Status and Physics reach of LHCb

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On behalf of the LHCb collaboration
LHC start up is approaching:

- Cooling down proceeding well, aiming for machine cold in the first half of July.
- Beam injected end July - early August. First collision 1-2 months later.
- Luminosity $\sim 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
Huge $b\bar{b}$ production in pp collisions at $\sqrt{s}=14\text{TeV}$, in the forward region

$\sigma_{bb} = 500 \mu\text{b} \quad \rightarrow \quad N \sim 10^{12} \, \text{bb events in } L_{\text{int}} = 2 \text{ fb}^{-1}$

$\sigma_{\text{inel}} = 80 \text{ mb}$

A possible running scenario:

2008    Expect $\sim 50$ days of data taking with limited efficiency, $L \sim 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
        Calibration and Trigger commissioning / First results for non-CP physics

2009    Expect $\sim 140$ days of data taking, $L \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
        First results on rare decays and CP physics $\sim 0.5 \text{ fb}^{-1}$

2010-   Stable running. Expect $\sim 2 \text{ fb}^{-1}$/ year

LHCb planes to collect an integrated luminosity of 10 fb$^{-1}$ for year $\sim 2013$
Detector installed, going to close and be ready for data-taking. Commissioning with cosmics on-going.
LHCb expected performance (I)

B vertex and mass measurement

- B vertex and mass measurement
- $B_{s} \rightarrow \mu\mu$
- $B_{s} \rightarrow KK$
- $B_{s} \rightarrow \pi^{+}\pi^{-}$
- $D_{s} \rightarrow K^{+}K^{-}\pi^{-}$
- Momentum resolution $\sigma(p)/p \sim 0.3\% - 0.5\%$ increasing with $p$
- B proper time resolution $\sim 40$ fs
- Primary vertex resolution $\sim 144 \mu m$
- Primary vertex resolution $\sim 47 \mu m$
- Primary vertex resolution $\sim 440 \mu m$
- VErtex Locator (Silicon strip) resolution $\sim 5 \mu m$
- IP resolution $\sim 30 \mu m$
- B mass resolution $\sim 15 - 20$ MeV/c$^2$

All results obtained from full Detector (GEANT4) MC simulation
LHCb expected performance (II)

Particle IDentification

RICH1:
5cm aerogel n=1.03
4m$^3$ C$_4$F$_{10}$ n=1.0014

RICH2:
100m$^3$ CF$_4$ n=1.0005

Flavour Tagging performance
from combination of several methods
(electron, muon, kaon, pion, inclusive vertex):
$\varepsilon D^2 = 4\text{--}5\%$ for $B_d$
$\varepsilon D^2 = 7\text{--}9\%$ for $B_s$ depending on channel
LHCb Trigger

40 MHz

Level-0

Pile up e, γ, h, high pT μ, high pT

1 MHz

All DATA

High Level Trigger

2 kHz

event size ~50 kB

Storage

L0, HLT and L0×HLT efficiency

<table>
<thead>
<tr>
<th>HLT rate</th>
<th>Event type</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 Hz</td>
<td>Exclusive B selec.</td>
<td>B (core program)</td>
</tr>
<tr>
<td>600 Hz</td>
<td>High mass μμ</td>
<td>J/ψ, b→J/ψX</td>
</tr>
<tr>
<td>300 Hz</td>
<td>D* candidates</td>
<td>Charm</td>
</tr>
<tr>
<td>900 Hz</td>
<td>Inclusive b (b→μ)</td>
<td>B (data mining)</td>
</tr>
</tbody>
</table>

M. Calvi

HQ&L08

(7/24)
LHCb: motivation and Physics Program

LHCb is a 2nd generation precision experiment coming after B-Factories and Tevatron:

- $b \rightarrow d$ transitions: broadly studied, in general good agreement with SM.
- $b \rightarrow s$ transitions: still limited knowledge, space for NP effects.
- Strong constraints to SM available from precision measurements of CKM parameters, but $\gamma$ angle still poorly known.
- High statistics production of all kind of $b$- (and $c$-) hadrons at LHC allows extensive studies in wide set of channels.

