Tilting vertically the LHC beam while crossing in LHCb
Highlights of LHCb results from 2012 Winter Conferences (1)

Moriond EW, $B_s \rightarrow \mu \mu$

$B(B_s \rightarrow \mu \mu) < 4.5 \times 10^{-9}$ at 95% CL

Moriond QCD, $B_d \rightarrow K^* \mu \mu$

Moriond EW, $B_s \rightarrow J/\psi \phi$

CPV in $c$ quark

$\Delta a_{CP}$

$\Delta \Gamma_s$ vs $\phi_s^{J/\psi \phi}$ (rad)
Highlights of LHCb results from 2012 Winter Conferences (II)

Moriond QCD
$\Delta m_s$ from $B_s \to K^+K^-$

E. weak FW asymm.

L. Louise CPV in $B \to DK$

LaThuile $A_{CP}(B_d \to K^{*}\gamma)$
• Consolidation of Electrical Network

~ 5 km cable - 2x2MVA new transformers
New switchboards
→ More Redundancy, flexibility, reliability
→ Max down time in case of EBD or EXD failure: 1h

• Consolidation of detector cooling plants

• Consolidation of IT & TT fridges

• Radioprotection survey

• Start preparing LS1 (with several maintenances but also in view of upgrade)
Shutdown activities (detectors)

Aerogel – installation of gas tight box to prevent $\text{C}_4\text{F}_{10}$ contamination

$TT$ - Electrostatic shielding improvement

$IT$ – Survey with and w/o magnetic field, VCSEL exchange

$OT$ – General maintenance and source scans for aging studies (NO AGING)

$RICH$ – HPD exchange (37 in total)

$CALO$ – Usual maintenance (PM and electronics)

$Muon$ – New shielding (partial) for M5 chambers + general maintenance (chambers and electronics)

$Online$ - +10% in CPU and upgraded disk space (for deferred trigger)

+ radiation tolerance & shielding upgrade studies (SiPM, SciFi, Ecal/Hcal modules)
Prospects for LHCb data taking in 2012

**LHC running conditions**
- $\sqrt{s} = 8$ TeV (b-bbar cross section increases +15%)
- $L \sim 4 \times 10^{32}$ cm$^{-2}$s$^{-1}$ (in LHCb)
- Bunch spacing 50 ns (ok, this level of pileup is not an issue for LHCb)
- LHC crossing angle in LHCb in the vertical plane (fully symmetric with magnet swaps) → useful for the future (when spacing=25 ns)

**LHCb running conditions**
- Keep detector efficiency and data quality high
- L0 output ~ 1 MHz (maximum allowed)
- HLT output ~ 4.5 kHz (with upgraded farm [+10%] and better HLT trigger) → increase in yields of charm ($K_s$ in HLT1) and in b-hadronic channels
- Deferred HLT event processing during LHC inter-fills (planning to gain at least another 10% in CPU power)

Considering the experience of 2011 → target of $\geq 1.5$/fb on tape in 2012
- Expected increase in event yields in 2012
- Energy (better S/B) + improved HLT + more CPU $\sim +20$-30% (mainly had. decays)
2012 data taking startup

Good startup of data taking: ~90% eff.
~60/pb of usable data collected

First week of collisions useful to:
- test vertical collision scheme in LHCb (delicate, but successful)
- L0 & HLT tuning (8 vs 7 TeV)
- test successfully HLT deferred trigger (at level of 10% CPU gain)

HLT-online reconstructed charm 2-body: same S/B, increased yield (amount under study)
Performance w/o & during deferring

Deferred HLT - Tuesday Meeting 24/4/12 - Niko Neufeld
B mesons Rare Decays
A multivariate discriminant BDT: kinematical and geometrical variables signal uniformly distributed [0,1] trained with MC estimated with data:
signal $B \rightarrow h h$ trigger unbias background: $B_s \rightarrow \mu \mu$ sidebands

Events expected in the most sensitive region (BDT>0.5): 5.3 ($B_s \rightarrow \mu \mu$), 0.6 ($B_d \rightarrow \mu \mu$)
Pre-Higgs, with $M = 125$ GeV and $g-2$ constraint dropping $g1$.

