Status of the LHCb Experiment

Mitesh Patel (CERN)

29th March 2006
Introduction

• LHCb is the dedicated B physics experiment at the LHC designed for the precision study of CP violation and rare decays

• Following cancellation of BTeV + foreseen closure of BaBar, LHCb may become the only running B physics experiment after the B-factories (unless Super-Belle is approved)

• Syracuse University group from BTeV recently joined LHCb → now 47 institutes in 16 countries > 600 authors

• Why are we preparing a B physics experiment, after the B-factories?
• Spectacular progress from the B-factories:
  Precision result of their baseline measurement $A_{CP} (J/\psi K_S)$
  in striking agreement with the Standard Model CKM picture

• Also performed an impressive range of additional measurements
• However… sin $2\beta_{b \rightarrow s} = sin 2\beta_{b \rightarrow c}$ in the Standard Model

Box: $V_{td} \rightarrow 2\beta$

$\bar{b}$\hspace{1cm}W\hspace{1cm}\bar{d}$

$b \rightarrow c$ tree: $V_{cb} \rightarrow 0$

$b \rightarrow s$ penguin: $V_{ts} \rightarrow \sim 0$

• If $b \rightarrow s$ transition has a contribution from new physics
  – should see effect in other modes, such as $B_s \rightarrow \phi\phi$
  – may give increased branching ratio for $B_s \rightarrow \mu^+\mu^-$
  – $B_s$ oscillation may be affected $\rightarrow$ higher frequency $\Delta m_s$
  – or larger CP violation in $B_s \rightarrow J/\psi\phi$

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\( B_s - \overline{B}_s \) oscillation

- Expected value of \( \Delta m_s < 30 \text{ ps}^{-1} \) from Standard Model CKM fits

- If \( \Delta m_s \) as expected in Standard Model CDF or D0 might measure it …

But if the value is beyond the Standard Model expectation, LHCb should be the first to see it (or rule out the entire SM range)
B physics sensitivity

• Illustrate analysis steps for measurement of $B_s - \bar{B}_s$ oscillations

• Use mode: $B_s \rightarrow D_s^{-}\pi^+$
  Plot made for 1 year of data
  (80k selected events) for
  $\Delta m_s = 20$ ps$^{-1}$ (SM preferred)

• Diluted by flavour tagging:
  $\epsilon D^2 \sim 6\%$ for $B_s$ decays

• Proper time resolution $\sim 40$ fs

• Signal/Background $\sim 3$
  (from $10^7$ inclusive $bb$ events)

• Include effect of acceptance:
  Oscillations still clearly seen

Perfect reconstruction
+ flavour tagging
+ proper time resolution
+ background
+ acceptance
\( B_s - \bar{B}_s \) oscillation sensitivity

- Plot uncertainty on amplitude of fitted oscillation vs \( \Delta m_s \):

- \( 5\sigma \) observation of \( B_s \) oscillation for \( \Delta m_s < 68 \text{ ps}^{-1} \) (in one year)
  \( \rightarrow \) LHCb could exclude full SM range
  Once observed, precise value is obtained: \( \sigma_{\text{stat}}(\Delta m_s) \approx 0.01 \text{ ps}^{-1} \)

- Use mode \( B_s \rightarrow J/\psi \phi \) to measure the phase of \( B_s \) oscillation
  In Standard Model expected asymmetry \( \propto \sin 2\chi = \text{very small} \ (\sim 0.04) \rightarrow \) sensitive probe for new physics

- 120,000 events should be reconstructed per year
  \( \rightarrow \sigma(\sin 2\chi) \approx 0.06, \ \sigma(\Delta \Gamma_s/\Gamma_s) \approx 0.02 \) in one year
New D0 result on $\Delta m_s$

- V.M. Abazov et al. (D0 collaboration),
  “First Direct Two-Sided Bound on the $B_s$ Oscillation Frequency”
  hep-ex/0603029, March 15, 2006, submitted to PRL:
  - 1 fb$^{-1}$ of data (April 2002–October 2005)
  - $B_s \rightarrow D_s^-(*)\mu^+\nu X$, $D_s^- \rightarrow \phi(K^+K^-)\pi$
  - 26.7 k signal events
  - proper decay length measured in transverse plane
    use MC “K factor” to correct $p_T(D_s\mu)$ to $p_T(B_s)$
  - opposite-side tagging, $\varepsilon D^2 = (2.48 \pm 0.21 \pm 0.07)\%$

