First mass measurements at LHCb

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University of Genova & INFN

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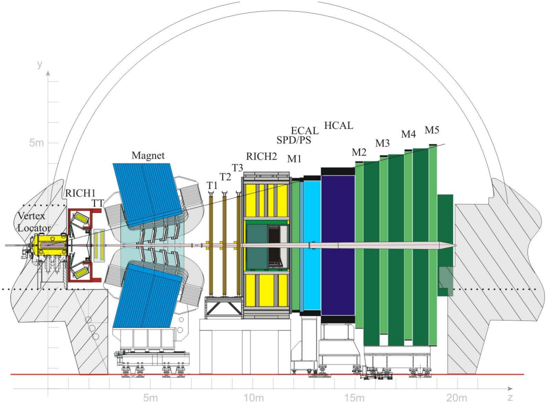
Motivations

- Measurement of the absolute mass of b-hadrons $(B^+, B^0, B_s^0, \Lambda_b, B_c^+)$ and $X(3872)$ [see talk given by Bo Liu] using $\sim 35\,\mathrm{pb}^{-1}$ data collected during 2010 at LHCb at $\sqrt{s} = 7\,\mathrm{TeV}$
- Quarks and gluons in baryons and mesons are bound together by strong interaction described by QCD
- Hadrons masses are fundamental physical observables
- Mass spectra are calculated using QCD
- A test of QCD can be performed using this simple property of hadrons.

LHCb

Single arm spectrometer for B physics



- Tracking System: VErtex LOcator, Trigger Tracker, T1-T3 tracking stations ($\Delta p/p = 0.35 - 0.55\%$) $\oplus$ Dipole Magnet
- Muon Detector ($\mu - ID \sim 98\%$)

Event Selection

Using exclusive decay modes with $J/\psi X$ final states:

1. $B^+ \to J/\psi K^+$
2. $B^0 \to J/\psi K^{*0}$
3. $B^0 \to J/\psi K^0_s$
4. $B^0_s \to J/\psi \phi$
5. $\Lambda_b \to J/\psi \Lambda$
6. $B^+_c \to J/\psi \pi^+$

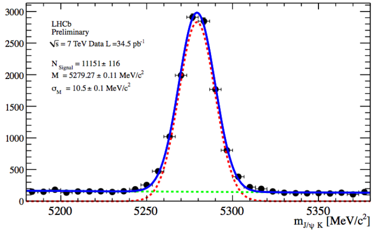
with:

- $J/\psi \to \mu^+\mu^-$
- $\phi \to K^+K^-$
- $K^{*0} \to K^-\pi^+$
- $K^0_s \to \pi^+\pi^-$
- $\Lambda \to p\pi^-$

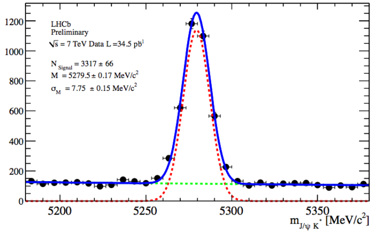
and charge-conjugate modes

- Selection based on track quality, vertex quality, p_t, impact parameter, b-hadron proper time, PID
- J/Ψ, K^0_s and Λ mass-constrained vertex fit (improve b-hadron mass resolution)