→ Improve precision on $\gamma$ and other CKM parameters, search for NP from comparison between tree and box / penguin contributions.

Examples: $\beta_s$ from $B_s \rightarrow J/\psi \phi$, $\gamma$ from $B_{(s)} \rightarrow D_{(s)}K$, penguins in $B_s \rightarrow \phi \phi$

→ Search for NP in rare decays, with high precision measurements of BRs and time dependent CP asymmetries.

Examples: $B_s \rightarrow \mu \mu$, $B_d \rightarrow K^0 \phi \mu$, $B_s \rightarrow \phi \gamma$
Bs Mixing phase $\beta_s$ with $b \rightarrow c\bar{c}s$ (I)

- The $\sin 2\beta_d$ analogous in the $B_s$ sector.
- The phase arising from interference between $B$ decays with and without mixing is a sensitive probe to new physics.

In the SM

$\Phi^{SM} = -2\beta_s = -0.0368 \pm 0.0017$

- Could be much larger if New Physics contributes to $B_s$-$\bar{B}_s$ transitions.

From $B_s \rightarrow J/\psi \phi$ we measure $\Phi^{meas} = \Phi^{SM} + \Phi^{NP}$

- Tevatron results:  
  D0 $2\beta_s = -0.57^{+0.24}_{-0.30}$ with 2.8 fb$^{-1}$
  CDF $2\beta_s = [0.32, 2.82] \at 68\%$CL with 1.35 fb$^{-1}$

- Time-dependent asymmetry in decay rates:

$$A_{CP} (t) = -\frac{\eta_f \sin 2\beta_s \sin(\Delta m_s t)}{\cosh \left(\frac{\Delta \Gamma_s t}{2}\right) - \eta_f \cos 2\beta_s \sinh \left(\frac{\Delta \Gamma_s t}{2}\right)}$$
Bs Mixing phase $\beta_s$ with $b \rightarrow c \bar{c}s$ (II)

- $B_s \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ is the golden channel, requires angular analysis to disentangle the mixture of CP-even ($\eta_f = -1$) and CP odd ($\eta_f = +1$).
- Use flavour tagged and untagged events.
- Need very good proper time resolution to resolve $B_s$ oscillations.

- Can add pure CP modes: $J/\psi \eta$, $J/\psi \eta'$, $\eta_c \phi$, $D_s^+D_s^-$ but much lower statistics.

<table>
<thead>
<tr>
<th>Decay Channel</th>
<th>Yield (2fb$^{-1}$)</th>
<th>$\sigma(2\beta_s)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow J/\psi(\mu\mu)\phi(KK)$</td>
<td>130k</td>
<td>0.023</td>
</tr>
<tr>
<td>Pure CP modes</td>
<td>$\sim$25k total</td>
<td>0.048</td>
</tr>
<tr>
<td>All modes</td>
<td></td>
<td>0.021</td>
</tr>
</tbody>
</table>

Sensitivity to other fit parameters (with 2 fb$^{-1}$):
$\sigma(\Delta \Gamma_s/\Gamma_s) = 0.0092$, $\sigma(R_T) = 0.0040$

With 0.5 fb$^{-1}$ $\sigma(2\beta_s) \sim 0.046$

With 10 fb$^{-1}$ $\sigma_{\text{stat}}(2\beta_s) \sim 0.009$
$> 3\sigma$ evidence of non-zero $\beta_s$ even if only SM
New Physics in $B_s$ mixing amplitude $M_{12}$ parameterized with $h_s$ and $\sigma_s$:

$$M_{12} = (1 + h_s \exp(2i\sigma_s)) M_{12}^{SM}$$

Additional constraints can come from semileptonic Asymmetry. In SM: $A_{SL}^s \sim 10^{-5}$.

