Edwige Tournefier (LAPP, Annecy) on behalf on the LHCb collaboration

LHCC open session

March, 5th 2014
Outline

• LS1 activities
• Run 2 preparation
• LHCb physics output
• LHCb upgrade
• Conclusion
The LHCb detector

IP resolution: 20μm ⇒ 45ps on 2-body decay

Δp/p~0.5% (5-100 GeV/c)

B→Kππγ
σ~90MeV/c²
LS1 activities

- Consolidation of dipole magnet:
  - Rubber protections moved due to the Up/Down cycles
  - Old protections removed and replaced with an improved version

Done!

Removing the old rubber protections

New frame

In-situ machining
LS1 activities

- Ongoing maintenance + improvements to subdetector (hardware and software)
  - HCAL: replacement of ~15% PMs
  - RICH: improved version of the spare HPDs (improved vacuum)
  - ECAL: replacement of the fibers+LED system used for calibration
    - Degradation of fibers due to radiation
    - Plastic fibers replaced with quartz rad hard one
LS1 activities

• **Computing:** preparing the full re-stripping of Run1 data with final calibrations (legacy dataset) → planned for end of summer

• **Preparing the LHCb upgrade during LS1!**
  – Installation of the supports for the optical fibers in preparation

• **Preparing the restart for Run2:**
  – Regular commissioning weeks
Run2 preparation

- LHCb Run2:
  - Stay at $L = 4 \times 10^{32}$ cm$^{-2}$s$^{-1}$, 50ns $\rightarrow$ 25ns $\Rightarrow$ less pile-up
  - $8 \rightarrow 13$ TeV $\Rightarrow$ bbbar and ccbar cross-sections $\times \sim 1.6$

$\Rightarrow$ The trigger needs to be improved for the new conditions

L0 (hardware trigger limited to 1MHz):
- An example of efficiency and stability increase:
  - Ageing correction of HCAL and ECAL (fill by fill):
    - Monitor using minbias events
    - Adjust HV on fill by fill basis to correct gain

HLT: CPU increase by a factor 2
- can perform more complex selections in HLT
  - Optimize tracking algorithm ($\Rightarrow$ $p_T$ threshold)

Work in progress
Run2 preparation

⇒ HLT improvements and optimizations (cont’d)
  – Online alignment of tracking system + RICH calibration using minbias events fill by fill
  – HLT2 fully deferred: uses tracking/RICH calibration ⇒ improved efficiency + less reprocessing
  – Split HLT1 and HLT2 processes
  – Re-use HLT1 reconstruction in HLT2

Work in progress
LHCb physics output

Published papers
Accepted
Submitted
Papers submitted since last LHCC

**B-hadron lifetimes**

Measurement of the $B_s^0 \rightarrow D_s^- D_s^+$ and $B_s^0 \rightarrow D D_s^+$ effective lifetimes

Measurement of the $B_c^+$ meson lifetime using $B_c^+ \rightarrow J/\psi \mu^+ \nu \mu X$ decays

Measurements of the $B^+, B^0, B_s^0$ meson and $\Lambda_b^0$ baryon lifetimes

Precision measurement of the $\Lambda_b^0 / B^0$ lifetime ratio

**Production, cross-sections**

Observation of associated production of a $Z$ boson with a $D$ meson in the forward region

Updated measurements of exclusive $J/\psi$ and $\psi(2S)$ production cross-sections in $pp$ collisions at $\sqrt{s}=7$ TeV

Measurement of Upsilon production in $pp$ collisions at $\sqrt{s}=2.76$ TeV

Measurement of charged particle multiplicities and densities in $pp$ collisions at $\sqrt{s}=7$TeV in the forward region

**B-hadron decay**

Searches for $\Lambda_b^0$ and $\Xi_b^0$ decays to $K_S^0 p \pi^-$ and $K_S^0 p K^-$ final states with first observation of the $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ decay

**CP violation**

A study of CP violation in $B^\pm \rightarrow D K^\pm$ and $B^\pm \rightarrow D \pi^\pm$ decays with $D \rightarrow K_S^0 K^\pm \pi^\mp$ final states

