30 mm for injection and beam adjustments. The measurement pitch is as low as 40 micrometres in the centre, up to 100 micrometres outside. The mechanical repositioning should then be accurate to only a few micrometres. The performance can be appreciated on the nearby plot, showing the impact parameter resolution as function of $1/P_t$.



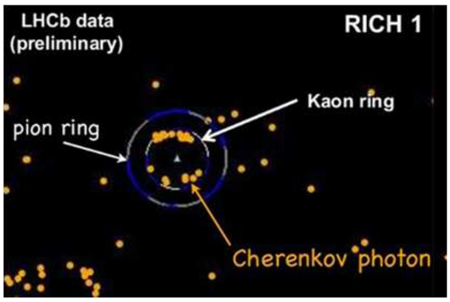
The trackers

The tracks are also measured before the magnet (TT detector, made of silicon strips) and after (IT in the centre, made of silicon strips, and OT for the rest, made of straw tubes). With the ~4 T.m field, the momentum is accurately measured. A clear indicator of the performance is the nearby J/Ψ mass plot, with a resolution of 13 MeV, close to the MC expectation.

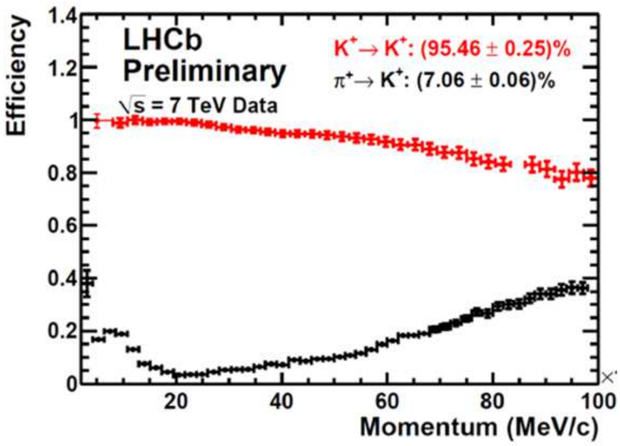


Particle identification

The two RICH detectors are intended to separate π from K from ~2 to ~100 GeV. The photons emitted by a particle in each of the 3 radiators are distributed on a circle around the trajectory, whose radius depends on the mass. The nearby figure depicts a case with a clear difference between the pion and kaon rings.



The identification efficiency and contamination, measured with data, is shown below.

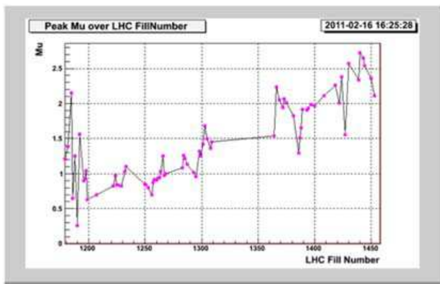


Calorimeter and muon detectors

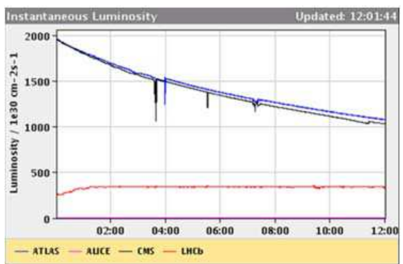
The electromagnetic calorimeter has about 6000 cells, with a charged particle tagger and a pre-shower detector in front, with the same geometry. The hadron calorimeter with about 1500 cells is mainly used in the trigger. The muon detector, made of 5 stations separated by iron walls, is built with MWPC and GEM, with a projective geometry. These detectors are performing as expected in the simulations.

Data taking conditions

LHCb was designed to run with a low luminosity, to have a single interaction per beam crossing. As the LHC is working at a lower number of bunches, and as the detector, the event reconstruction and the analysis are working well in a dirtier environment, the mean number of interaction per crossing (μ) has been increased up to 2.5 interactions per crossing, as shown on the nearby plot.



From the end of spring 2011, the number of bunches in the machine is high enough so that we are limited by the instantaneous luminosity the detectors can sustain, almost twice the nominal value. A levelling system has been developed together with the LHC operation team, so that our luminosity is kept constant by frequently adjusting the vertical separation of the beams. The nearby plot shows the exponential decay of the luminosity at ATLAS and CMS and our constant (lower) luminosity in red.



