Status of the LHCb Experiment
LHCC open session
24 November 2004

on behalf of the LHCb Collaboration
Tatsuya Nakada
CERN
and
École Polytechnique Fédéral de Lausanne (EPFL)
Contents

I) Experimental Area

II) Sub-detector systems
   1) Magnet
   2) Beam Pipe
   3) VELO
   4) Tracking System (Si Tracker and Outer Tracker)
   5) RICH System
   6) Calorimeter System
   7) Muon System

III) Trigger

IV) Computing

V) Coming Installation

VI) Conclusions
I) Experimental Area
II) Status of Subsystems
1) Magnet

Completed and successfully switched on!

Fe Yoke 1.45 kt
Al normal conductive coil 2×25 t

Power 4.2MW at 1 T field
RICH-2 photon detector shielding box placed at right position

B field measurement in the box along the HPD plane

No problem for the HPD operation
Agree within a few Gauss with the simulation.

B at various points at the cryogenic plant given to machine group
Commissioning work will continue and improvement will be made for
• better adjustment of the incoming water temperature control
• more cooling power for the summer operation

A field map measurement is planned for the coming period, but no firm schedule can be made due to the limited power availability at CERN over the winter.

The final field map must be measured after all the metallic structures around the magnet are installed → end of 2005.
2) Beam pipe

VELO vacuum tank exit window

- Al flanges and bellows
- Al bellow + flanges
- Al-stainless steel bimetallic flange

- 25 mrad Be section
- 10 mrad Be sections

- stainless steel bellows, flange and beam pipe

- completed by industry
- ready for fabrication at CERN
- being fabricated by industry
- design being finalised
3) VELO

VELO vacuum tank

Si sensor

detector box support

secondary vacuum rf-box

84 mm

~ 1 m

collision point

beam axis

10°-20° stereo angle

r-sensors

φ-sensors

Readout Chips

diodes

routing lines
vacuum tank stand and support frame

secondary vacuum rf-box

stress test of rectangular bellows
final sensor, hybrid and readout chip (Beetle) all tested

pre-production n-on-n 200 µm

delivered of pre-production sensors delayed by 3 months
both 200 and 300 µm sensors measured → decision in January 2005
4) Tracking System

**Inner Tracker**
- Beam pipe
- 320 µm Si
- 410 µm Si
- 500 µm Si
- ~1.4×1.2 m²

**Trigger Tracker**
- ~130×45 cm²

**Outer Tracker**
- Straw drift chambers
- T1 to T3

**RICH1**
- Magnet
Outer Tracker

i.e. assembly of
- 56,000 straws
- 620 panels
- 185 F and 124 S Modules

Module production

-Krakow: all the panels produced
-Heidelberg: 60 F modules to be produced
  17 produced  1 rejected (first one)
  5 days/module
-NIKHEF: 125 F modules to be produced
  30 produced  1 rejected (first one)
  <3 days/module
-Warsaw: 124 S modules to be produced
  28 produced  2 not gas tight and to be repaired
  4.5 days/module

F module production OK    S module production OK but tight.
OTIS 1.2 (TDC chip) being tested and works well so far. Engineering run summer next year.
Silicon Tracker

Trigger Tracker

2+2 Si layers
\(x-u\leftrightarrow30 \text{ cm}\leftrightarrow v-x\)

thickness: 500 µm
strip pitch: 183 µm
so called CMS-OB2 from HPK
~1000 sensors being ordered
(problem with the production priority)

Inner Tracker

three stations
\(x-u-v-x/\text{station}\)

thickness: 300 µm for up and down
400 µm for left and right
strip pitch: 198 µm
~500 sensors ordered in June 2004
first delivery December 2004
last delivery Autumn 2005

Both readout by the Beetle chip
Trigger Tracker

4 sensors
3 sensors + 39 cm Kapton cable
1 sensor + 59 cm Kapton cable

3 sensors + 39 cm Kapton cable

between the two strips

V-bias 460V, CMS3+Flex ladder
V_{I_s}=400mV

Integration of TT being finalised
Inner Tracker

IT detector box sits in the middle of the acceptance → minimizing material is crucial

Integration of IT being finalised

IT and OT can be moved independently of each other

EDR for IT and TT planned for December 2004.
5) RICH System

mechanics and radiator

RICH1

aerogel and $C_4F_{10}$

RICH2

$CF_4$

Photon detector: Hybrid Photo Diode
RICH2 mechanics

gas enclosure and spherical mirror support

mounting of the front window

RICH1 mechanics

Engineering Design Report completed
HPD shielding box ordered

Schedule is tight → extra manpower has been injected
HPD

6 preproduction HPD’s have just been tested in beam.