Measurement of resonant and CP components in $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays

Search for Majorana neutrinos in $B^- \rightarrow \pi^+ \mu^- \mu^-$ decays

Observation of photon polarization in the $b \rightarrow s \gamma$ transition

**Search for new physics with rare decays**

arXiv:1312.1217

arXiv:1401.6932

arXiv:1402.2554

arXiv:1402.6242

arXiv:1401.3245


arXiv:1401.3288

arXiv:1402.2539

arXiv:1402.4430

arXiv:1402.0770

arXiv:1402.2982

arxiv:1402.6248

arXiv:1401.5361

arXiv:1402.6852
Photon polarization in $b \to s \gamma$

- Standard Model: photon almost fully left-handed in $b \to s \gamma$
  NP can introduce a significant right-handed component

- Measurement of up/down asymmetry in $B^+ \to K^+ \pi^- \pi^+ \gamma$ decay: $A_{	ext{UD}} \propto \lambda_\gamma$

- Proportional factor between $A_{	ext{UD}}$ and $\lambda_\gamma$ depends on the $K^{\text{res}} \to K^+ \pi^- \pi^+$ resonances and their interference: not well known
Photon polarization in $b \to s \gamma$

- Up-Down asymmetry measured in 4 bins of the $K^+ \pi^- \pi^+$ invariant mass

<table>
<thead>
<tr>
<th>$M(K\pi\pi)$</th>
<th>1.1, 1.3</th>
<th>1.3, 1.4</th>
<th>1.4, 1.6</th>
<th>1.6, 1.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{ud}$</td>
<td>6.9±1.7</td>
<td>4.9±2.0</td>
<td>5.6±1.8</td>
<td>-4.5±1.9</td>
</tr>
</tbody>
</table>

⇒ The photon is polarized at 5.2σ
⇒ First direct observation of photon polarization!

Theory input needed to extract polarisation
Search for Majorana neutrinos

• Search for Majorana neutrino in $B^- \rightarrow \pi^+ \mu^- \mu^-$ (forbidden in SM)
  – Search also for long-lived neutrinos: detached $\pi^+ \mu^-$ vertex

\[ \Rightarrow \text{Upper limit on } \text{Br}(B^- \rightarrow \pi^+ \mu^- \mu^-) \]
and on the coupling of N to muons
Lifetime measurements: introduction

Why?

• B-hadron lifetimes prediction: all equal at 0th order + corrections $\propto 1/m_b^2$
  ⇒ Test of Heavy Quark Expansion theory

• Width ($\Gamma_L, \Gamma_H$) and width difference ($\Delta \Gamma_{s,d}$) of mass eigenstates ($B_{s,d}$) ⇒ SM test

• $B_c$ exception: 2 heavy quarks, difficult predictions (weak and strong force interplay)
  ⇒ Test theory models (predictions $\tau(B_c) = 300 \text{-} 700$ fs)
  + important inputs to other measurements

How?

• Methods:
  – Absolute lifetime:
    • b-hadrons arXiv:1402.2554
    • $B_c$ arXiv:1401.6932
  – Ratio of lifetimes:
    • $\Lambda^0_b$ arXiv:1402.6242
    • $B^0_s \to D_s^- D_s^+$ arXiv:1312.1217

⇒ Most precise measurement of $\Gamma_L$

$\Gamma_L = 0.725 \pm 0.014 \pm 0.009 \text{ ps}^{-1}$
Measurement of $B_c^+$ lifetime using $B_c^+ \rightarrow J/\psi \mu^+ \nu_{\mu} X$

- $B_c$: only observed open-flavor state formed by 2 heavy quarks
  $\Rightarrow$ its decay dynamics have distinctive features

- Measurement of $B_c^+$ lifetime provides an essential test of theoretical models