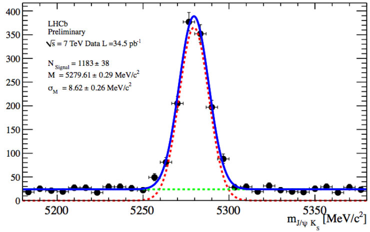
b-hadron



$B \to J/\psi K$

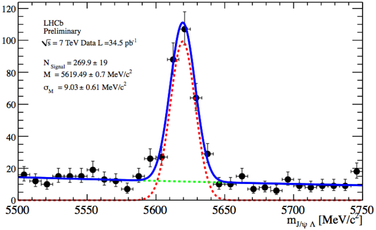


$B \to J/\psi K^*$

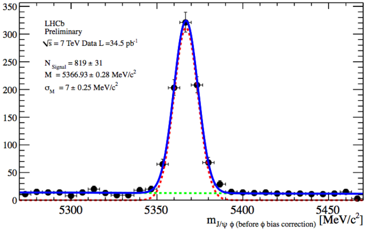


$B \to J/\psi K_s^0$

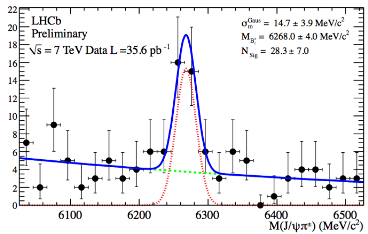
b-hadron



$\Lambda_b \to J/\psi\Lambda$



$B_s^0 \to J/\psi\phi$



$B_c \to J/\psi\pi$

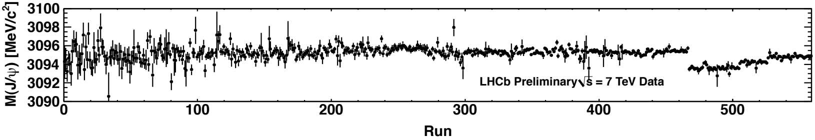
Alignment (I)

Good alignment of the LHCb spectrometer is essential for precise particle mass measurements

- Standard Alignment using $J/\psi \to \mu\mu$ high-momentum tracks with vertex and mass constraint
- New Alignment using $D^0 \to K^- \pi^+$: clean signal, less sensitive to background and more asymmetric decays available
- Study of bias of reconstructed J/ψ mass as a function of track pseudorapidity (η), momentum (p) and the angle between the normal to the decay plane and the orientation of the magnetic field (ϕ_d)
- Shifts in the J/ψ mass correlated to TT temperature: time dependent alignment procedure

Alignment (II)

- TT operational temperature changed during 2010 data taking
- Thermal expansion/contraction of the TT modules: $\sim 400\,\mu\text{m}$
- To be compared with intrinsic resolution of the detector up to $50\,\mu\text{m}$
- Not negligible
- Time dependent alignment needed



Momentum Scale Calibration

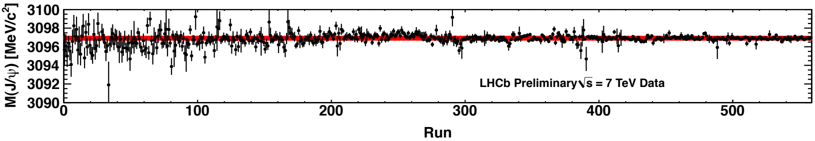
- No bias on the momentum measurement (precision sub-per mil)

$$m_{12}^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2) \cdot (\vec{p}_1 + \vec{p}_2)$$

$(1 - \alpha)$ is the correction factor to be applied to the track momenta:

$$\Delta m = m_P - m_{12} = -\alpha m_P$$

- Calibration using $J/\psi \to \mu\mu$ decay channel



- Mass of the J/ψ stable after time dependent alignment and momentum scale calibration
- $\frac{\Delta m(J/\psi)}{m(J/\psi)} = 2 \times 10^{-5}$
- $0.2\,\mathrm{MeV/c^2}$ over entire 2010 run

Validation (I)

- Check of momentum scale calibration using other two-body resonance decay modes (Υ, D^0, K_s^0)