$B(B_s \to \mu^+ \mu^-)$ < $4.5 \times 10^{-9}$ at 95% CL

$B(B \to \mu \mu)$ < $10.3 \times 10^{-10}$ at 95% CL

<table>
<thead>
<tr>
<th>Mode</th>
<th>Limit</th>
<th>at 95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s^0 \to \mu^+ \mu^-$</td>
<td>Exp. bkg+SM</td>
<td>$7.2 \times 10^{-9}$</td>
</tr>
<tr>
<td></td>
<td>Exp. bkg</td>
<td>$3.4 \times 10^{-9}$</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>$4.5 \times 10^{-9}$</td>
</tr>
<tr>
<td>$B^0 \to \mu^+ \mu^-$</td>
<td>Exp. bkg</td>
<td>$1.1 \times 10^{-9}$</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>$1.0 \times 10^{-9}$</td>
</tr>
</tbody>
</table>

Observed limit is stronger than expected: if (true) BR equals SM, under-fluctuation of the signal

With 2.5/ fb (expected at the end of 2012), still able to observe SM signal at 3 sigma

BR estimation:
simultaneous unbinned LL fit to the mass to the 8 BDT bins

$B(B_s \to \mu \mu) = (0.8^{+1.8}_{-1.3}) \times 10^{-9}$
LHCb flavor results constraining New Physics

\( \text{BR}(B_s \rightarrow \mu\mu) \) puts strong bounds on mass scale (at least in high \( \tan \beta \) models), complementary to direct searches; LHCb results enter the SUSY fits and moreover put severe bounds on several models.

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N. Mazhoudi, Moriond QCD2012

D. Straub [arXiv:1107.0266]
Several angular variables can be fitted to search for NP in a clean theoretical environment:

- \( F_L \), fraction of \( K^* \) longit. polar.
- \( A_{FB} \), the forward backward asymmetry
- \( S_3 \), the asymmetry in \( K^* \) transv. polar.
- \( A_{IM} \), a T-odd CP asymmetry

Strong agreement (so far) with SM, also for the differential branching ratio \((dB/F/dq^2)\)
B^0 \rightarrow K^{*0} \mu^+\mu^- \quad A_{FB} \text{ zero-crossing point}

- The SM predicts $A_{FB}$ to change sign at a well defined point in $q^2$
- This zero-crossing point $q_0^2$ is largely free from form-factor uncertainties
- Extracted through a 2D fit to the forward- and backward-going $m_{B^0}$ and $q^2$ distributions

The world's first measurement of $q_0^2$, at $q_0^2 = 4.9^{+1.1}_{-1.3}$ GeV$^2$/c$^4$ [preliminary]

This is consistent with SM predictions which range from $4 - 4.3$ GeV$^2$/c$^4$ [2, 3, 4]
First observation of $B^+ \rightarrow \pi^+ \mu^+ \mu^-$

- This is the first observation of a $b \rightarrow d\ell\ell$ transition
- LHCb$(1.0 \text{ fb}^{-1})$: $B^+ \rightarrow \pi^+ \mu^+ \mu^-$: $25.3^{+6.7}_{-6.4}$ signal events
  - $5.2\sigma$ excess above background
- The measurement is consistent with the SM prediction

$$B(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-8} \text{ [preliminary]}$$

The rarest B decay ever observed
CP violation in B meson decays
Results on CP Violation in $B_s$ Mixing
[measurements of $\phi_s$ and $\Delta\Gamma_s$]

- Measure relative phase difference $\phi_s = \phi_M - 2\phi_D$ between two “legs”

- $B_s \rightarrow J/\psi\Phi$ and $B_s \rightarrow J/\psi\pi\pi$ are very clean decays

- Approx. 21200 signal events ~ CP odd in the whole mass range
$\phi_s = -0.002 \pm 0.083 \pm 0.027$ rad

$\Gamma_s = 0.6580 \pm 0.0054$ (stat.) $\pm 0.0066$ (syst.) ps$^{-1}$

$\Delta \Gamma_s = 0.116 \pm 0.018$ (stat.) $\pm 0.006$ (syst.) ps$^{-1}$
Removing the ambiguity: the sign of $\Delta \Gamma_S$

- There are two ambiguous solutions related by $\phi_s \Leftrightarrow \pi - \phi_s$ and $\Delta \Gamma \Leftrightarrow -\Delta \Gamma$
- We can disambiguate using the P-Wave $\Leftrightarrow$ S-Wave interference (strong phase of KK)

- $\Delta \Gamma_S = \Gamma_L - \Gamma_H > 0$: solution I (the correct one) shows the lighter $B_s$ mass eigenstate is aligned with CP=+1 and is decaying faster
- Analogy with the $K_L - K_S$ system

**Graphical Elements:**
- Strong phase plots for P wave and S wave
- Graph showing $\delta_S - \delta_P$ versus $m_{KK}$
- LHCb data points for solutions I and II

**ArXiv Reference:** arXiv:1202.4717
Observation of CP violation in $B^{\pm} \rightarrow DK^{\pm}$ decays

**ADS suppressed modes**

**Very rare transitions:**
$BR \sim 10^{-7}$

**Combining all $B \rightarrow DK$ decays,**
CPV in $B^{\pm}$ observed with 5.8 $\sigma$

First steps toward measurement of $\gamma$ with tree decays

Significant impact on determination of $\gamma$ expected

arXiv:1203.3662
Time-dep. CPV in B charmless decays (hh)

