Status of the *LHCb* Experiment

2nd International Symposium, LHC physics and detectors
28-30 June 2000, JINR, Dubna, Russia

On behalf of the LHCb collaboration
Tatsuya Nakada
CERN/University of Lausanne

(permanent address: PSI)
When LHCb will come to operation in 2005,
Test of the KM model by: BABAR, BELLE, CLEO-III
CDF, D0, HERA-B

Theoretically clean analysis based on the Standard Model:

\[ |V_{cb}| \text{ from } B \rightarrow H_c X \text{ decays: } A \]
\[ |V_{ub}| \text{ from } B \rightarrow H_u \ell \nu \text{ decays: } \rho^2 + \eta^2 \]

\[ B_d - \overline{B}_d \text{ and } B_s - \overline{B}_s \text{ mixing, } \Delta m_d / \Delta m_s : (1 - \rho)^2 + \eta^2 \] 
\[ (\rho, \eta) \text{ determined} \]

CP asymmetry in \( B_d \rightarrow J/\psi \ K_S \): \( \sin 2\phi_1 \)
\[ \phi_1 = \tan^{-1} \frac{\eta}{(1 - \rho)} \]

\[ \text{NB } \phi_1 + \phi_3 \text{ measurement will be difficult...?} \]
\[ \phi_3 = \tan^{-1} \frac{\eta}{\rho} \]

Theoretically clean \( \approx \) One decay diagram
\[ F(\text{CP asymmetry in } B \rightarrow J/\psi \ K_S) = \tan^{-1} \frac{\eta}{1-\rho} \]

\[ k' \Gamma(B \rightarrow H_u \ell \nu) = \rho^2 + \eta^2 \]

\[ k \frac{\Delta m_d}{\Delta m_s} = \eta^2 + (1-\rho)^2 \]

Standard Model analysis
~2005
BABAR, BELLE, CDF, D0, HERA-B
Extensions to the Standard Model

$\Delta b = 1$ process: **Decays**
through penguin

$\Delta b = 2$ process: **Oscillations**
through box

through tree

The Standard Model tree process not affected.
May be the truth is ...

\[ F(\text{CP asymmetry in } B \rightarrow J/\psi K_S) = \tan^{-1} \frac{\eta}{1-\rho} + NP' \]

\[ k \frac{\Delta m_d}{\Delta m_s} = \eta^2 + (1-\rho)^2 + NP \]

\[ k' \Gamma(B \rightarrow H_u \ell \nu) = \rho^2 + \eta^2 \]
LHC

The most intensive source of $B_u$, $B_d$, $B_s$ and $B_c$,

$\sigma_b = 500 \ \mu b$, $\sigma_{\text{inelastic}} = 80 \ \text{mb}$

Search for physics beyond CKM

good measurement of $\phi_1 + \phi_3$: $B_d \rightarrow \rho \pi$
good measurement of $2\phi_1 + \phi_3$: $B_d \rightarrow D^* n\pi$
good measurement of $2\delta\phi_3 - \phi_3$: $B_s \rightarrow D_s K$
good measurement of $\delta\phi_3$: $B_s \rightarrow J/\psi \phi$
measurement of $\phi_3$: $B_d \rightarrow K\pi$
penguin decays, $K^* \gamma$, $\phi\pi^0$..., etc.
The *LHCb* experiment

Running with a modest luminosity of

\[ \langle L \rangle \sim 2 \times 10^{32} \ (L_{\text{nominal}} = 10^{34}), \quad 10^{12} \ \text{bb}/10^7 \ \text{sec} \]

with a detector capable of

- **trigger**: efficient for both leptonic and hadronic final states.
- **particle identification** \((K/\pi)\): \( \sim 1\text{GeV}/c < p < \sim 100\text{GeV}/c \)
  
  lepton + kaon tag \( \rightarrow \varepsilon_{\text{tag}} = 0.4, \ \omega = 0.3 \)
- **\(\sigma_{\tau}\)**: able to study CP violation in the \(B_s\) system,
  
  \( \sim 43 \ \text{fs for } B_s \rightarrow D_s \ \pi(K) \)
  
  \( \sim 30 \ \text{fs for } B_s \rightarrow J/\psi \ \phi \)
The LHCb Collaboration (May 2000)

France: Clermont-Ferrand, CPPM Marseille, LAL Orsay

Germany: Humboldt Univ. Berlin, Univ. Freiburg, Tech. Univ. Dresden,
Phys. Inst. Univ. Heidelberg, IHEP Univ. Heidelberg, MPI Heidelberg,

Italy: Bologna, Cagliari, Ferrara, Firenze, Frascati, Genoa, Milan,
Univ. Rome I (La Sapienza), Univ. Rome II (Tor Vergata)

Netherlands: NIKHEF


Spain: Univ. Barcelona, Univ. Santiago de Compostela

Switzerland: Univ. Lausanne, Univ. Zürich

UK: Univ. Bristol, Univ. Cambridge, Univ. Edinburgh, Univ. Glasgow, IC London,
Univ. Liverpool, Univ. Oxford, RAL

CERN

Brazil: UFRJ

China: IHEP (Beijing), Univ. Sci. and Tech. (Hefei), Nanjing Univ., Shandong Univ.,
Tsinghua Univ.