Preliminary results on the LHCb measurement of time dependent charge asymmetry in $B_s \rightarrow D_s^{\pm} \mu\nu$

Expect $\sim 10^9$ events/2fb$^{-1} \rightarrow \delta(A_{SL}^s) \sim 2 \times 10^{-3}$ in 2fb$^{-1}$
**b → s\bar{s}s** hadronic penguin decays

\[ B_s → φφ \]

- In SM CP violation < 1% due to cancellation of the mixing and penguin phase:
  \[ φ_{B_s → φφ}^{SM} ≈ 2 \arg(V_{ts} * V_{tb}) − \arg(V_{ts} V_{tb}^*) = 0 \]

- In presence of NP expect different contributions in boxes and in penguins:
  \[ φ_{B_s → φφ}^{NP} = φ_{M}^{NP} - φ_{D}^{NP} \]

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (2 fb(^{-1}))</th>
<th>B/S (90%CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_s → φφ )</td>
<td>3100</td>
<td>&lt; 0.8</td>
</tr>
<tr>
<td>( B_d → φ K_S )</td>
<td>920</td>
<td>&lt; 1.1</td>
</tr>
</tbody>
</table>

- From the time dependent angular distribution of flavour tagged events, in 2 fb\(^{-1}\)
  \[ σ_{stat}(φ^{NP}) = 0.11 \]

- Less statistics on \( B_d → φ K_S \), expected precision: \( σ(sin(2β_{eff})) ≈ 0.23 \)
Different ways to $\gamma$ at LHCb

<table>
<thead>
<tr>
<th>B mode</th>
<th>D mode</th>
<th>Method</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \to D_s K$</td>
<td>$K\bar{K}\pi$</td>
<td>tagged, $A^{\text{CP}}(t)$</td>
<td>$\gamma - 2\beta_s$</td>
</tr>
<tr>
<td>$B^+ \to D K^+$</td>
<td>$K\pi, K\bar{K}/\pi\pi$</td>
<td>counting, ADS+GLW</td>
<td>$\gamma$</td>
</tr>
<tr>
<td>$B^+ \to D K^+$</td>
<td>$K_s\pi\pi$</td>
<td>Dalitz, GGSZ</td>
<td>$\gamma$</td>
</tr>
<tr>
<td>$B^+ \to D K^+$</td>
<td>$K\bar{K}\pi\pi$</td>
<td>4 body Dalitz</td>
<td>$\gamma$</td>
</tr>
<tr>
<td>$B^0 \to D K^*$</td>
<td>$K\pi, K\bar{K}, \pi\pi$</td>
<td>counting, ADS+GLW</td>
<td>$\gamma$</td>
</tr>
<tr>
<td>$B \to \pi\pi, K\bar{K}$</td>
<td>$-$</td>
<td>Tagged, $A^{\text{CP}}(t)$</td>
<td>$\gamma / \beta_d / \beta_s$</td>
</tr>
</tbody>
</table>

And several additional modes under study: $B^+ \to D^* K^+ (D \to K\pi, K\bar{K}, \pi\pi)$, $B^+ \to D K^+ (D \to K\pi\pi\pi)$ ...
\[ \gamma \text{ from } B_s \rightarrow D_s K \]

- Two tree decays which interfere via \( B_s \) mixing \( \rightarrow \) determine \( \gamma \) in a very clean way

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (2 fb(^{-1}))</th>
<th>B/S (90%CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_s \rightarrow D_s K )</td>
<td>6200</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>( B_s \rightarrow D_s \pi )</td>
<td>140 k</td>
<td>0.4</td>
</tr>
</tbody>
</table>

- Fit time-dependent rates of \( B_s \rightarrow D_s K \) and \( B_s \rightarrow D_s \pi \)
  - Including \( B_s \rightarrow D_s \pi \) to constrain \( \Delta m_s \) and mistag
  - Use tagged and untagged \( B_s \rightarrow D_s K \) samples

Sensitivity with 2fb\(^{-1}\):

\[
\begin{array}{|c|c|}
\hline
2\beta_s + \gamma & 9^\circ - 12^\circ \\
\Delta m_s & 0.007 \text{ ps}^{-1} \\
\hline
\end{array}
\]
Different ways to $\gamma$ at LHCb