10 GeV/c pion with N\textsubscript{2} in one HPD

with C\textsubscript{4}F\textsubscript{10} over four HPD’s
Remaining issues before the HPD mass production

Technical problems with the sensor processing, never had before.

Compared with prototype Si sensors:

1) introducing SiO₂ passivation (front side)
   photo-resist peels off (metallography)
   no bump-solder deposit possible
   → Photo-resist sticks with an additional Ti/W coating

2) change of the Al sputtering machine at sub-contractor (back side)
   back side Al peels off (quality control?)
   no grounding possible
   → Sputtering redone at the bonding factory works fine

We believe that solutions are found

A couple of months delay has been introduced: as soon as the production starts, work out the overall plan—early next year.
6) Calorimeter System

Scintillator-Pad-Detector, Preshower Detector, EM-Calorimeter and H-Calorimeter
Preshower-SPD: more than 50% of modules completed (outer region)

PS supermodules
Ecal: 100% completed and being tested with the cosmic rays at CERN

Light output variation between different modules is better than 8%.

Hcal: 96% completed and being tested with $^{137}$Cs at CERN

r.m.s. of light output from different scintillators in one module is only 4.7% in average.
support structures have been designed, constructed and arriving
Calorimeter front-end electronics

Front-end cards for ECAL/HCAL and SPD/Preshower using antifuse FPGA’s have been fully prototyped and debugged.

However, recently reprogrammable FPGA’s which can be used in radiation environment have become available
→ introduces 2 to 3 months delay
but large gain in flexibility
(details will be reported in January)
7) Muon System

five stations with a pointing pad geometry in four regions

1368 MWPC’s
12 GEM’s for M1R1
+ spares
Chamber production in five sites:

- **CERN**: 18 produced, 116 remaining
- **Firenze**: 0 produced, 218 remaining
- **Ferrara**: 14 produced, 232 remaining
- **LNF**: 56 produced, 192 remaining
- **PNPI2**: 0 produced, 276 remaining
- **PNPI1**: 55 produced, 269 remaining

10% milestone reached with 7.5 month delay
Enough chambers will be ready to start installation in 01.06 however not possible to complete by end 06 with current plan
main problem is manpower for production and testing

By March 2005, we should have enough experience in all sites to make a firm prediction:

→ a scenario ensuring physics in 2007 will be worked out
Muon filter construction advancing well

one layer/week
completed by the end of 04

chamber and rack support structure

EDR completed
Muon readout chain

**FE-boards**
- Carioca chip: amplifier discriminator
- DIALOG chip: logical OR of the 2 double-gaps
- LVDS links of ~12m length

**Intermediate boards**
- Required in some regions where the logical channels go across chambers.
- ODE-boards
  - SYNC chip containing the L0-pipeline and time adjustment

**Racks on the sides of the muon system**
- Optical links of ~100m length (with an intermediate patch panel on the balconies behind M5)

**Electronics barracks**
- Tell1, originally developed for Velo now also adopted by TT, IT, OT, Calorimeters, L0 trigger and Muon

Three types of chips from the engineering run are now being evaluated.
III) Trigger

Level-0

Input rate = 40 MHz bunch crossing $\rightarrow$ 1 MHz accept

High $p_T$ h, e, $\gamma$, $\pi^0$, $\mu$ \}$ $\rightarrow$ L0 decision

pile-up information

custom made electronics (Calo, Muon, Pile-up, L0 Decision Unit)

Completing the prototype validation

Calorimeter Trigger; Production Readiness Review 2Q/2005
Muon Trigger; PRR 4Q/2005
Pile-up; PRR 4Q/2005
L0 Decision Unit; PRR Q4/2005

Muon processor card
Level-1

Input rate = 1 MHz Level-0 accept $\rightarrow$ 40 kHz accept
$p_T$ of 2 tracks with large impact parameters
single lepton with large IP and $p_T$
single $\gamma$ with large $p_T$
dimuon

$\rightarrow$ L1 decision

CPU farm common with High Level Trigger (VELO, TT, L0)

Improving the selection algorithms

efficiency on offline selected events

$B^0 \rightarrow \pi^+ \pi^-$ 63% (TDR) $\rightarrow$ 81%
$B_s \rightarrow D_s K$ 63% (TDR) $\rightarrow$ 81%
$B_s \rightarrow J/\psi \phi$ 71% (TDR) $\rightarrow$ 87%

speed

with 1 GHz Pentium III 8.3 ms (TDR) $\rightarrow$ 5 ms* )

*) this is already within the allocated time budget
with 2007 CPU
High Level Trigger

Input rate = 40 kHz Level-1 accept → event store rate selections using all the detector information
CPU farm (all the detector)

Baseline selection

Exclusive B decay reconstruction modes e.g. given in TDR work in progress, trigger rate is a few Hz for each decay mode,
i.e. 200Hz appears to be sufficient for them.