Preferred value: $\Delta m_s = 19$ ps$^{-1}$

90% CL limit: 14.8 ps$^{-1}$

Claim: “This is the first 2-sided bound”

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• D0 do not claim a measurement

<table>
<thead>
<tr>
<th>D0 sensitivity</th>
<th>Now at 1 fb(^{-1})</th>
<th>Extrapolated to 10 fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>5(\sigma) observation of (\Delta m_s) up to</td>
<td>5.6 ps(^{-1})</td>
<td>14.4 ps(^{-1})</td>
</tr>
<tr>
<td>3(\sigma) observation of (\Delta m_s) up to</td>
<td>9.3 ps(^{-1})</td>
<td>18.6 ps(^{-1})</td>
</tr>
<tr>
<td>95% CL exclusion up to</td>
<td>14.1 ps(^{-1})</td>
<td>24.1 ps(^{-1})</td>
</tr>
</tbody>
</table>

• No sensitivity yet to observe a signal above 10 ps\(^{-1}\)

• Need 10 times more data (or equivalent analysis improvements) for a 3\(\sigma\) observation at 19 ps\(^{-1}\)
Other topics

- $\sin 2\beta$ not a central physics goal (as so well measured by B-factories) but an important check:
  
  Expect 240,000 reconstructed $B^0 \rightarrow J/\psi K_S$ events/year
  
  $\sigma_{\text{stat}}(\sin 2\beta) \sim 0.02$ in one year

- Measure $\gamma$ in various channels, differing sensitivity to new physics:
  
  - Time-dependent CP asymmetry of $B_s \rightarrow D_s^- K^+$ and $D_s^+ K^-$ $\rightarrow \sigma_\gamma \sim 14^o$
  
  - Asymmetries of $B^0 \rightarrow \pi^+ \pi^-$ and $B_s \rightarrow K^+ K^-$ (U(1) sym, loop eff.) $\rightarrow \sigma_\gamma \sim 5^o$
  
  - Decay rates in the $B^0 \rightarrow D^0 K^*$ system $\rightarrow \sigma_\gamma \sim 8^o$
  
  - Asymmetries of decays $B^\pm \rightarrow D^0 K^\pm$ – potentially LHCb’s most precise measurement of $\gamma$ – will come back to…

- Study rare decays such as $B_s \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ etc…
B production at LHC

- Large b cross section $\sigma_{bb} \sim 500 \, \mu b$
  But only $\sim 0.5\%$ of total cross section

- Pile-up at high luminosity:
  Choose luminosity $\sim 2 \times 10^{32} \, \text{cm}^{-2}\text{s}^{-1}$
  Tuneable by defocusing beams
  → most events have single interactions
  + reduced radiation dose

- $10^7$ s taken as nominal “year” = 2 fb$^{-1}$
  → $10^{12}$ bb produced/year

- Forward peaked b production at the LHC
  → LHCb is a forward spectrometer
LHCb at Point 8

- Shielding wall
- Offset interaction point
- Electronics + CPU farm
- Detectors can be moved away from beam-line for access
Detector status

• Conical Be beam-pipe: completed

• Warm dipole magnet: $\int B \, dL = 4$ Tm
Regular field reversal planned
for systematic control of CP

Field mapping completed

Predicted

Measured
Vertex locator

- Silicon microstrip detector with $r$-$\phi$ geometry
- Variable pitch 40–100 $\mu$m
  300 $\mu$m thick

Interaction region

~1m

21 stations

8 cm

Test beam setup

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• To give precise reconstruction, silicon approaches to 8 mm from beam

• Uses secondary vacuum system like a Roman Pot

• Complex mechanics to allow retraction during injection: close to completion

• Module production in progress
Trigger Tracker

- Silicon strip detectors covering full acceptance upstream of magnet: \( \sim 8 \text{ m}^2 \)
  Together with Vertex Locator measures \( p_T \) of tracks for use in the trigger

- 500\( \mu \text{m} \) silicon, CMS OB2-type sensors

- Now in production

low-mass Kapton readout cable
Outer Tracker

- 3 stations each made up of 4 double-layers of Kapton/Al straws glued together to form modules: module production now complete
Inner Tracker