<table>
<thead>
<tr>
<th>B mode</th>
<th>D mode</th>
<th>Method</th>
<th>Parameter</th>
<th>$\sigma(\gamma)$ 2fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow D_s K$</td>
<td>$KK\pi$</td>
<td>tagged, $A^C_P(t)$</td>
<td>$\gamma-2\beta_s$</td>
<td>9$^\circ$-12$^\circ$</td>
</tr>
<tr>
<td>$B^+ \rightarrow D K^+$</td>
<td>$K\pi, KK/\pi\pi$</td>
<td>counting, ADS+GLW</td>
<td>$\gamma$</td>
<td>11$^\circ$-14$^\circ$</td>
</tr>
<tr>
<td>$B^+ \rightarrow D K^+$</td>
<td>$K_s\pi\pi$</td>
<td>Dalitz, GGSZ</td>
<td>$\gamma$</td>
<td>7$^\circ$-12$^\circ$</td>
</tr>
<tr>
<td>$B^+ \rightarrow D K^+$</td>
<td>$KK\pi\pi$</td>
<td>4 body Dalitz</td>
<td>$\gamma$</td>
<td>18$^\circ$</td>
</tr>
<tr>
<td>$B^0 \rightarrow D K_s^0$</td>
<td>$K\pi, KK,\pi\pi$</td>
<td>counting, ADS+GLW</td>
<td>$\gamma$</td>
<td>9$^\circ$</td>
</tr>
<tr>
<td>$B \rightarrow \pi\pi, KK$</td>
<td>0</td>
<td>tagged, $A^C_P(t)$</td>
<td>$\gamma/\beta_d/\beta_s$</td>
<td>10$^\circ$</td>
</tr>
</tbody>
</table>

- Global fit combining $\chi^2$ from the different ADS/GLW rates and Dalitz:

<table>
<thead>
<tr>
<th>$\delta_{B^*}$ $(^\circ)$</th>
<th>0</th>
<th>45</th>
<th>90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined $B^+/B^0$ (ADS+GLW)</td>
<td>4.6$^\circ$</td>
<td>7.6$^\circ$</td>
<td>6.3$^\circ$</td>
<td>7.1$^\circ$</td>
<td>4.6$^\circ$</td>
</tr>
<tr>
<td>+ model independent Dalitz</td>
<td>4.2$^\circ$</td>
<td>5.7$^\circ$</td>
<td>5.3$^\circ$</td>
<td>5.7$^\circ$</td>
<td>4.2$^\circ$</td>
</tr>
</tbody>
</table>

- Combining with time dependent measurements ( $D_s K$ and $D\pi$ ) gives a global LHCb sensitivity to $\gamma$ with tree decays only: $\sigma(\gamma) \sim 4^\circ$ with 2 fb$^{-1}$
- Highly suppressed in SM: \( \text{BR}(B_s \rightarrow \mu\mu) = (3.35 \pm 0.32) \times 10^{-9} \)
- Could be strongly enhanced by SUSY: \( \text{BR}(B_s \rightarrow \mu\mu) \propto \tan^6 \beta / M_H^2 \)

- Current limits from Tevatron \( \sim 2 \text{ fb}^{-1} \):
  - CDF: \( \text{BR} < 4.7 \times 10^{-8} \) 90% CL
  - D0: \( \text{BR} < 7.5 \times 10^{-8} \) 90% CL

LHCb: high stat. & high trigger efficiency for signal, main issue is background rejection.
Largest background is \( b \rightarrow \mu, b \rightarrow \mu \).
Specific background dominated by \( B_c^{\pm} \rightarrow J/\psi(\mu\mu) \mu^{\pm} \nu \)
Exploit good mass resolution and vertexing, and good particle ID.
Analysis in a Phase Space with 3 axis:

- Geometrical Likelihood (GL) (impact parameters, distance of closest approach between $\mu\mu$, $B_s$ lifetime, vertex isolation)
- Particle-ID Likelihood
- Invariant mass window around $B_s$ peak

- Sensitive Region: GL > 0.5
- Divide in N bins
- Evaluate expected number of events for signal/background in each bin.