Event selection

The selection is performed in 3 steps

Hardware trigger: Level 0

From the beam crossing rate (the clock runs at 40 MHz but the collision rate is about 14 MHz) one first reduce the rate to ~800 kHz by requesting either a high Pt (about 1 GeV) muon, or a high Et cluster (3.8 GeV) in the hadronic calorimeter. We have also triggers on high Et electrons, photons and π^0 that are together only a small fraction of the rate. This is a synchronous hardware trigger. Selected events are then readout and sent to a PC in the trigger farm for selection.

Software trigger: the HLT

About 1300 PCs are running in total about 22000 copies of the triggering code. The code should take in average less than 27 milliseconds per event to sustain the 800 kHz input rate. The selection proceeds in two steps:

1. Search for a high Pt track with a significant impact parameter to the primary vertex. This is done by reconstructing all tracks in the vertex detector, reconstructing the primary vertices, selecting the track with an impact parameter of at least 100 micrometres, and reconstructing them fully to get their momentum. If one of these tracks has a Pt over 1 GeV, the event is retained. For muon triggers, the track has also to be validated by the muon detector. A rejection factor of about 20 is obtained by this step.
2. The retained events are then fully reconstructed, with a somewhat simplified track fit and without particle identification, for speed reasons. A first selection is made by a topological trigger, searching for a displaced vertex with a high enough mass. Other selections are made for dedicated channels, like for example J/Ψ, Φ, D→Kπ. The total rate is about 3 kHz, and includes some random triggers and some unbiased samples taken at various stages of the processing, for monitoring.

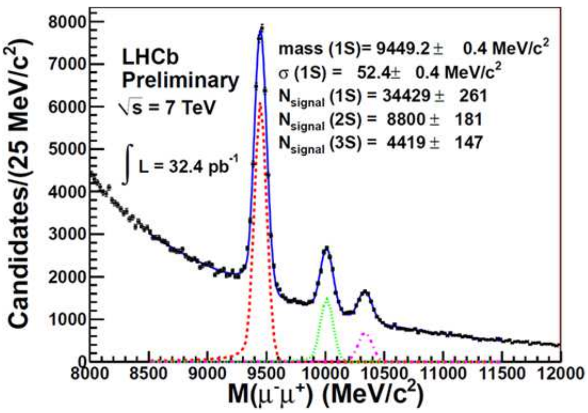
Offline selection: The stripping

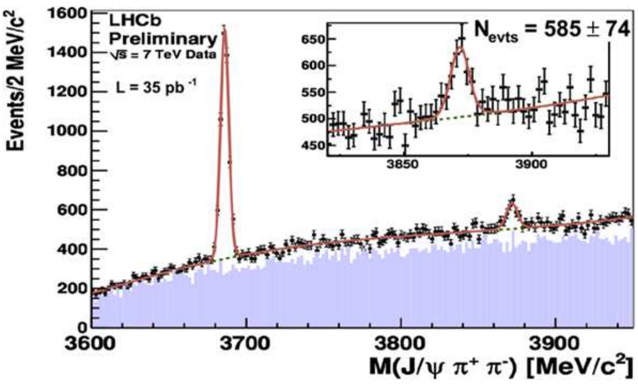
The recorded events are fully reconstructed almost immediately on the LHC Computing Grid, and monitored to detect faults in the detector that have escaped the attention of the online shift crew. This is mainly to spot an unexpected change in alignment or calibration. Less than 1% of the data is rejected by data quality cuts. Events are then stripped according to the wishes of the various physics groups, in order to provide less than a few Hz per channel, this means less than 10^7 events to analyse per year. The code is a collection of the various pre-selections. The resulting streams are made available for offline analysis within a few days after data taking. A full reprocessing with final calibrations and alignment, and the subsequent stripping, is run again at the end of the year for the final analysis.