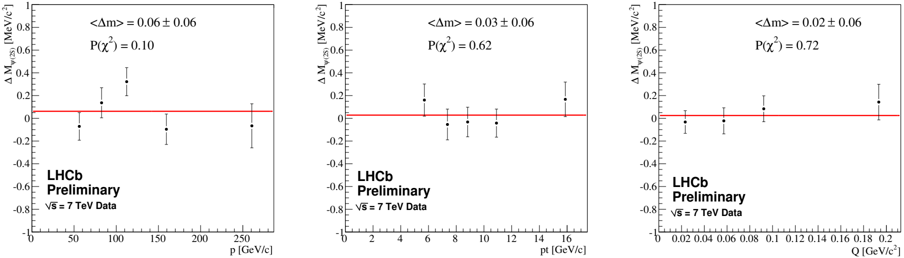
Decay	Measured mass $[\mathrm{MeV/c^2}]$	PDG average $[\mathrm{MeV/c^2}]$
$\Upsilon(1S) \to \mu^+\mu^-$	9459.90 ± 0.54	9460.30 ± 0.26
$J/\psi \to \mu^+\mu^-$	3096.97 ± 0.01	3096.916 ± 0.011
$D^0 \to K^-\pi^+$	1864.75 ± 0.07	1864.83 ± 0.14
$K_\mathrm{S}^0 \to \pi^+\pi^-$	497.62 ± 0.01	497.61 ± 0.02

- Estimation of the momentum scale uncertainty: 10^{-4}

Validation: $\psi(2S) \to J/\psi\pi^+\pi^-$

Uncalibrated Mass [$\mathrm{MeV/c^2}$]	3685.94 ± 0.06
Calibrated Mass [$\mathrm{MeV/c^2}$]	3686.12 ± 0.06
PDG average [$\mathrm{MeV/c^2}$]	3686.09 ± 0.04

$\psi(2S)$ mass in very good agreement!



- Difference of measured $\psi(2S)$ mass and PDG value as a function of momentum, transverse momentum, energy Q released in the decay
- No evidence systematic bias

Systematic Uncertainties

- Fit Model
- Momentum Calibration
  - Precision on the momentum scale: 10^{-4}
  - η dependance of the momentum scale factor
- Detector Material: material distribution affects momentum scale determination (10% increasing of material budget)
- Detector Alignment
  - TT removal effect
  - VELO z-scaling: investigated scaling track slopes in the VELO
- ϕ bias (opening angle)

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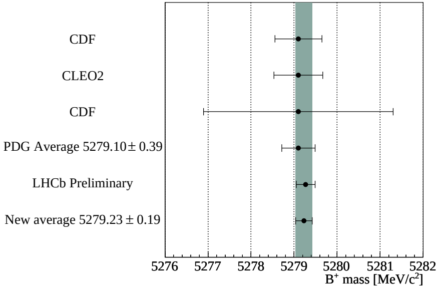
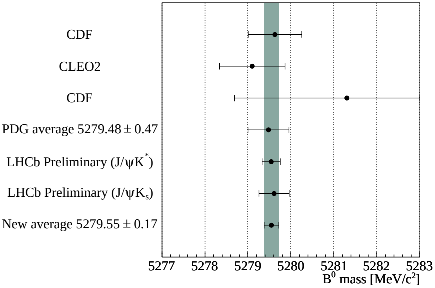
For all the modes except B_c:
$0.16 \div 0.20\,\mathrm{MeV/c^2}$

Results: B_u and B_d



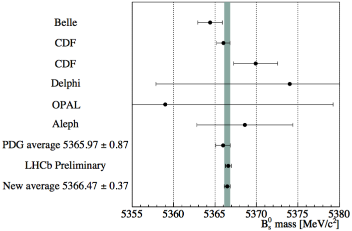


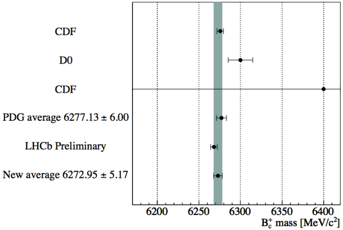
LHCb Preliminary

$$M(B^+ \to J/\psi K^+) = 5279.27 \pm 0.11\ (\mathrm{stat}) \pm 0.20\ (\mathrm{syst})\ \mathrm{MeV}/\mathrm{c}^2$$
$$M(B^0 \to J/\psi K^{*0}) = 5279.54 \pm 0.15\ (\mathrm{stat}) \pm 0.16\ (\mathrm{syst})\ \mathrm{MeV}/\mathrm{c}^2$$
$$M(B^0 \to J/\psi K^0_s) = 5279.61 \pm 0.29\ (\mathrm{stat}) \pm 0.20\ (\mathrm{syst})\ \mathrm{MeV}/\mathrm{c}^2$$