Assuming SM BR, in 2fb$^{-1}$ ~30 signal events
~83 background events

- Normalization from $B^+ \rightarrow J/\Psi K^+$ events. Dominant uncertainty on BR from relative $B_s,B^+$ hadronization fractions ~14%.
$B_s \rightarrow \mu\mu$

90% CL limit on BR (only bkg is observed)

Expected final CDF+D0 limit

SM prediction

Sensitivity to signal (signal+bkg is observed)

Exclusion: 0.5 fb$^{-1}$ $\Rightarrow$ < SM

Within SM BR:
2 fb$^{-1}$ $\Rightarrow$ 3σ evidence
6 fb$^{-1}$ $\Rightarrow$ 5σ observation

\[ B_d \rightarrow K^*\mu\mu \]

- BR measured at B-factories, in agreement with SM: \[ \text{BR}(B_d \rightarrow K^*\mu\mu) = (1.22^{+0.38}_{-0.32}) \times 10^{-6} \]
- Decay described by three angles (\( \theta_{\mu}, \phi, \theta_{K^*} \)).

- Zero crossing point of forward-backward asymmetry \( A_{FB} \) in \( \theta_{\mu} \) angle, as a function of \( m_{\mu\mu} \), precisely computed in SM: \[ s_0^{SM}(C_7,C_9) = 4.39^{+0.38}_{-0.35} \text{ GeV}^2 \]

- Fast MC, LHCb 2 fb\(^{-1} \)

- Simple linear fit suggests precision:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (2 fb(^{-1} ))</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_s \rightarrow K^*\mu^+\mu^- )</td>
<td>7200</td>
<td>(~0.5)</td>
</tr>
</tbody>
</table>

Ignoring non-resonant \( K\pi\mu\mu \) events

<table>
<thead>
<tr>
<th>( \sigma(s_0) )</th>
<th>0.5 fb(^{-1} )</th>
<th>2 fb(^{-1} )</th>
<th>10 fb(^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s_0 )</td>
<td>0.8 GeV(^2 )</td>
<td>0.5 GeV(^2 )</td>
<td>0.3 GeV(^2 )</td>
</tr>
</tbody>
</table>
Fitting projections of $\theta_\mu$, $\phi$, $\theta_{K^*}$ angular distributions can measure the fraction of longitudinal polarization $F_L$ and the transverse asymmetry $A_T^{(2)}$:

Points LHCb 2 fb$^{-1}$

Stat. precisions in the region $s = m_{\mu\mu}^2 \in [1, 6]$ (GeV/c$^2$)$^2$ where theory calculations are most reliable

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity with</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_T^{(2)}$</td>
<td>$2 \text{ fb}^{-1}$  $10 \text{ fb}^{-1}$</td>
</tr>
<tr>
<td>$F_L$</td>
<td>$0.016$           $0.007$</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>$0.020$           $0.008$</td>
</tr>
</tbody>
</table>

Under investigation also full angular fit in terms of transversity amplitudes $A_{\perp L,R}$, $A_{// L,R}$, $A_0^{L,R}$. Will improve precision on $A_{FB}$. 

M. Calvi

HQ&L08 (20/24)
Radiative decays

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (2 fb⁻¹)</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_d \rightarrow K^*\gamma )</td>
<td>68000</td>
<td>~0.6</td>
</tr>
<tr>
<td>( B_s \rightarrow \phi \gamma )</td>
<td>11500</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

\( B_d \rightarrow K^*\gamma \) \( A_{\text{dir}}^{\text{CP}} < 1\% \) in SM, up to 40\% in SUSY.

\( B_s \rightarrow \phi \gamma \) Time dependent CP asymmetry allows to test the helicity structure of the emitted photon. In SM \( b \rightarrow s \gamma \) predominantly left-handed.

\[
A_{\text{CP}}(t) = - \frac{A_{\text{dir}} \cos(\Delta m_q t) + A_{\text{mix}} \sin(\Delta m_q t)}{A_{\text{dir}} \sinh(\Delta \Gamma_q t / 2) - \cosh(\Delta \Gamma_q t / 2)}
\]

As \( \Delta \Gamma_s \neq 0 \) \( B_s \rightarrow \phi \gamma \) probes \( A^{\Delta} \), as well as \( A^{\text{dir}} \) and \( A^{\text{mix}} \).