- Silicon strip detectors close to beam pipe, in region of high occupancy: only 2% of area, but 20% of tracks

- 11 cm strips, 198 µm pitch arranged in boxes around beam pipe

Production of ladders under way

410 µm thick for two-sensor ladders

320 µm thick for single sensors
RICH system

- Three radiators used to give $\pi$-K separation from 2–100 GeV
- Novel photon detectors: Hybrid Photon Detectors
  ~ 500 tubes, each with ~1000 pixels
  Production underway

Test beam image
• RICH-1 (before magnet) combines the use of aerogel and $\text{C}_4\text{F}_{10}$ gas radiators for low momentum tracks

• Vessel under construction, magnetic shielding box for HPDs installed

• High clarity aerogel developed, production nearing completion
• RICH-2 (after magnet) uses CF$_4$ gas radiator for high $p$ tracks
• Vessel completed and in position, mirrors installed and aligned
Calorimeter system

- **Pre-shower**: scintillating pads + WLS fibres + 2 $X_0$ Pb
- **Electromagnetic**: Pb-scintillator Shashlik calorimeter, 25 $X_0$
- **Hadronic**: Fe-scintillator tile calorimeter, 5.6 $\lambda_l$
• ECAL modules: $\sigma_{E} / E = 10\% / \sqrt{E} \oplus 1\%$

• 3300 modules stacked: ~ 6 m high
dimensions agree to specification < 1 mm
Muon system

- MWPCs used for all except highest rate region (inner part of M1, > 100 kHz/cm²) where triple-GEMs are used instead

~50% of chambers complete
Installation status

Muon system
- iron shielding
- electronics tower

Calorimeter
- E-cal, H-cal modules

RICH2 Magnet
- shielding box

RICH1
**Trigger**

- **L0**: high $p_T$ ($\mu$, $e$, $\gamma$, $h$) [hardware, 4 $\mu$s latency]
- **L1**: high IP, high $p_T$ tracks [software, 1 ms]
- **HLT**: software using complete event [10 ms]

### HLT rate

<table>
<thead>
<tr>
<th>HLT rate</th>
<th>Event type</th>
<th>Calibration</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 Hz</td>
<td>Exclusive B candidates</td>
<td>Tagging</td>
<td>B (core program)</td>
</tr>
<tr>
<td>600 Hz</td>
<td>High mass di-muons</td>
<td>Tracking</td>
<td>J/ψ, $b \rightarrow J/ψX$ (unbiased)</td>
</tr>
<tr>
<td>300 Hz</td>
<td>D* candidates</td>
<td>PID</td>
<td>Charm (mixing &amp; CPV)</td>
</tr>
<tr>
<td>900 Hz</td>
<td>Inclusive $b$ (e.g. $b \rightarrow \mu$)</td>
<td>Trigger</td>
<td>B (data mining)</td>
</tr>
</tbody>
</table>
Computing

- Final system: filter farm of ~ 2000 CPU nodes at pit + extensive use of the Grid for offline computing

- Test-bed of a CPU sub-farm set up with 44 CPU nodes
  Test the transfer of data through the system, running the trigger code

Populated with 150M events generated using the Grid in 3 weeks
Expected performance

• Study performance using fully-simulated events (GEANT4) and full pattern recognition
Tracking

- Reconstruction of tracks passing through full spectrometer: efficiency ~ 95%, with a few percent of ghost tracks

- Momentum resolution $\Delta p/p \sim 0.4\%$
- Impact parameter resolution $\sigma_{IP} \sim 20 \mu m$ for high-$p_T$ tracks
Particle ID

- RICH system provides excellent hadron identification 2–100 GeV → K tagging + clean separation of two-body B decays

- Lepton ID: for e (µ) in ECAL (Muon) efficiency ~ 90% for π misid rate of < 1%
A physics study ...
The ADS Method - Introduction

• Decays $B$ and $\bar{B}$ to $D^0(\bar{D}^0)K$ involve $b \to c$ and $b \to u$ transitions
  $\to$ sensitive to $\gamma$ if a common final state is studied for both $D^0$ and $\bar{D}^0$

• LHCb will exploit a number of strategies to study such decays:
  – Atwood-Dunietz-Soni ('ADS') $B^\pm$ decays
  – Dalitz $B^0$ and $\bar{B}^0$ decays
  – Gronau-London-Wyler-(Dunietz) ('GLW')