Some preliminary physics results

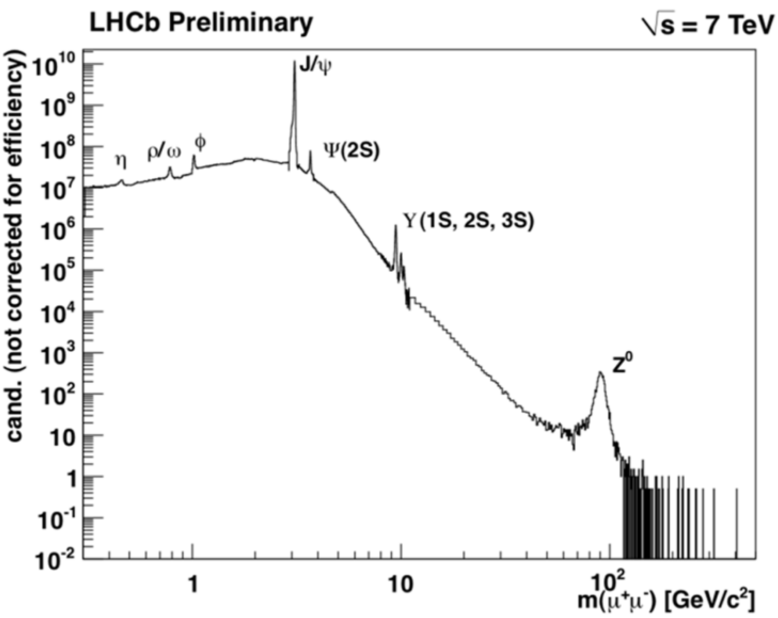
Spectroscopy

A first series of results is the search for resonances and mass peaks. This allows checking the momentum scale and finding alignment problems. The next plot shows on the left the mass resolution in the upsilon region in the di-muon channel. The plot on the right shows the clear X(3872) signal in J/Ψππ mass plot.





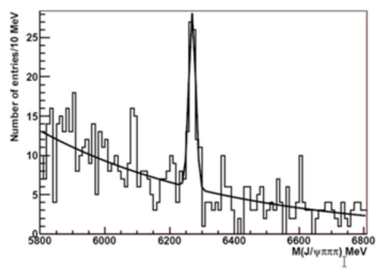
A complete mass plot in the di-muon channel, seriously biased by the trigger, shows (note the log-log scale) the various resonances discovered and studied in the XXth century.



Mass measurements of several beauty particles are obtained with better error that the world averages.

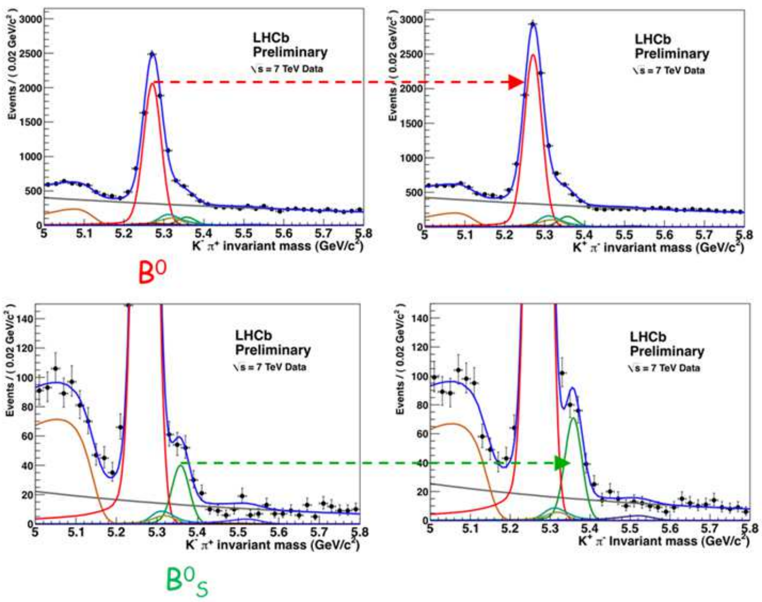
LHCb-CONF-2011-027: masses [MeV/c^2]		PDG [MeV/c^2]
$M(B^+ \to J/\psi K^+)$	$= 5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.17 ± 0.29
$M(B^0 \to J/\psi K^{*0})$	$= 5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50 ± 0.30
$M(B^0 \to J/\psi K^0_S)$	$= 5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.50 ± 0.30
$M(B^0_s \to J/\psi \phi)$	$= 5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30 ± 0.60
$M(\Lambda_b \to J/\psi \Lambda)$	$= 5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2 ± 1.6
$M(B^+_c \to J/\psi \pi^+)$	$= 6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277 ± 6

New decay modes have been observed, and branching fractions measured: The nearby plot shows the J/Ψπππ mass plot, a new mode of decay for the B_c^+; the branching fraction of this mode is 3.0 ± 0.6 ± 0.4 times the branching fraction to J/Ψπ.



CP asymmetries

The raw asymmetries are already visible on the nearby plots. The top row is optimized for B^0 studies, and shows a clear difference between B^0 and $\overline{B^0}$. The second row displays the same mass plot, optimized for the study of B_S^0, and shows an even higher difference between particle and antiparticle.