For \( \cos \varphi \approx 1 \) \( A^{\Delta} \sim \sin 2\psi \) determines the fraction of “wrongly” polarized photon.

With 2 fb⁻¹: \( \sigma \left( A^{\Delta} \right) = 0.22 \)

\( \sigma \left( A^{\text{dir}}, A^{\text{mix}} \right) = 0.11 \)
Charm physics

- LHCb will collect a large tagged $D^* \to D^0 \pi$ sample (also used for PID calibration). A dedicated $D^*$ trigger is foreseen for this purpose.
  - Tag $D^0$ or anti-$D^0$ flavour with pion from $D^{*\pm} \to D^0 \pi^\pm$

- Performance studies not as detailed as for B physics.

- Interesting (sensitive to NP) & promising searches/measurements:
  - Time-dependent $D^0$ mixing with wrong-sign $D^0 \to K^+\pi^-$ decays
    $\sigma_{\text{stat}(x')} \sim 0.14 \times 10^{-3}$, $\sigma_{\text{stat}(y')} \sim 2 \times 10^{-3}$ with 2 fb$^{-1}$
  - Direct CP violation in $D^0 \to K^+K^-$
    • $A_{\text{CP}} \leq 10^{-3}$ in SM, up to 1% with New Physics
    • Expect $\sigma_{\text{stat}}(A_{\text{CP}}) \sim 0.001$ with 2 fb$^{-1}$
  - $D^0 \to \mu^+\mu^-$
    • BR $\leq 10^{-12}$ in SM, up to $10^{-6}$ with New Physics
    • Expect to reach down to $\sim 5 \times 10^{-8}$ with 2 fb$^{-1}$
LHCb beyond 10 fb\(^{-1}\)

- Several measurements limited by stat. precision after 10 fb\(^{-1}\): investigating upgrade of detector to handle luminosity 2\times10^{33} \text{ cm}^{-2}\text{s}^{-1} and integrate up to \sim 100 fb\(^{-1}\)
  - Not directly coupled to SLHC machine upgrade since luminosity already available, but may overlap in time with upgrades of ATLAS and CMS.

- Technical solutions under study (increase trigger efficiency for hadronic modes, fast vertex detection, electronics, radiation dose, pile-up, higher occupancy etc.)
  - Expression of Interest for an LHCb upgrade submitted to LHCC.

- Physics case:
  - CPV in \(B_s\) mixing (tree and penguins)
  - \(\gamma\) angle with \sim 1^\circ\) precision
  - Chiral structure of \(b \rightarrow s\) from \(B \rightarrow \phi\gamma\) and \(B \rightarrow K^*\mu^+\mu^-\)

<table>
<thead>
<tr>
<th>Observable</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S(B_s \rightarrow \phi\phi))</td>
<td>0.01 – 0.02</td>
</tr>
<tr>
<td>(S(B_d \rightarrow \phi K^0_S))</td>
<td>0.025 – 0.035</td>
</tr>
<tr>
<td>(\phi_s (J/\psi\phi))</td>
<td>0.003</td>
</tr>
<tr>
<td>(\sin(2\beta) (J/\psi K^0_S))</td>
<td>0.003 – 0.010</td>
</tr>
<tr>
<td>(\gamma (B \rightarrow D^{(<em>)}K^{(</em>)}))</td>
<td>&lt; 1^\circ</td>
</tr>
<tr>
<td>(\gamma (B_s \rightarrow D_s K))</td>
<td>1 – 2^\circ</td>
</tr>
<tr>
<td>(B(B_s \rightarrow \mu^+\mu^-))</td>
<td>5 – 10%</td>
</tr>
<tr>
<td>(B(B_d \rightarrow \mu^+\mu^-))</td>
<td>(3\sigma)</td>
</tr>
<tr>
<td>(A_T^{(2)}(B \rightarrow K^{*0}\mu^+\mu^-))</td>
<td>0.05 – 0.06</td>
</tr>
<tr>
<td>(A_{FB}(B \rightarrow K^{*0}\mu^+\mu^-))</td>
<td>0.07 GeV(^2)</td>
</tr>
<tr>
<td>(S(B_s \rightarrow \phi\gamma))</td>
<td>0.016 – 0.025</td>
</tr>
<tr>
<td>(A^{\Delta \Gamma_s}(B_s \rightarrow \phi\gamma))</td>
<td>0.030 – 0.050</td>
</tr>
<tr>
<td>charm (x^{72})</td>
<td>(2 \times 10^{-5})</td>
</tr>
<tr>
<td>mixing (y')</td>
<td>(2.8 \times 10^{-4})</td>
</tr>
<tr>
<td>CP (y_{CP})</td>
<td>(1.5 \times 10^{-4})</td>
</tr>
</tbody>
</table>