• The ADS method is a candidate for LHCb’s most precise measurement of $\gamma$

• Dalitz plot analysis sensitive to some of the same parameters – two methods complementary
ADS method – $B^\pm \rightarrow DK^\pm$ diagrams

- $B^-$ can decay into both $D^0$ and $\bar{D}^0$, diagrams have very different amplitudes

```

B^-  b  \hline
  \bar{u}  c  \hline
  s  \bar{u}  \hline
  colour favoured

D^0  \hline
  \bar{u}  \bar{u}  \hline
  u  \bar{c}  \hline
  \bar{s}  \bar{u}  \hline
  colour suppressed

```

- Decays of $D^0$, $\bar{D}^0$ to same final state allows these two *tree diagrams* (theoretically clean!) to interfere

eg. consider decays $D^0 \rightarrow K\pi$ ($K\pi\pi\pi$) …
ADS method – $D \rightarrow K^+\pi^-$ diagrams

- Both $D^0$ and $\bar{D}^0 \rightarrow K^+\pi^-$:

  $B \rightarrow D^0K^-$ (colour favoured) then:

  $B \rightarrow \bar{D}^0K^-$ (colour suppressed) then:

- For these decays the reversed suppression of the $D$ decays relative to the $B$ decays results in much more equal amplitudes → big interference effects

- Counting experiment – no need for flavour tagging or proper time determination
Interference parameters

• Interference depends on a number of parameters:
  – From the B decays:
    - $\gamma$ – because have $b \to u$, $b \to c$ interference
    - $r_B$ – the ratio in magnitude of two diagrams (0.1 – 0.3)
    - $\delta_B$ – a CP conserving strong phase difference
  – The D decays introduce:
    - $r_D^{K\pi}$ – the ratio in magnitude of two diagrams (0.060)
    - $\delta_D^{K\pi}$ – a CP conserving strong phase difference

• BELLE measure:
  - $r_B = 0.25 \pm 0.22$
  - $\delta_B = 157 \pm 30$
  [hep-ph/0411049, 0504013 – Dalitz analysis]
  - BR(suppressed) = $(3.9 \pm 2.1) \times 10^{-7}$
  [hep-ph/0412025 – ADS anal, 275M BB]
  - $r_B < 0.18$ (90% CL)
  [hep-ex/0508048 – ADS anal, 386M BB]

• BABAR measure:
  - $r_B = 0.12 \pm 0.09$
  - $\delta_B = 104 \pm 53$
  [hep-ph/0504039, 0507101 – Dalitz analysis]
  - $r_B < 0.23$ (90% CL)

• We have assumed:
  - $r_B = 0.15$, $\delta_B = 130^\circ$, $\delta_D^{K\pi} = 180^\circ$ (arb.) $\to$ BR(sup.) $\sim 4.5 \times 10^{-7}$
• Allowing for all possibilities, have 4 $B^\pm \to D(K\pi)K^\pm$ rates we can measure:

\begin{align*}
\Gamma(B^- \to (K^-\pi^+)D K^-) &\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos \left(\delta_B - \delta_D^{K\pi} - \gamma\right), \\
\Gamma(B^- \to (K^+\pi^-)D K^-) &\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos \left(\delta_B + \delta_D^{K\pi} - \gamma\right), \\
\Gamma(B^+ \to (K^+\pi^-)D K^+) &\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos \left(\delta_B - \delta_D^{K\pi} + \gamma\right), \\
\Gamma(B^+ \to (K^-\pi^+)D K^+) &\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos \left(\delta_B + \delta_D^{K\pi} + \gamma\right)
\end{align*}

(1)  
(2)  
(3)  
(4)

• Two rates are favoured (1) and (3)
• Two rates are suppressed (2) and (4)
  – but these *suppressed rates have order 1 interference effects* as $r_B \sim r_D$

• Although $r_D^{K\pi}$ known, taking the relative rates have more unknowns than equations – need information from other decays
  eg. $D \to K\pi\pi\pi$, or the CP eigenstates $KK, \pi\pi$ ($r_D^{KK}=1$, $\delta_D^{KK}=0$)
  CLEO-C also expected to measure $\delta_D$

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Present Experimental Status

B factories are looking for these suppressed decays (2) & (4)

eg. Belle, hep-ex/0412025

275M BBbar

DK decays (~ 15 events; hint of asymmetry)

Dπ decays (control channel; order 30 events)

Analysis is statistically limited … what can LHCb add … ?
What can LHCb add...?