- Predictions: $\tau(B_c) = 300-700$ fs

- LHCb analysis using partially reconstructed decay $B_c^+ \rightarrow J/\psi \mu^+ \nu_{\mu} (X)$
  - High statistic and clear $3\mu$ signature
  - Partial reconstruction
    $\Rightarrow$ Decay models needed for the dynamics of $B_c^+ \rightarrow J/\psi \mu^+ \nu_{\mu}$
Measurement of $B_c^+$ lifetime using $B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu X$

- **Important ingredients:**
  - Relate the pseudo propertime $t_{ps}$ to the decay time
  - 2D models of $M(J/\psi \mu)$ and $t_{ps}$ for bkg and signal

- The lifetime is extracted from a 2D fit of $t_{ps}$ and $M(J/\psi \mu)$

\[ \Rightarrow \tau(B_c^+) = 509 \pm 8 \text{ (stat)} \pm 12 \text{ (syst) fs} \]

PDG 2013: $\tau(B_c^+) = 452 \pm 33 \text{ fs}$
Measurement of b-hadron lifetimes

• Heavy quark expansion theory predicts b hadron lifetimes:
  ⇒ all b-hadrons lifetimes equal at 0th order + corrections $\propto 1/m_b^2$

• Measurement of absolute b-hadron lifetimes using $J/\psi$ X final states:
  – Detached $J/\psi$ vertex
  ⇒ Need to understand the efficiency as a function of the propertime
  ⇒ Data-driven technique based on $B^+ \to J/\psi K^+$ unbiased sample

Online VELO-track reconstruction efficiency
(for $J/\psi$)

Offline VELO-track reconstruction efficiency
(for K, $\pi$)

Distance to the beam line (mm)

Distance to the beam line (mm)
Measurement of b-hadron lifetimes

⇒ Most precise single measurements of b hadron lifetimes! (except $\Lambda^0_b$)

<table>
<thead>
<tr>
<th>Lifetime</th>
<th>Value [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{B^+ \to J/\psi K^+}$</td>
<td>$1.637 \pm 0.004 \pm 0.003$</td>
</tr>
<tr>
<td>$\tau_{B^0 \to J/\psi K^{*0}}$</td>
<td>$1.524 \pm 0.006 \pm 0.004$</td>
</tr>
<tr>
<td>$\tau_{B^0 \to J/\psi K^0_S}$</td>
<td>$1.499 \pm 0.013 \pm 0.005$</td>
</tr>
<tr>
<td>$\tau_{\Lambda^0_b \to J/\psi \Lambda}$</td>
<td>$1.415 \pm 0.027 \pm 0.006$</td>
</tr>
<tr>
<td>$\tau_{B^0 \to J/\psi K}$</td>
<td>$1.480 \pm 0.011 \pm 0.005$</td>
</tr>
</tbody>
</table>

⇒ Lifetime ratios in agreement with SM prediction and CPT invariance

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{B^+} / \tau_{B^0 \to J/\psi K^{*0}}$</td>
<td>$1.074 \pm 0.005 \pm 0.003$</td>
</tr>
<tr>
<td>$\tau_{B^0} / \tau_{B^0 \to J/\psi K^{*0}}$</td>
<td>$0.971 \pm 0.009 \pm 0.004$</td>
</tr>
<tr>
<td>$\tau_{\Lambda^0_b} / \tau_{B^0 \to J/\psi K^0_S}$</td>
<td>$0.929 \pm 0.018 \pm 0.004$</td>
</tr>
<tr>
<td>$\tau_{B^+} / \tau_{B^-}$</td>
<td>$1.002 \pm 0.004 \pm 0.002$</td>
</tr>
<tr>
<td>$\tau_{\Lambda^0_b} / \tau_{\Lambda_b}$</td>
<td>$0.940 \pm 0.035 \pm 0.006$</td>
</tr>
<tr>
<td>$\tau_{B^0 \to J/\psi K^{*0}} / \tau_{B^0 \to J/\psi K^0}$</td>
<td>$1.000 \pm 0.008 \pm 0.009$</td>
</tr>
</tbody>
</table>
Measurement of the $\Lambda^0_b / B^0$ lifetime ratio