B_d and B_u world best measurements

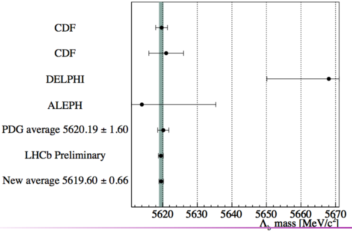
Results: B_s, B_c and Λ_b





LHCb Preliminary

$$M(B_s^0 \to J/\psi\phi) = 5366.60 \pm 0.28(\text{stat}) \pm 0.21(\text{syst})\ \text{MeV}/\text{c}^2$$
$$M(\Lambda_b \to J/\psi\Lambda) = 5619.49 \pm 0.70\ (\text{stat}) \pm 0.19\ (\text{syst})\ \text{MeV}/\text{c}^2$$
$$M(B_c^+ \to J/\psi\pi^+) = 6268.0 \pm 4.0\ (\text{stat}) \pm 0.6\ (\text{syst})\ \text{MeV}/\text{c}^2$$

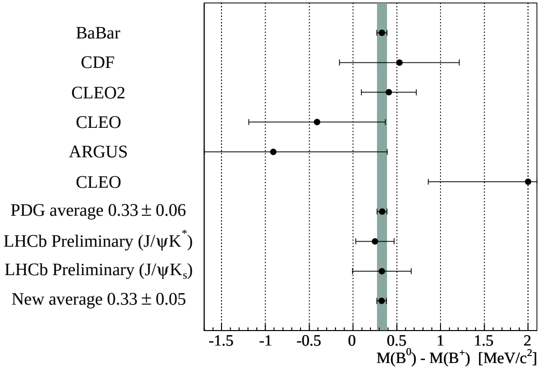


- B_s and Λ_b world best measurements
- For B_c we need a bit more data

Mass Difference Results

$$
\begin{aligned}
M(B^0 \to J/\psi K^*) - M(B^+ \to J/\psi K^+) &= 0.27 \pm 0.19\,(\text{stat}) \pm 0.12\,(\text{syst}) \\
M(B^0 \to J/\psi K^0_S) - M(B^+ \to J/\psi K^+) &= 0.34 \pm 0.31\,(\text{stat}) \pm 0.10\,(\text{syst}) \\
M(B^0_s \to J/\psi \phi) - M(B^+ \to J/\psi K^+) &= 87.33 \pm 0.30\,(\text{stat}) \pm 0.19\,(\text{syst}) \\
M(\Lambda_b \to J/\psi \Lambda) - M(B^+ \to J/\psi K^+) &= 340.22 \pm 0.71\,(\text{stat}) \pm 0.08\,(\text{syst}) \\
M(B^+_c \to J/\psi \pi^+) - M(B^+ \to J/\psi K^+) &= 988.7 \pm 4.0\,(\text{stat}) \pm 0.5\,(\text{syst})
\end{aligned}
$$

Systematic error related to the determination of the average momentum scale largely cancels if mass differences are considered.