Detector asymmetries and production asymmetries are corrected using other decay channels, and the final asymmetries are measured to be:

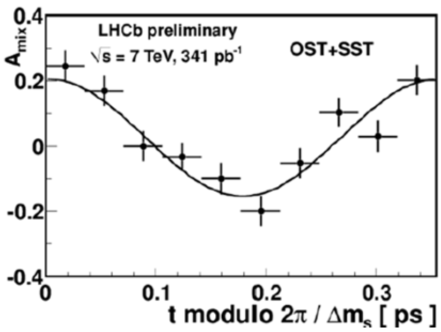
$A_{CP}(B^0 \rightarrow K+\pi-)$ = -0.088 ± 0.011 (stat) ± 0.008 (syst)

This is the first 5σ measurement of CP violation in the B system in hadron collider)

$A_{CP}(B_S^0 \rightarrow \pi+K-)$ = 0.27 ± 0.08 (stat) ± 0.02 (syst) (preliminary)

This is the first evidence of CP violation in $B_S \rightarrow \pi K$

Mixing frequency: Δm_s



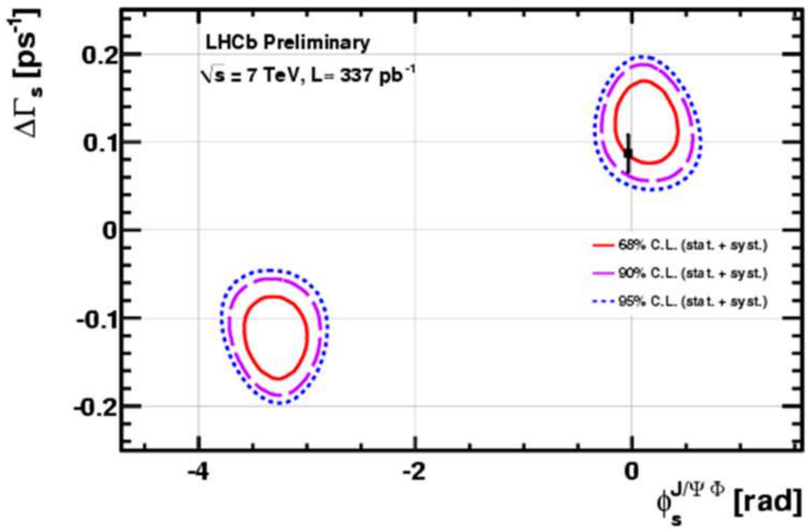
The oscillation of the B_s is studied in the decay mode $B_s \rightarrow D_s\pi$ with 3 different decay modes for the D_s. The tagging of the original nature of the B_s is a key ingredient. The nearby plot shows the mixing amplitude versus the phase in the oscillation period. The result is Δm_s = 17.725 ± 0.041(stat) ± 0.025(syst) ps^{-1}

Measurement of φ_S

The decay $B_s \rightarrow J/\Psi\phi$ is dominated by a tree diagram. But the B_s can oscillate to $\overline{B_s}$ before decaying in the same mode. The interference allows measuring the phase of the CKM matrix elements, together with the mass difference between the particle and antiparticle. The time resolution of 50 ps is critical for this measurement. The result is shown in the figure below and can be summarized as:

$$\phi s = 0.13 \pm 0.18\ stat \pm 0.07\ sys\ \text{rad}$$
$$\Delta\Gamma s = 0.123 \pm 0.029\ stat \pm 0.008\ sys\ ps^{-1}$$
$$\Gamma s = 0.656 \pm 0.009\ stat \pm 0.008\ sys\ ps^{-1}$$

As shown on the figure, this result is in very good agreement with the standard model prediction, shown as a black square.



Search for rare decay modes

The last measurement reported in this talk is the search for the rare decay $B_S \to \mu\mu$ that has a predicted branching ratio (BR) of $(3.2 \pm 0.2) \cdot 10^{-9}$ in the standard model. The analysis is described in detail in the conference note LHCb-CONF-2011-037, and is based on a boosted decision tree method. The result for the 2011 dataset alone is BR($B_S \to \mu\mu$) < 1.3 (1.6) $\cdot 10^{-8}$ at 90%(95%) C.L. Combined with the 2010 result and the CMS result, the limit becomes BR($B_S \to \mu\mu$) < 0.9 (1.1) $\cdot 10^{-8}$ at 90%(95%) C.L. which doesn't confirm the higher value reported by CDF.

Summary

The LHCB detector is working as expected, even if the luminosity is almost twice the nominal one with only half the number of bunches in the machine. The first physics results obtained with 300 pb^{-1} are already providing world class measurements in many domains. Better results will be obtained soon as the 2011 dataset will be at least 3 times the presented one. However, there is still no sign of New Physics…