- HQE theory predicts that $\Lambda^0_b$ and $B^0$ lifetimes differ only by few %
- 2013 PDG value: $\tau(\Lambda^0_b)/\tau(B^0)=0.798\pm0.052$
- LHCb measurement uses the ratio of yields:
  - $\Lambda^0_b \rightarrow J/\psi pK^-$
  - $B^0 \rightarrow J/\psi K^*(\rightarrow \pi^+K^-)$
  
  Same 4 track topology $\Rightarrow$ cancelation of systematics

Decay time distributions obtained by performing mass fits in bins of decay time

$\Rightarrow \tau(\Lambda^0_b)/\tau(B^0)=0.974 \pm 0.006 \pm 0.004$

in agreement with theory expectation!

$\Rightarrow \tau(\Lambda^0_b) = 1.468 \pm 0.009 \pm 0.008$ ps

(when combined with LHCb result arXiv:1402.2554)
Exclusive $J/\psi$ and $\psi(2S)$ production

- Exclusive $J/\psi$ and $\psi(2S)$ production: test of QCD and pomeron theory + constraint on gluon PDF

- Select events with
  - Exclusively 2 tracks identified as $\mu$
  - No photons
  - Low $p_T$

Shapes from HERA + theory for extrapolation

![Graphs and diagrams showing $J/\psi$ and $\psi(2S)$ distributions](image)
Exclusive $J/\psi$ and $\psi(2S)$ production

- First measurement of differential cross-section for $\psi(2S)$!
- Comparisons with theory predictions (LO, NLO and saturation effects)
  - $\Rightarrow$ need NLO
  - $\Rightarrow$ results agree with saturation models
Measurement of charged particles multiplicities in pp collisions

- Soft QCD measurements used for tuning of parameters in MC
  ⇒ vital for understanding background in NP search or precision measurements

- Prompt charged particle multiplicity measurement at 7 TeV
  ⇒ clear disagreement with PYTHIA6
Measurement of charged particles multiplicities in pp collisions

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  ⇒ clear disagreement with PYTHIA6
  ⇒ better with PYTHIA 8 (expected) but not perfect
LHCb Upgrade

- Velo and PID TDRs submitted to LHCC in December
- LHCb Tracker upgrade delivered to the LHCC on Feb 21st
- Only one more TDR to come: Online, DAQ and Trigger (June)
Tracker upgrade

**LHCb upgrade:**

- **Detector readout at 40 MHz** (1MHz hardware trigger removed)
  - ⇒ replacement of front-end electronics and of some sensitive elements
- **L = 2\times10^{33} \text{ cm}^{-2}\text{s}^{-1}, nb of pp int. per bunch crossing (\nu)=7.6 ⇒ higher occupancy**
  - ⇒ Need to increase granularity (TT, OuterT-stations)
- **Radiation dose**
  - ⇒ Some detectors need to be replaced to sustain the radiation during the upgrade
TT upgrade: UT

Why a TT? (upgraded version = Upstream Tracker)
- Fast momentum estimate for use in trigger
- Reconstruction of long-lived particles decaying beyond VELO
- Ghost rate reduction by ~ a factor 3
- Improves the momentum resolution (~25%)

Geometry of UT:
- Silicon sensors (10x10cm²) - 512 or 1024 strips

Detector optimization:
- minimize gaps (sensors overlap)
- maximize acceptance (beam pipe clearance)
- minimize material

- thermal insulation + box
TT upgrade

- Silicon sensors placed on staved system inspired by ATLAS upgrade silicon
- Cooling integrated into staves: -5 °C

40MHz silicon strip R/O → dedicated SALT ASICs chip

Occupancy
T stations upgrade: SciFi

- Current T-stations composed of 2 subdetectors:
  - Outer tracker (straw tubes) + Inner tracker (silicon micro-strip)
- Upgrade: replace all with scintilating fibers
  - Advantage of 1 single technology
  - Pattern recognition fast enough for HLT
  - Resolution <100\(\mu\)m, very low material budget (active material)

