PROSPECTS FOR CP VIOLATION MEASUREMENTS IN *LHCb*

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At day 1 of LHCb (2005):

Will have provided:

- accurate measurements of $|V_{cb}|$, $|V_{ub}|$, $|V_{td}|$, rare B decays channels, perhaps Δm_s
- $\sin(2\beta)$ from $B_d \rightarrow J/\psi K_S$ with $\sigma \leq 0.05$

signals of New Physics or agreement with Standard Model ?

precise measurements of all Unitarity Triangles parameters will be required to get more informations and to over constrain the UT

Few examples:

- $B_d^0 \rightarrow J/\psi K_S^0$:

$$A_{CP}(t) = A_{dir} \cos(\Delta m t) + A_{mix} \sin(\Delta m t)$$

$\searrow$
 $= 0 ?$

high statistics is necessary to have sensitivity on A_{dir}
(LHCb 1 year's data) ➤

● New Physics
in $B^0\bar{B}^0$ mixing?

both B^0 oscillations and $B_d^0 \rightarrow J/\psi K_s^0$ asymmetry would be affected: β measurements biased

From CP asymmetry in $B_d^0 \rightarrow D^{*\mp} \pi^\pm$: $-2\beta + \Phi_{NP} - \gamma$
 subtracting from $B_d^0 \rightarrow J/\psi K_s^0$: $-2\beta + \Phi_{NP}$

a clean determination of γ and a test of New Physics

Experimental requirements:

- High statistics on B_d and B_s to reach channels with small BR's ($< 10^{-7}$)
- Measure rapid B_s oscillations: good proper time resolution
- Good efficiency on several final states, including hadronic multi-body :
 - sensitive trigger (leptonic and hadronic final states)
 - particle identification
 - good mass resolution

B production at LHC

pp collisions at $\sqrt{s} = 14$ TeV :

$$\sigma_{\text{inel}} \approx 80 \text{ mb}$$
$$\sigma_{b\bar{b}} \approx 500 \mu\text{b} \quad \text{S/B} \sim 1 \%$$

★ Forward production of $b\bar{b}$, correlated

Good acceptance in single arm forward spectrometer

LHCb: $15 \text{ mrad} < \theta < 300 \text{ mrad}$ ($1.9 < \eta < 4.9$)

★ Several pp interactions per bunch crossing

LHCb chooses to work **with single interaction**

Advantages for: radiation damage
detector occupancy
triggering
pattern recognition, flavour tagging

The detector will be operated at $L \sim 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

► beams defocussed at LHCb interaction point

► compatible with LHC running @ $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

$10^{12} \text{ b}\bar{\text{b}} \text{ events / year}$

★ Charged particle multiplicity

New tuning of simulation on UA5, CDF data after LHCb Technical Proposal:

(PYTHIA 6.1, multiple parton-parton interaction model, CTEQ4L structure function “post-HERA”)

but TRIGGER performances are not affected!

***LHCb* Milestones**

- ❑ Feb 1996 *LHCb* Letter of Intent
- ❑ Sep 1998 Approval of Technical Proposal
- ❑ 2000-2002 Technical Design Report of Detector Subsystems:

Magnet	TDR approved April 2000
Vertex Locator	TDR April 2001
Inner Tracker	TDR September 2001
Outer Tracker	TDR March 2001
RICH System	TDR submitted 7 September 2000
Calorimeter System	TDR submitted 6 September 2000
Muon System	TDR January 2001
Trigger	TDR January 2002
Computing	TDR July 2002

- ❑ 2000- July 2004 Construction Phase
- ❑ July 2005 1st beam in *LHCb*

LHCb TRIGGER

GOALS:

*40 MHz trigger, robust and flexible (not relying on a single subdetector)
efficient on several B decay topologies (also fully hadronic final states)*

TRIGGER Efficiency

	L0(%)	L1(%)	L2(%)	Total(%)
$B_d \rightarrow J/\psi (e e) K_s + \text{tag}$	72	42	81	24
$B_d \rightarrow J/\psi (\mu \mu) K_s + \text{tag}$	88	50	81	36
$B_s \rightarrow D_s K + \text{tag}$	54	56	92	28
$B_d \rightarrow \pi \pi + \text{tag}$	76	48	83	30
$B_d \rightarrow D_s^+ K^{*0}$	37	59	95	21

for reconstructed and correctly tagged events

High p_t μ trigger

L1 vertex

Future improvements of L1:
will take into account L0 informations
to form a new decision

will increase efficiency, e.g. in $\mu\mu$ channels
triggering on 2 high- p_t muons

Vertex Locator (VELO)

- Strips segmentation and pitch ($40\ \mu\text{m}$ - $105\ \mu\text{m}$) determined by occupancy:

always below 1%

- Number of readout channels = 2.2×10^5

Silicon strip detector in LHCb vacuum chamber

- 17 stations with R and ϕ measuring planes
- sensitive area $10\ \text{mm} < r < 60\ \text{mm}$
- 2 half disks: retracted during injection by 3 cm to reduce radiation damage