Expected sensitivity for 100 fb\(^{-1}\) assuming a factor 2 in hadronic trigger efficiency and same reconstruction efficiency
Conclusions

• LHCb is ready for data taking at LHC start-up.

• Very interesting results will come already with first 0.5 fb⁻¹ of data:

  \[ B_s \rightarrow J/\psi \phi \]  \[ 2\beta_s \] measurement with \( \sim 0.05 \) precision

  \[ B_s \rightarrow \mu \mu \]  BR limit down to SM value

  \[ B_d \rightarrow K^0 \mu \mu \]  \( \sim 1800 \) events, overtaking B-Factories statistics

• LHCb results will provide in the coming years a strong improvement to
flavour physics, in particular to the knowledge of all \( B_s \) sector.

• Actively preparing for analysis of several channels with high potential for indirect NP discovery.

Looking forward next HQ&L Conference to show all that!
BACK-UP
\[ \gamma \text{ from } B^\pm \to D^0K^\pm (\text{ADS+GLW}) \] (I)

\textbf{Charged }B\text{ decay}

- \[ B^\pm \to D^0K^\pm \]
  - Colour favoured
  - Colour suppressed

\textbf{\( D^0 \) and \( \bar{D}^0 \) can both decay into }\( K^-\pi^+ \) (or \( K^+\pi^- \))

- \[ D^0 \to K^-\pi^+ \]
  - Doubly Cabibbo suppressed
- \[ \bar{D}^0 \to K^+\pi^- \]
  - Cabibbo favoured

\[ \Gamma(B^- \to (K^-\pi^+)_{D(K^-)} = N^k_{\pi} (1 + r_B r_D + 2 r_B r_D \cos(\delta_B - \delta^K_{D(K^-) - \gamma})) \]
\[ \Gamma(B^- \to (K^+\pi^-)_{D(K^-)} = N^k_{\pi} (r^2_B + r^2_D + 2 r_B r_D \cos(\delta_B + \delta^K_{D(K^-) - \gamma})) \]
\[ \Gamma(B^+ \to (K^+\pi^-)_{D(K^+)} = N^k_{\pi} (1 + r_B r_D + 2 r_B r_D \cos(\delta_B - \delta^K_{D(K^+) + \gamma})) \]
\[ \Gamma(B^+ \to (K^-\pi^+)_{D(K^+)} = N^k_{\pi} (r^2_B + r^2_D + 2 r_B r_D \cos(\delta_B + \delta^K_{D(K^+) + \gamma})) \]
\[ \Gamma(B^- \to (h^-h^+)_{D(K^-)} = N^{hh} (1 + r^2_B + 2 r_B \cos(\delta_B - \gamma)) \]
\[ \Gamma(B^+ \to (h^-h^+)_{D(K^+)} = N^{hh} (1 + r^2_B + 2 r_B \cos(\delta_B + \gamma)) \]

Amplitude ratio \( r_B \sim 0.08 \)

\[ \text{Amplitude ratio } r^{D(K\pi)}_{D(K\pi)} = 0.060 \pm 0.003 \]