First measurement of time dependent CP asymmetries with $B_s \rightarrow KK$

First step toward the measurement of $\gamma$ with loops
CP violation in Charm decays
CP violation in charm decays

Measure CP asymmetry in Time Integrated single Cabibbo suppressed $D^0 \to hh$ decays

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(D^- \to f)}{\Gamma(D^0 \to f) + \Gamma(D^- \to f)}$$

$f = KK$ or $\pi\pi$
$D^0$ tagged by $D^* \to D^0 \pi_{soft}$

$$A_{raw}(f) = A_{CP}(f) + A_{D}(\pi_s) + A_{P}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of $D^0$

Detection asymmetry of "slow" pions

Production asymmetry

$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

In the difference $A_{raw}(KK) - A_{raw}(\pi\pi)$ the production and the $\pi_{soft}$ asymmetries cancel (at 1st order)
In first approximation, measuring $\Delta A_{\text{CP}}$ at LHCb, means measuring direct CPV

$$\Delta A_{\text{CP}} = [a_{\text{CP}}^{\text{dir}}(K^-K^+) - a_{\text{CP}}^{\text{dir}}(\pi^-\pi^+)]$$

The analysis (\(~0.6 /fb\)) takes into account
- $p_t$ spectrum of $\pi_{\text{soft}}$
- $\eta$ and L/R detector acceptance
- magnet polarities swaps
- run blocks, etc..

Fit of $\Delta A_{\text{CP}}$ value in 216 “kinematic” bins
$\rightarrow$ 3.5 $\sigma$ effect (compatible with HFAG data)

$$\Delta A_{\text{CP}} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})] \%$$

Next steps:
- Update analysis with 1/fb
- Complementary analysis with $B \rightarrow D$ semileptonic tagging
- Search for CPV in other charm decays
CPV in charm: theoretical framework

LHCb result generated a strong interest among theoreticians

CP violation in charm was expected to be very small: $O(0.1\%)$ or less: a larger value would have implied NP

Deeper analyses of current constraints (eg D mixing) suggest less strong statements. SM could still explain the current result, re-evaluating penguin contributions

Theorists have suggested several channels that we can study to try to confirm or disprove if the effect can be accommodated in the SM

Explanations of the LHCb result in SM, and in NP models:
- Isidori et.al. arXiv:1103.5785 ⇒ NP explanation in a model independent way
- Brod et.al. arXiv:1111.4987 ⇒ Large 1/$m_c$ suppressed amplitude
- Rozanov et.al. arXiv:1111.5000 ⇒ Large penguin in sequential 4th generation model
- Pirtskhalava et.al. arXiv:1112.5451 ⇒ Badly broken $SU(3)_F$ symmetry
- Cheng et.al. arXiv:1201.0785 ⇒ Large weak penguin annihilation contribution
- Bhattacharya et.al. arXiv:1201.2351 ⇒ CP conserving NP in penguin
- Giudice et.al. arXiv:1201.6204 ⇒ Left-right flavour mixing via chromomagnetic operator
- Altmannshofer et.al. arXiv:1202.2866 ⇒ Chirally enhanced chromomagnetic penguins
- Brod et.al. arXiv:1203.6659 ⇒ In SM via s- and d-quark penguin contraction
- ........many more
... and many more other results

- Inclusive Low mass Drell Yan production in the forward region (LHCb-CONF-2012-013)
- Search for $B_{(d,s)} \rightarrow \mu\mu\mu\mu$ (LHCb-CONF-2012-010)
- Search for $D^0 \rightarrow \mu\mu$ (LHCb-CONF-2012-005)
- $B_s$ decays in double charm final state (LHCb-CONF-2012-009)
- CP asymmetry in $B_d \rightarrow K^*\gamma$ decay (LHCb-CONF-2012-004)
- $B_s \rightarrow \phi\mu\mu$ decays (LHCb-CONF-2012-003)
- $B_s \rightarrow KK$ lifetime (LHCb-CONF-2012-001)
- Measurement of $\sigma(\chi_{c2}) / \sigma(\chi_{c1})$ of prompt $\chi_c$ mesons (arXiv 1202.1080)
- $Y$ production (arXiv 1202.6579)

+ searches for Majorana neutrinos, exotic states, quarkonia, etc…

As of today, 49 LHCb physics papers (+ 9 final drafts in circulation in the Collaboration)
(at last RRB we had 15 papers, > 200% increase)
Based on 2011 experience LHCb can collect ~ 1.5/fb per year