Recent development

We realised that J/ψ and D⁰ are important for detector calibration,
a lesson from the Tevatron experiments
\( J/\psi \rightarrow \mu^+\mu^- \)  (well defined mass with two muons)
easy channel to trigger and reconstruct
→ dimuon trigger without impact parameter cuts
-Calibration of the absolute momentum (alignment, B field, dE/dx, etc.) then control it with \( \psi(2S), \ Upsilon(1-3S) \) and \( Z^0 \)
-Vertex resolution (prompt \( J/\psi \))
-Control of the proper-time calibration (\( B^+ \rightarrow J/\psi \ \pi^+, \ B^0 \rightarrow J/\psi \ K^{*0} \))

Signal rate
\( L_0 \times L_1 \times \text{Offline reconstruction} = 170 \text{ Hz of } J/\psi \text{ signal} \)

Trigger rate if
\( L_0 \times L_1 \times \text{HLT} (m_{\mu^+\mu^-} \gtrsim J/\psi \text{ mass}) = 600 \text{ Hz} \)

\( D^0 \rightarrow K^-\pi^+ \)  (well defined mass with two hadrons)
a good source for absolute momentum and \textbf{PID calibration} and calibration of detector simulation for lifetime measurements.

Signal rate
\( L_0 \times L_1 \times \text{Offline reconstruction} \approx 50 \text{ Hz of } D^{*+} \rightarrow \pi^+ D^0 (K^-\pi^+) \)

Trigger rate
\( L_0 \times L_1 \times \text{HLT}(D^{*+} \rightarrow \pi^+ D^0 \rightarrow h^+h^-) = 300 \text{ Hz} \)
and they also address interesting physics

b-hadron spectroscopy and lifetimes

\[ B_c \rightarrow J/\psi \pi, \ \Lambda_b \rightarrow J/\psi \Lambda, \ \Xi_b \rightarrow J/\psi \Lambda K_S \text{ etc.} \]

if \( D^0 \) is tagged by \( \pi^+ \) from \( D^{*+} \rightarrow \pi^+ D^0 \)

D-D oscillations

CP asymmetry in \( K^+K^- \) to a \( 10^{-4} \) level

NB: 50 M \( D \rightarrow K^+K^- \) might be collected in \( 10^7 \)s

(systematics is of course the issue)
Another interesting possibility is inclusive $\mu$ trigger with $p_T$ and impact parameter cuts triggering on $b \rightarrow \mu X$. Simple trigger and other $b$-hadron unbiased may be useful for the initial phase...

Trigger rate

$L0 \times L1 \times HLT(p_T > 2\text{GeV}/c, \text{IP} > 0.15\text{mm}) = 2\text{ kHz}$

Signal rate

true $b \rightarrow \mu X$ events and $m$ detected $\approx 800\text{ Hz}$
**Where do we stand?**

<table>
<thead>
<tr>
<th>Well motivated exclusive final state trigger</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B exclusive decays for TDR physics</td>
<td>200 Hz</td>
</tr>
<tr>
<td>dimuon (m_{\mu^+\mu^-} \gtrsim \text{J}/\psi) mass</td>
<td>600 Hz</td>
</tr>
<tr>
<td>(D^* \rightarrow D^0\pi)</td>
<td>300 Hz</td>
</tr>
</tbody>
</table>

An additional trigger for unbiased b sample

- high \(p_T\), high IP \(\mu\) trigger up to \(~2\) kHz

A sensible combination must be made to **maximise physics** within the **available computing resources**.

Desirable to have a **flexible** computing model which is scalable and able to accommodate different scenarios.
IV) Computing

Online

DAQ architecture

Level-1 Traffic
1000 kHz
5.5-11.0 GB/s

Front-end Electronics

Switch

SFC

Switch

CPU Farm

Storage System

~40 MB/s Total

TIER0

~2000 CPUs

Switch

Switch

Switch

1.6 GB/s

Mixed Traffic

Level-1 Traffic

HLT Traffic

40 kHz

DAQ has no limitation for a data storage rate of ~2 kHz

94-175 SFCs
7.1-12.6 GB/s

94-175 SFCs

New: Separate Storage Network

preneur_TFC System
Testbed setup with two complete subfarms (2×23 Processors)

Ethernet Cabling in the barracks starts end 11.04
~3000 connections, ~300 patch panels
Optical Fibers from computer room to barracks will be done in 01.05
Experiment Control System software status

Configuration Database
- TFC system implemented including connectivity and paths
- navigation and visualization tools developed