- LHCb intends to take $2\text{fb}^{-1}$ per year – $10^{12} \text{bb}$, 0.4 of which expected to be $B^\pm$ in both sign combinations signal yields then:

$$10^{12} \text{bb/ year} \times 0.4 \times 2 \times \varepsilon_{\text{TOT}} \times \text{BR}$$

- Our total efficiency, $\varepsilon_{\text{TOT}}$, and resulting sensitivity depend entirely on our ability to control the background – in very different environment to the B factories

- Full simulation indicates that acceptance $\times$ trigger efficiency $\times$ selection efficiency gives $\varepsilon_{\text{TOT}} = 0.5\%$ (more in a moment):
  - Favoured $\rightarrow$ ~60,000 events/year
  - Suppressed $\rightarrow$ ~2,000 events/year

cf. the ~15 events in the suppressed modes currently seen by BELLE
Full MC performance

- LHCb uses full MC simulation to estimate the signal selection efficiency and the background:
  - PYTHIA - generation of p-p collisions at $\sqrt{s} = 14$ TeV
  - GEANT - full detector response/spill-over and tracking through material
  - on/offline pattern recognition, full trigger chain, selections

- Signal selection efficiency $\varepsilon_{TOT} = 0.5\%$:
  - $8.2\%$ (geom.) $\times 87.8\%$ (rec.) $\times 28.4\%$ (seln.) $\times 25.0\%$ (trig.)

- Mass resolutions
  - $B^\pm \sim 15$ MeV
  - $D^0 \sim 6.5$ MeV

- Vertex resolutions
  - Primary vertex $\sigma_z \sim 50$ $\mu$m
  - $B$ decay vertex $\sigma_z \sim 200$ $\mu$m
Estimating the background

- From a large sample of minimum bias events find no events are selected by selection cuts

- To study background in more detail focus on \textit{bb} events where one \textit{b} decays in 400 mrad – after the application of the trigger most likely source of background

- Background sample 20 million \textit{bb} events generated with above condition
  \(( \rightarrow \text{factor } 0.434, \text{ sample equivalent to } \sim 46\text{M } \text{bb events})\)

- Still equivalent to only a few minutes of LHCb running!
Background studies

• Favoured modes - expect ~60k signal events/year
  - Background from $D^0\pi$ decays dominates (BR \(\sim 13 \times D^0K\))
    • Use RICH information to separate $D^0K$ and $D^0\pi$
    • Find 3 $D^0\pi$ events survive analysis from bb sample
    • Generate a larger sample of $D^0\pi$ decays to get better idea of B/S – find 387/580k $D^0\pi$ events accepted
  
  \[\Rightarrow\] Expect ~25k bkgrd events/year from $D^0\pi$

  - Find no other events from bb sample survive all cuts
  - To improve background estimate – in particular from ‘combinatoric’ events – widen B mass window to 10\(\times\)the standard one :
    • Then find 3 events survive analysis from bb sample
    • Linearly extrapolate into normal mass window
  
  \[\Rightarrow\] Expect ~1k bkgrd events/year from combinatoric (making conservative assumption trigger efficiency same for combinatoric background as for signal)

  - B/S \(\sim 0.5\) [dominated by $D^0\pi$]
Background studies

- Suppressed modes – expect 2k signal events/year
  - $D^0\pi$ suppressed by subsequent DCS $D^0$ decay → contribution with $B/S \sim 0.5$
  - In addition, $bb$ sample indicates that there is significant combinatoric contribution:
    - No events in normal mass window
    - Find 3 events in the 10× standard mass window
    - Linearly extrapolate into normal mass window
    → Expect $\sim$1k background events/year from combinatoric events
  - $B/S \sim 1$ [both $D^0\pi$ and combinatoric events]

- Other sources of background have been considered:
  - Favoured sign events when $K\pi$ mis-identified as $\pi K$
    - Factor $\geq 0.05$ for $\pi$ mis-id as $K$, factor for $K$ mis-id as $\pi \leq 0.10 \rightarrow 300$ events, $B/S \sim 0.15$
      (BELLE veto on $D^0$ mass with particle hypotheses reversed)
  - $B\rightarrow K\pi K$ mode – BELLE estimate from $D^0$ mass sidebands → contribution with $B/S \sim 0.20$
  - $B\rightarrow D^0(KK)\pi$ mode – $BR \sim 40 \times$ sup. modes - BELLE use veto on $m(KK)$ – little impact on $E_{TOT}$