- Detector technology:
  - Scintillating fibers (\(\varnothing 250\mu\)m, L=2.5m)
  - Mirrors in the center for better light collection
  - Readout at 40MHz by SiPM
  - SiPMs + FE electronics in readout box
SciFi Tracker

- **Fibers**
  - Radiation studies:
    - Small effect on wavelength
    - Signal loss due to attenuation length acceptable
- **SiPM**
  - Hamamatsu and KETEK tested: OK
  - Fast signal response and recovery
  - Radiation: to be kept at -40 °C
- **Electronics**
  - Fast shaper (10ns)
  - 25ns gated integrator
  - Clusterization in FPGA
Upgrade Tracking performance

- New detector in simulation
- Track reconstruction algorithm rewritten for new detector
  \[ \Rightarrow \text{Efficiency, ghost rates, resolution} \]

- **Long tracks reconstruction efficiency:**
  For b-hadron daughters, \( p > 5 \text{GeV/c} \):
  \[
  \begin{array}{ccc}
  \text{current LHCb} & \text{Upgrade LHCb} & \text{Upgrade LHCb} \\
  \text{Luminosity (cm}^{-2}\text{s}^{-1}) & 4 \times 10^{32} & 1 \times 10^{33} \mid 2 \times 10^{33} \\
  \text{efficiency (\%) } & 96.8 & 95.6 \mid 94.7 \\
  \end{array}
  \]
  \[ \Rightarrow \text{Good overall efficiencies} \]
  - Algorithm not tuned
  - Detector geometry can be tuned as well

- **Momentum resolution:**
  - Better than current design thanks to less material
Conclusions

- LHCb is producing lots of high quality data results
  And still more to come with Run1 data!

- Improvements / maintenance on the detector going smoothly during LS1

- Actively preparing Run2 and the restart

- The penultimate TDR has been submitted (Tracker)
  Last TDR to come: Online, DAQ and trigger (June)

- All the upgrade activities are on schedule for LS2
SPARES
Search for b-baryons decays:
\[ \Lambda_b^0 (\Xi_b^0) \rightarrow K_s^0 p \pi^- \] and \[ K_s^0 pK^- \]

- Study of b-baryons is an almost unexplored field: large program!
- Search for \[ \Lambda_b^0 (\Xi_b^0) \rightarrow K_s^0 p \pi^- \] and \[ K_s^0 pK^- \] and \( B \) measurement wrt \[ B_s^0 \rightarrow K_s^0 \pi^+ \pi^- \]

First observation of \[ \Lambda_b^0 \rightarrow K^0 p \pi^- \]

First measurement of CP asymmetry

\[ B(\Lambda_b^0 \rightarrow \bar{K}^0 p \pi^-) = \frac{(1.57 \pm 0.21 \pm 0.08 \pm 0.42 \pm 0.06) \times 10^{-5}}{ \text{Candidates} / (10^6 \text{MeV}^2) } \]

\[ A_{CP}(\Lambda_b^0 \rightarrow \bar{K}_s^0 p \pi^-) = (0.22 \pm 0.13 \pm 0.03) \]
Study of CP violation in $B \to DK(\pi)$ decays

SS

OS
Bc lifetime

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**Graph 1:**
- **LHCb**
- Misid. prob. [%] vs Momentum [GeV/c]
- Data points for Kaons, Protons, and Pions

**Graph 2:**
- **Bc** lifetime (fs)
- Data points for CDF, CDF II, D0, PDG2013 (all channels), and LHCb

**References:**
- CDF
- CDF II
- D0
- PDG2013 (all channels)
- LHCb

**Publications:**
- PRL 81 2432
- PRL 97 012002
- PRL 102 092001
- PRD 87 011101
- PRD 86 010001
- LHCb-PAPER-2013-063
\( \Lambda^0_b \) lifetime

- Background from misid: shapes from MC, yields from data
Search for Majorana neutrino: limits
Upgrade Tracking performance

- Adding UT hits to Long tracks:
  - reduction of ghost rates by a factor $> 2$
  - Drop of efficiency $\sim 1\%$