PC farm monitoring & control
- monitoring of PC information within PVSS implemented
- control of running processes
- first prototype will be available at CERN soon.
Offline Computing

Software framework, GAUDI, based applications are in place for
detector simulation
event reconstruction
event analysis
however, consolidation with the ongoing development needed.
Event store is done by the LCG product, POOL
Strategy development for detector alignment and calibration started
Data Challenge 04
Phase-1 (MC production and reconstruction) completed
close collaboration with the LCG deployment team finally
resulted in reaching to a stage where 3500 jobs concurrently
running in LCG sites with an average of 61% efficiency
-due to a problem with the random number seed, only 16’777’216 unique
events (24 bits). Now this is fixed and start some new generation-
Phase-2 (Fast event selection) just started
delayed due to adaptation of LHCb software to LCG and
SRM (LCG software for mass storage access) not being ready
Evolution of the LHCb computing model

At the time of “Hoffmann review”, we thought
- $\bar{b}b$ inclusive MC events were important to understand background
- for the real data, only events with exclusive $B$ decay final states should be recorded
→ MC sample dominating the computing need

However now, we think
- no way to generate enough statistics to understand background in a generic way
- MC events are important to understand signal acceptance and specific background, as before
- real data must be used as much as possible to understand all the systematic effects and to tune the simulation
→ much less $\bar{b}b$ inclusive MC events needed
→ much more data such as $J/\psi$ and $D^0$ needed

CPU and storage requirements would change
→ consequence is being studied

essential for the Computing TDR in 2005
## IV) Coming Installation

<table>
<thead>
<tr>
<th>Component</th>
<th>Date(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electromagnetic Calorimeter</strong></td>
<td>January ‘05, February ‘05</td>
</tr>
<tr>
<td>• Support</td>
<td>January ‘05</td>
</tr>
<tr>
<td>• modules installation</td>
<td>February ‘05</td>
</tr>
<tr>
<td><strong>Hadron Calorimeter</strong></td>
<td>February ‘05, March ‘05</td>
</tr>
<tr>
<td>• Support</td>
<td>February ‘05</td>
</tr>
<tr>
<td>• modules installation</td>
<td>March ‘05</td>
</tr>
<tr>
<td><strong>RICH 2</strong></td>
<td>August ‘05</td>
</tr>
<tr>
<td><strong>Preshower &amp; SPD, lead &amp; super-modules</strong></td>
<td>December ‘06</td>
</tr>
<tr>
<td><strong>Outer Tracker, structure and detector</strong></td>
<td>November ‘05</td>
</tr>
<tr>
<td><strong>Vertex Locator</strong></td>
<td>November ‘05, October ‘06</td>
</tr>
<tr>
<td>• Vacuum vessel</td>
<td>November ‘05</td>
</tr>
<tr>
<td>• Sensors</td>
<td>October ‘06</td>
</tr>
<tr>
<td><strong>RICH 1</strong></td>
<td>April ‘05</td>
</tr>
<tr>
<td>• Shielding box</td>
<td>November ‘05</td>
</tr>
<tr>
<td>• Gas enclosure</td>
<td>November ‘05</td>
</tr>
<tr>
<td><strong>Inner Tracker</strong></td>
<td>February ‘06, June ‘06</td>
</tr>
<tr>
<td>• First box</td>
<td>February ‘06</td>
</tr>
<tr>
<td>• Remaining sensors</td>
<td>June ‘06</td>
</tr>
<tr>
<td><strong>Trigger Tracker</strong></td>
<td>June ‘06</td>
</tr>
<tr>
<td><strong>Muon chamber installation</strong></td>
<td>January ‘06</td>
</tr>
<tr>
<td><strong>Beam pipe installation</strong></td>
<td>April ‘06, May ‘06, August ‘06</td>
</tr>
<tr>
<td>• UX1&amp;2</td>
<td>April ‘06</td>
</tr>
<tr>
<td>• UX3&amp;4</td>
<td>May ‘06</td>
</tr>
<tr>
<td>• Bake out &amp; commissioning</td>
<td>August ‘06</td>
</tr>
</tbody>
</table>
V) Conclusions

Good achievement made for the construction of many subsystems:
- Beam pipe, Magnet, RICH2 mechanics, Calorimeter system, and Online system are progressing well.
- Outer Tracker, RICH1 mechanics, HPD and VELO are also making good progress, however with tight planning.
- We are looking forward to seeing the production of the Trigger Tracker and Inner Tracker start as planned. A major concern is how to solve the conflict with CMS on the delivery schedule for the TT sensors.
- Production of the Muon chambers is facing a substantial delay. Necessary action will be decided in March 2005 when we expect to have all the information needed.
- Need on computing resource is evolving and its effect on computing model is being investigated.