Conclusions

- Mass measurements of B_u, B_d, B_s, B_c and Λ_b have been shown
- Agreement of LHCb measurements with previous values
- LHCb measurements improve the uncertainties by a factor two
- World best measurements: B_u, B_d, B_s and Λ_b
- 2011 data will give us the possibility of more precise mass measurement of B_c
- Plans for 2011: study of Ω_b and other b-baryons
- Searching of excited B hadrons (B_{s1}, B^*_{s2})

Spare Slides

Systematic uncertainties on $B^+ \to J/\psi K^+$

Source of uncertainty	Value [$\mathrm{MeV/c^2}$]
Mass fitting:	
Background model	0.04
Signal model	0.01
Momentum calibration:	
Average momentum scale	0.15
η dependance of momentum scale	0.04
Detector description:	
Energy loss correction	0.10
Detector alignment:	
Vertex detector (track slopes)	0.05
Tracking stations (TT information)	0.05
Quadratic sum	0.20

Systematic uncertainties for the $B^0 \to J/\psi K^{*0}$

Source of uncertainty	Value [$\mathrm{MeV/c^2}$]
Mass fitting:	
Background model	0.03
Signal model	0.02
Momentum calibration:	
Average momentum scale	0.14
η dependance of momentum scale	0.00
Detector description:	
Energy loss correction	0.00
Detector alignment:	
Vertex detector (track slopes)	0.04
Tracking stations (TT information)	0.05
Quadratic sum	0.16

Systematic uncertainties for the $B^0 \to J/\psi K^0_S$

Source of uncertainty	Value [$\mathrm{MeV/c^2}$]
Mass fitting:	
Background model	0.00
Signal model	0.06
Momentum calibration:	
Average momentum scale	0.15
η dependance of momentum scale	0.09
Detector description:	
Energy loss correction	0.05
Detector alignment:	
Vertex detector (track slopes)	0.04
Tracking stations (TT information)	0.05
Quadratic sum	0.20

Systematic uncertainties for the $B_s^0 \to J/\psi\phi$

Source of uncertainty	Value [MeV/c^2]
Mass fitting:	
Background model	0.01
Signal model	0.02
Momentum calibration:	
Average momentum scale	0.11
η dependance of momentum scale	0.03
Detector description:	
Energy loss correction	0.03
Detector alignment:	
Vertex detector (track slopes)	0.03
Tracking stations (TT information)	0.05
ϕ-bias	0.16
Quadratic sum	0.21

Systematic uncertainties for the $\Lambda_b \rightarrow J/\psi\Lambda$

Source of uncertainty	Value $[\mathrm{MeV/c^2}]$
Mass fitting:	
Background model	0.00
Signal model	0.07
Momentum calibration:	
Average momentum scale	0.14
η dependance of momentum scale	0.02
Detector description:	
Energy loss correction	0.09
Detector alignment:	
Vertex detector (track slopes)	0.04
Tracking stations (TT information)	0.05
Quadratic sum	0.19

Tabella:

Systematic uncertainties for the $B_c^+ \to J/\psi\pi^+$

Source of uncertainty	Value [MeV/c^2]
Mass fitting:	
Background model	0.32
Signal model	0.07
Momentum calibration:	
Average momentum scale	0.23
η dependance of momentum scale	0.44
Detector description:	
Energy loss correction	0.11
Detector alignment:	
Vertex detector (track slopes)	0.06
Tracking stations (TT information)	0.05
Quadratic sum	0.61

ϕ bias

Estimation of the bias using $D^{\pm} \to \phi\pi^{\pm}$

Before momentum scale calibration: $1869.28 \pm 0.02\,\mathrm{MeV/c^2}$

After momentum scale calibration: $1869.93 \pm 0.02\,\mathrm{MeV/c^2}$

PDG D mass: $1869.60 \pm 0.02\,\mathrm{MeV/c^2}$

Apply this correction to $B_s \to J/\psi\phi$ and assign error on the PDG D mass: $0.16\,\mathrm{MeV/c^2}$

Detector alignment

TT hit removal bias estimation

- Sample where no detectors are removed
- Sample with TT hits removed
- Fit of the tracks
- Same Offline Selection for the two samples
- $\Delta M = M$(without TT)$-M$(with TT)
- Mean value of the distribution calculated analitically
- $< \Delta m >= -0.034 \pm 0.05$, compatible with zero
- Systematic error $= 0.05$