- The other modes that are required to solve for all unknowns are under study
  eg. $B \rightarrow D^0(KK,\pi\pi,K\pi\pi\pi)$
Estimating LHCb’s sensitivity

• Preliminary studies performed using toy MC to generate event yields
  – Fix:
    • $\gamma = 60^\circ$
    • $\delta_B = 130^\circ$
    • $r_B = 0.15$
    • $r_{D^{K\pi}}, r_{D^{K3\pi}} = 0.060$
  – Try full range of values for $\delta_{D^{K\pi}}, \delta_{D^{K3\pi}}$

• Using particular set of parameters generate event yields

• Assume cos ($\delta_D$) known to ±0.20 (conservative estimate CLEO-C precision)

• Fit parameters ($r_B$, $\delta_B$, $\delta_{D^{K\pi}}$, $\delta_{D^{K3\pi}}$ and $\gamma$)

• Establish errors from spread of results over 1000 experiments
Typical fit results: $\delta_D^{K\pi} = 180^\circ$, $\delta_D^{K^3\pi} = 120^\circ$

2 fb$^{-1}$

Without background included

Fit results return input values

Error on $\gamma = 3.9^\circ$
Adding the background ...

- Precision on $\gamma$ after adding the background:

```
<table>
<thead>
<tr>
<th>B/S</th>
<th>$\pi K$, KK, $\pi \pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.9° 4.0° 4.0° 4.1°</td>
</tr>
<tr>
<td>1</td>
<td>4.6° 4.8° 4.8° 5.0°</td>
</tr>
<tr>
<td>2</td>
<td>5.0° 5.1° 5.3° 5.5°</td>
</tr>
<tr>
<td>5</td>
<td>5.6° 5.9° 6.0° 6.3°</td>
</tr>
</tbody>
</table>
```

taking same example position in parameter space ($\delta_{D^{K\pi}}=180°$, $\delta_{D^{K3\pi}}=120°$)

Recall background estimate for $B \to D(K\pi)K : B/S \sim 1$

$B \to D(K\pi\pi\pi)K$ under study
Robustness

- Scan over range of $D$ strong phases, $\delta_D^{K\pi}$, $\delta_D^{K3\pi}$

While there are some values where close lying ambiguities cause problems, in general fit robust to range of values:

- A global fit including Dalitz information (or more $D$ decays) may get rid of these ambiguities

- Precision also found to be only weakly dependent on $r_B$ and $\cos \delta_D$ knowledge

An unlucky position in parameter space
Conclusions

• Construction of the LHCb experiment proceeding well

• Hope to address wide range of B physics topics:
  – $B_s$ oscillations, 5σ observation of $B_s$ osc. for $\Delta m_s < 68$ ps$^{-1}$ (in one year)
  – Rare decays eg. $B_s \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow K^{*0} \mu^+\mu^-$, sensitive to NP
  – CKM angles $\alpha$, $\beta$ (cross-check)
  – CKM angle $\gamma$
    • ADS method - candidate for LHCb’s most precise measurement
    • Other $B \rightarrow DK$ decay modes will provide complementary information on $\gamma$:
      – GLW method
      – Dalitz plot analysis

• Eagerly awaiting the first collisions at the LHC!
Belle, hep-ex/0508048

UT fit:
\[ r_B = 0.078 \pm 0.028 \]

Point taken by LHCb –
Would expect 18 evts from 275M BB (cf. 15 reported) and 28 evts above!
$r_B = 0.15$

$B = 0.078$
Extending to $B \rightarrow D^*K$

- $D^*K$ has an extremely attractive feature:
  - $D^* \rightarrow D^0\pi^0$ – here the $D^*$ and $D^0$ have the same CP
  - $D^* \rightarrow D^0\gamma$ – here the $D^*$ and $D^0$ have opposite CP

  → relative $180^\circ$ offset to $\delta_B$ in the expression for the rates

- If can distinguish the two decays → powerful additional constraint! [Bondar and Gershon: hep-ph/0409281]

- LHCb’s ability to separate the $\pi^0$ and $\gamma$ contributions is under investigation