Optimization for TDR:

of stations (25), positions, outer & inner radii

- on average 9.5 hits / track

Vertex Locator (VELO)

- Single sided 200 μm Si, double metal read out:

thin detector
S/B ~ 12

- Impact parameter resolution:

Accuracy on primary vertex:

40 μm

- Front-end chip: 2 options under development (DMILL SCTA128 or sub micron BEETLE)

Prototype detector with 3 R and 3 ϕ sectors

Proper time resolution for $B_s \rightarrow D_s \pi$

- * time - dependent asymmetry measurements
- * oscillations measurements

$$\sigma_\tau \sim 43 \text{ fs}$$

> 5σ measurement for $\Delta m_s \leq 48 \text{ ps}^{-1}$ ($x_s = 75$)

MAGNET

warm dipole 4 Tm (4.2 MW, yoke 1450 t)

TDR
approved
april 2000

MAIN TRACKER

OUTER TRACKER: straw drift tubes

INNER TRACKER: triple GEM with 2D readout
Si strips

best solution under study

$$\sigma_p / p = 0.3 \%$$

$$5 \text{ GeV}/c < p < 200 \text{ GeV}/c$$

$$\sigma(M) = 17 \text{ MeV} \quad \text{for} \quad B_d \rightarrow \pi^+ \pi^-$$

$$\sigma(M) = 4 \text{ MeV} \quad \text{for} \quad D_s \rightarrow K^- K^+ \pi^-$$

RICH

Hadron identification in LHCb:

* Background suppression

⇒ high momentum hadrons
in two-body B decays

* B flavour tag

identify K from $b \rightarrow c \rightarrow s$
⇒ low momentum hadrons

RICH 1

2 RICH detectors
with 3 radiators

RICH 2

	RICH 1		RICH 2
radiator	Aerogel	C ₄ F ₁₀	C F ₄
length	5 cm	85 cm	167 cm
n	1.03	1.0014	1.0005
p _π thre. (GeV/c)	0.6	2.6	4.4
p _K thre. (GeV/c)	2.0	9.3	15.6
σ(θ) (mrad)	2.0	1.45	0.58
N pe	6.6	32.7	22.5

more than 3σ π /K separation in 3 < p < 100 GeV/c

$$B_d \rightarrow \pi\pi$$

RICH PHOTODETECTORS

Requirements: $\sim 3 \text{ m}^2$ area, $2.5 \times 2.5 \text{ mm}^2$ granularity, single photon sensitivity, high Q.E.

3 options considered:

Pixel HPD

↗ base line solution

Pad HPD

MaPMT

↗ backup solution

Pixel Hybrid PhotoDiode [CERN and DEP (The Netherlands) project]

❑ 1024 ($500\mu\text{m} \times 500\mu\text{m}$) Si pixel sensor bump bonded to binary read out electronics - ALICE chip

❑ $\int \text{Q.E. } dE \sim 0.77 \text{ eV}$

❑ 80 mm diameter envelope cross-focusing electrodes

❑ 70% active area coverage (~ 450 tubes, $\sim 325 \text{ k}$ channels)

TEST BEAM RESULTS

61-pixel HPD (80 mm)

Accumulated
Cherenkov
rings

Full scale RICH 1 prototype

Aerogel test

+ 8 GeV/c beam: π and protons

Accumulated Cherenkov rings on
two pad HPD (2048 channels)

CALORIMETERS

L0 trigger requires: fast detector with longitudinal segmentation for e/π separation
(electrons up to 200 GeV, hadrons up to 300 GeV)

Hit density varies 2 order of magnitude over calorimeter surface:
variable lateral segmentation (3 zones in ECAL, 2 zones in HCAL)

Joint Calorimeter Test

Pre-shower: sandwich
scintillator-Pb-scintillator $2 X_0$

ECAL: Shashlik type $25 X_0$

$$\sigma(E) / E = 10\% / \sqrt{E} \oplus 1.5\%$$

HCAL: Fe + scintillating tiles, $5.6 \lambda_I$

$$\sigma(E) / E = 80\% / \sqrt{E} \oplus 10\%$$

MUON CHAMBERS

5 muon stations: 870 m² of detector area,
~ 150 k physical channels, ~ 26 k logical channels

Regions **closer to the beam** have stronger requirements for **rate capability**

□ **Rate ≤ 1 kHz/cm²** (42% of Muon System)

RPC with 2 gaps (double gap or 2 single gap ORed)

*Test beam results: time resolution of 1.3 ns, with efficiency >99% in 10 ns
efficiency >95% at 1.8 kHz/cm²*

□ **1 kHz/cm² < Rate ≤ 100 kHz/cm²** (58% of Muon System)