Russia: INR, ITEP, Lebedev Inst., IHEP, PNPI (Gatchina)

Romania: IFIN-HH (Bucharest)


Associated member: Espoo-Vantaa Inst. Tech. (Finland), Geneva Engineering School (Switzerland)
Detector Subsystems

Magnet
TDR approved

Vertex Locator\(^1\)
TDR April 2001
Si \(r-\phi\) mini-strip detectors

Inner Tracker\(^1\)
TDR September 2001
All Si strip or Si+Triple GEM

Outer Tracker\(^1\)
TDR March 2001
Straw drift chambers

RICH System
TDR LHCC presentation October 2000

Calorimeter System\(^2\)
TDR LHCC presentation October 2000
Preshower (Scintillator/Pb/ Scintillator), E-cal (Shashlik), H-cal(Fe-Scintillator tile)

Muon System\(^3\)
TDR January 2001
MWPC’s + single or double gap RPC’s

Trigger\(^4\)
TDR January 2002

Computing
TDR July 2002

Separate talks by 1)O.Steinkamp, 2)A.Goloutvin, 3)B.Schmidt, 4)O. Callot, A. Tsaregorodtsev
Magnet

BDL = 4 Tm
Normal conductor (Al)
Power = 4.2 MW
Yoke = 1450 t
TDR submitted January 2000.

- Positively evaluated by the LHCC magnet advisory board.
- Recommended for approval by LHCC in March 2000.
- Approved by Research Board in April 2000.
- Authorisation to commit money by Resource Review Board in April 2000

- Call for tender soon.
Trigger

Muon System: high $P_T$ muons

Calorimeter System: high $P_T$ electrons, photons and hadrons

pile-up vertex detector

pile-up veto

40 MHz

Level-0 decision unit

40 kHz

Level-1 trigger unit

VELO

1 MHz

Level-0 yes

Level-1 yes

readout
<table>
<thead>
<tr>
<th>Level</th>
<th>Characteristics</th>
<th>Sub-detector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level-0</strong></td>
<td>high $p_T$</td>
<td>ECAL (60k channels)</td>
</tr>
<tr>
<td></td>
<td>$e, \gamma, \pi^0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h$</td>
<td>E+HCAL</td>
</tr>
<tr>
<td></td>
<td>$\mu$</td>
<td>Muon</td>
</tr>
<tr>
<td></td>
<td>pile-up</td>
<td>Pile-up</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in-put 40 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>latency 4.0 $\mu$s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Level-1</strong></td>
<td>sec. vertices</td>
<td>Vertex (220k)</td>
</tr>
<tr>
<td></td>
<td>high $p_T$</td>
<td>vertex+L0 information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MHz ~1 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Higher Levels</strong></td>
<td>refined sec. vertices, partial and full reconstruction of final states</td>
<td>All information available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To tape = 200 Hz</td>
</tr>
</tbody>
</table>

on-detector $\rightarrow$ off-detector electronics (1 TB/s)

off-detector $\rightarrow$ event buffer (2-4 GB/s)
Level-1 vertex trigger

- Si
- Off detector electronics
- Readout unit
- Network
- CPU’s

- set a benchmark using SCI technology
- validate the simulation results with measurements
- test different network architecture
- input to the selection of final technology

simulated by PTOLEMY
Level-1 algorithm:
1) Track finding with $r$-strip information
2) Primary vertex reconstruction
3) Selection of secondary track candidates
4) Full $r$-f reconstruction of secondary tracks
5) Reconstruction of two-track secondary vertices
6) Event selection

![r-track reconstruction](image)
<table>
<thead>
<tr>
<th>Process</th>
<th>L0(%)</th>
<th>L1(%)</th>
<th>L2(%)</th>
<th>Total(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_d \rightarrow J/\psi(\mu\mu)K_S + \text{tag}$</td>
<td>87 6 16 88</td>
<td>50 81</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>$B_d \rightarrow J/\psi(ee)K_S + \text{tag}$</td>
<td>17 63 17 72</td>
<td>42 81</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>$B_s \rightarrow D_s K + \text{tag}$</td>
<td>15 9 45 54</td>
<td>56 92</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>$B_d \rightarrow DK^*$</td>
<td>8 3 31 37</td>
<td>59 95</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>$B_d \rightarrow \pi^+\pi^- + \text{tag}$</td>
<td>14 8 70 76</td>
<td>48 83</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

- trigger efficiencies are ~ 30%
- hadron trigger is important for hadronic final states
- lepton trigger is important for final states with leptons
Optimal Running luminosity is determined by # of bunch crossing with one pp interaction vs radiation damage, detector occupancy, bunch-bunch pile-up, etc.