- 2012 @8 TeV and 2015-16-17 @13 TeV

By the end of 2017 ≥ 5/fb collected

Reaching ultimate theory precision in flavor variables will need more statistics

Current LHCb limitation: trigger rate capability. Upgrade plans:
- 1 MHz → 40 MHz readout
- Full software trigger
- Up to L ~ 2 \(10^{33} \text{ cm}^{-2}\text{s}^{-1}\) to collect 50/fb

Expected annual physics yields increase:
- \(x5\) in muonic channels
- more than \(x10\) in hadronic channels (\(B_s \rightarrow \phi\phi, \text{DK, charm, etc...}\))

Installation of upgraded LHCb during LS2 (2018)
LHCb Upgrade: the formal steps

- **March 2011**, “Letter of Intent for the LHCb Upgrade” submitted to LHCC
  → Endorsement of physics case. Review of proposed trigger concept (40 MHz)

- **June 2011**, Positive peer review of trigger concept
  → LHCC endorses the LOI, green light for TDR preparation

- **June 2012**, Submission of “Framework TDR for the LHCb Upgrade” to LHCC
  (intermediate document describing the plan, cost and resources needed for the upgrade)

- **September 2012**, Approval of “Framework TDR” expected

- **October 2012**, Presentation of “Framework TDR” to RRB and to Funding Agencies
  → Start of negotiations for signing the “Addenda to MoU for the LHCb Upgrade”

- **Fall 2013**, Submission of LHCb subsystems TDRs to LHCC

The “Framework TDR” will address the schedule, a first (reasonably accurate) evaluation of CORE costs and of interests of institutes
→ working document to the FA for R&D funding and for “cost envelopes” definition
The schedule for the LHCb Upgrade

2012  LHCb data taking (8 TeV)
2013-14  LHC LS1 / LHCb maintenance, first infrastructures for upgrade
2015-17  LHCb data taking (13 TeV → 14 TeV)
2018  **LHC LS2 / LHCb upgrade installation**
2019-21  LHCb data taking
≥ 2022  LHCb data taking @ HL-LHC*

LHCb Upgrade preparation

2012-13  R&D, technology choices, subsystems TDRs
2013-14  Requests for approval/Funding/Start of productions
2015-18  Construction & installation

* Coord. Committee between LHC-HL and experiments, setup by CERN management
“To agree upon a common and coherent set of goals, parameters and plans for the HL-LHC project, while providing a forum for official information transfer on the status of the project.”
LHCb detector modifications for the upgrade

- **VELO**
  - Si strips
  - (replace all)

- **Silicon Tracker**
  - Si strips
  - (replace all)

- **Outer Tracker**
  - Straw tubes
  - (replace R/O)

- **Muon MWPC**
  - (almost compatible)

- **RICH**
  - HPDs
  - (replace HPD & R/O)

- **Calo**
  - PMTs
  - (reduce PMT gain, replace R/O)

- **Alternative option:**
  - Central Tracker (fibers)
“40 MHz” upgrade scheme:
• new vertex detector (VELO)
• new tracking systems (TT, CT, OT)
• new photo sensors and FEE on RICH
• front end and readout electronics upgrade for OT – CALO – MUON
• software trigger (efficiency for hadronic channels ~ double)

Preliminary evaluation of upgrade cost ~ **57 MSF**
• CORE cost for upgraded detectors ~ 41 MSF
• CORE cost for Common Projects ~16 MSF (Online, Common Electronics, General Infrastructure)
Collaboration matters

- **Cincinnati University** (Babar - interests in charm physics, HLT and upgrade) has become LHCb associate member. Host institute: Syracuse. Grant application for funding to NSF submitted in October.

- **Lahore University** (interests in b physics) has become LHCb associate member. Host institute: Syracuse.

- **Negotiations ongoing** with several other institutes (strong commitment to enlarge the Collaboration, also in view of the upgrade)
LHCb performed well in the 2012 data taking startup (a particular thank to LHC team for the careful tuning of vertical crossing !)

A lot of activities and very good perspectives for “world record” measurements (several already achieved) with 1 fb⁻¹ in CPV in b and c decays, CKM angle γ , rare decays + a very large spectrum of other physics items

Looking forward to increase the statistics in 2012 and later in 2015-17

Standard Model remains “un-cracked” but still large room for New Physics: LHCb is complementing ATLAS & CMS searches for Supersymmetry
Charm CPV is a nice surprise ! Further experimental and theoretical study required

Upgrade goal: reaching ultimate theoretical errors in flavor variables and search for unexpected phenomena in the forward region: 50/fb needed

“Clock for LHCb Upgrade has started (Framework TDR)” (quote from LHCC chairman)