MWPC with anode wire and/or cathode pad readout

good ageing properties when operated with Ar/CO₂/CF₄ 40/50/10 mixture

*Test beam results: time resolution < 3 ns, with efficiency >99% in 20 ns
good performances at rates > 100 kHz/cm²*

□ **Rate > 100 kHz/cm²** (< 1% of Muon System)

??? still under study

γ from $B_d \rightarrow D^{*\mp} \pi^\pm$

- CP asymmetries from interference between $B_d \rightarrow D^{*-} \pi^+$ and $B_d \rightarrow \bar{B}_d \rightarrow D^{*-} \pi^+$ decays
- Tiny effect ($\sim 1\%$) due to double Cabibbo suppressed $b \rightarrow u$ transition
- Extract $2\beta + \gamma$ from time dependent fit of CP asymmetries. No penguin contributions.

exclusive reconstruction

~ 84 k ev/year S/B ~ 12

(reconstructed and tagged)

partial reconstruction

~ 260 k ev/year S/B ~ 3

$\sigma(2\beta + \gamma)$

Sensitivity will depend
on strong phase difference

$B_d \rightarrow D^{*\mp} a_1^\pm$ can be added ~ 360 k events /year, S/B ~ 4 .

$\sigma(\gamma) \sim 12^\circ$ in 1 year ($\Delta_s = 0$)

γ from $B_s^0 \rightarrow D_s^{\mp} K^{\pm}$

B_s counterpart of $B_d \rightarrow D^{*-} \pi^+$ but interference effects much larger. No penguins contributions.

Extract $\gamma - 2\delta\gamma$ from time dependent fit of CP asymmetries.

Assuming $2\delta\gamma$ known from $B_s \rightarrow J/\psi \phi$ this will be a clean measurement of γ

- Background from $B_s^0 \rightarrow D_s^- \pi^+$ ~ 20 times higher --> RICH for K/ π separation (π misid 0.1%)
- Fast B_s oscillations --> good proper time resolution (VELO $\sigma(\tau)=43$ fs)

2500 events
expected in 1 year
(reconstructed and tagged)

reconstr. efficiency 0.5 %

$\sigma(M_B) \sim 11$ MeV

S/B ~ 12.5

Sensitivity to $\gamma - 2\delta\gamma$ will depend on Δm_s , $\Delta \Gamma_s / \Gamma_s$, strong phase difference:

expected precision $\gamma - 2\delta\gamma$: $6^\circ - 12^\circ$ ($\Delta m_s = 15$ ps⁻¹)

α from $B_d^0 \rightarrow \rho \pi$

Tree and Penguins parameters, including α , can be extracted from a full **3 body analysis**, taking into account **interference** effects between vector mesons of different charge

$\sigma(M_B) = 42 \text{ MeV}$
(35 MeV with π^0 constraint)

bck/signal=0.75

$M^2(\pi^+ \pi^- \pi^0)$

Time dependent analysis of event distribution in Dalitz plot

expected events: $\sim 1200 \rho^\pm \pi^\mp$
 $\sim 100 \rho^0 \pi^0$

Expected sensitivity: $\sigma(\alpha) \sim 3^\circ\text{-}6^\circ$ in 1 year

Expected CP sensitivities in 1 year *LHCb* (10^7 s, $L = 2 \times 10^{32}$ cm $^{-2}$ s $^{-1}$)

Decay channel	N events (reconstructed and tagged)	parameter	sensitivity
$B_d^0 \rightarrow J/\psi K_s$	100 k	$\sin(2\beta)$	0.021
$B_d^0 \rightarrow \pi^+ \pi^-$	5000	$\sin(2\alpha)$	0.05 (No Penguins)
$B_d^0 \rightarrow \rho \pi$	1300	α	$\sim 5^\circ$ ($\alpha=50^\circ$)
$B_d \rightarrow D^{*\mp} \pi^\pm$	84k excl. 260k incl.	$2\beta + \gamma$	$\sim 12^\circ$ ($2\beta + \gamma=0$, $\Delta_s=0$)
$B_s^0 \rightarrow D_s^\mp K^\pm$	2400	$-2\delta\gamma + \gamma$	$8^\circ - 12^\circ$ ($\Delta m_s=15-45$ ps $^{-1}$)
$B_s^0 \rightarrow J/\psi \phi$	50 k	$\sin(2\delta\gamma)$	0.03 ($\Delta m_s=25$ ps $^{-1}$)

CONCLUSIONS

- ▶ LHCb is rapidly evolving towards final design since TP.
Major technology choices made.
Magnet TDR approved, RICH and Calorimeter TDR submitted.
Other Subsystem coming soon.

▶ Looking forward for “*Ferrara 2005*” for first *LHCb* results
on new measurements of all UT angles with unprecedented precision
and may be hints for new Physics beyond the Standard Model