LHCb
Average running luminosity
\[ 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \] (tuneable)

4.5 \times 10^{11} B^0 + \bar{B}^0
1.3 \times 10^{11} B_s^0 + \bar{B}_s^0 \text{ in one year}
Example:
Thresholds for three different L0 trigger components can be adjusted depending on the running condition.

Stability of the trigger has been tested in many ways.
Event generator

Our current setting: (reproduces much better the UA5 and CDF data)

More complicated multiple parton interaction model (Pythia Model 3)

“$P_T^{\text{min}}$” increases with energy

CTEQ4L structure function (post-HERA)
b events are selected from minimum bias events (gluon splitting included)

\[
\text{Total } N_{\text{charge}}\text{ distribution at } \sqrt{s} = 14 \text{ TeV}
\]
In the LHCb acceptance

No big effect on the Level-0 trigger performance!
DAQ after L-1

required: 4GB/s sustained
current technologies: >8GB/s

High level trigger

No distinction between Level-2 and Level-3 trigger any more.
SICB
Event generation (PYTHIA), Detector tracking (GEANT3), Digitisation, Event reconstruction, Analysis all in one Fortran program

SICBMC
Event generation

SICBDST
Reconstruction and Analysis

GAUDI
C++ based LHCb offline framework

BRUNEL
event reconstruction (currently includes digitisation) wrapped Fortran routine → C++ routines

DA VINCI
event analysis wrapped Fortran routine → C++ routines

GEANT-4 based event generation to be defined
LHCb Computing Model For Production

~5k CPU’s @ 2005 total needed for LHCb

Production
Centres

Data
Production

Reconstruction
First-path analysis

Locally kept
real raw data (100TB/y)
ESD (100TB/y)

Distributed among
all the centres

AOD
Event Tag

m.c. raw data
ESD

m.c. raw data
ESD

~2 times real data

(~1/5 of ESD)
RICH Systems

Photo detectors

$C_4F_{10}$

mirror

Beam pipe

Track

Gas $CF_4$

$\theta_c$

330 mrad

300 mrad

120 mrad

( m)
Baseline photon detector Pixel HPD
(backup solution Multianode PMT)

Pixel sensor + electronics: LHCb
Tube design: LHCb + DEP
Encapsulation of tube: DEP
ALICE/LHCb Pixel electronics

ALICE pixel unit

Analog 130µm
- pre-amp (differential)
- shaper (differential)
- discriminator (+ fast OR)
- 50µW static consumption

Digital 260µm
- two digital delay units
- trigger coincidence logic
- 4-event FIFO buffer
- readout logic

1 LHCb pixel unit made out of 8 ALICE pixel units
-design has been sent for production-
RICH-2 prototype beam test

Results from the beam test are incorporated in the simulation!
**RICH Performance**

Realistic simulation:
- tested by the test beam data
- engineering design
- measured HPD performance
- all the background photons
- pattern recognition
  
  (some can still improve)

No. of detected photons
- 7.5: RICH-1 aerogel
- 41: RICH-1 $C_4F_{10}$
- 19: RICH-2 CF$_4$
$B_s \rightarrow D_s^+ K^\pm$ analysis ($-2\delta \phi_1 + \phi_3$)

\[ \sigma \sim 43 \text{ fs} \]

without RICH

with RICH

$D_s^+ \pi$ Background

$D_s K$ Signal

$D_s K$ Signal

$D_s^+ \pi$ Background

Invariant Mass (GeV/c$^2$)
Conclusions

-Evolving rapidly from the Technical Proposal
Changes are made and options are reduced: major items are
-Magnet: normal conductive coil
-RICH: pixel HPD baseline
-Outer tracker: straw drift tubes
-Inner tracker: Si or Si and triple-GEM
-Calorimeter: scintillator plane in front of Preshower
-Muon: MWPC or MWPC and SRPC (or DRPC)
-Trigger: no track trigger in Level-1
-Computing: push protocol for DAQ

Robustness of the trigger has been demonstrated.
Physics performance studies have been extended

-All the subsystems are proceeding well toward the Technical Design Reports

-Better understanding of necessary and available resource, MoU autumn 2000