\( \gamma \) has a right sign, lower sensitivity to \( \gamma \)

\( \delta^K_{D(K^-)} \) has a wrong sign, high sensitivity to \( \gamma \)

\( \text{Add CP eigenstate decays } D^0 \to K^+K^-, \pi^+\pi^- \)
γ from $B^\pm \rightarrow DK^\pm$ (ADS+GLW) (II)

6 decay rates and 7 parameters ($r_B$, $r_D$, $\delta_B$, $\delta_D$, $\gamma$, $N^h$, $N^K\pi$). $r_D$ well-measured and $\delta_D$ constrained by CLEO-c (from final statistics expect $\Delta\cos\delta_D \sim 20\%$)

Can solve for unknowns, including the weak phase $\gamma$. Add constraint on the relative $D^0$ two body BR and selection efficiencies (know to better than 3%)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield 2 fb$^{-1}$</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow D(K\pi)K$ favoured</td>
<td>56k</td>
<td>0.6</td>
</tr>
<tr>
<td>$B \rightarrow D(K\pi)K$ suppressed</td>
<td>~400</td>
<td>~ 2</td>
</tr>
<tr>
<td>$B \rightarrow D(hh)K$</td>
<td>7.8k</td>
<td>1.8</td>
</tr>
</tbody>
</table>

$\sigma(\gamma) = 11–14^\circ$ with 2 fb$^{-1}$

depending on D strong phases

( Inputs: $\gamma=60^\circ$, $r_B =0.1$, $\delta_B =130^\circ$, $\delta^K\pi$ from Cleo-c)
\( \gamma \) from \( B^0 \rightarrow D^0 K^{*0} \) (ADS+GLW)

\[
\begin{align*}
B^0 \left\{ \begin{array}{c}
\bar{b}^0 \\
\bar{c}^0
\end{array} \right\} D^0 \\
\begin{array}{c}
\bar{u}^0 \\
\bar{s}^0\end{array} K^{*0} \\
\begin{array}{c}
colour-suppressed \\
colour-suppressed
\end{array}
\end{align*}
\]

\[
B^0 \left\{ \begin{array}{c}
\bar{b}^0 \\
\bar{c}^0
\end{array} \right\} D^0 \\
\begin{array}{c}
\bar{d}^0 \\
\bar{s}^0 \\
\bar{u}^0
\end{array} K^{*0}
\]

Weak phase difference = \( \gamma \)

Magnitude ratio = \( r_B \sim 0.4 \)

- Treat with same ADS+GLW method as charged case:
  - So far used only D decays to \( K^-\pi^+, K^+\pi^-, K^+K^- \) and \( \pi^+\pi^- \) final states

\[ \sigma(\gamma) = 9^\circ \text{ with } 2 \text{ fb}^{-1} \]

<table>
<thead>
<tr>
<th>Decay mode ((+cc))</th>
<th>2 \text{ fb}^{-1} yield</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^0 \rightarrow (K^+\pi^-)_D K^{*0} )</td>
<td>3400</td>
<td>0.4–2.0</td>
</tr>
<tr>
<td>( B^0 \rightarrow (K^-\pi^+_D K^{*0} )</td>
<td>540</td>
<td>2.2–13</td>
</tr>
<tr>
<td>( B^0 \rightarrow (K^+K^-)_D K^{*0} )</td>
<td>470</td>
<td>&lt; 4.1</td>
</tr>
<tr>
<td>( B^0 \rightarrow (\pi^-\pi^+)_D K^{*0} )</td>
<td>130</td>
<td>&lt; 14</td>
</tr>
</tbody>
</table>

( Inputs: \( \gamma = 60^\circ, r_B = 0.4, \delta_B = 10^\circ \) )
Amplitude analysis of the D - Dalitz plots for $B^+$ and $B^-$ decays allows the extraction of $\gamma$ and $r_B$, $\delta_B$. Assume no CP violation in $D^0$ decays

$B$ decay amplitudes:

$A(B^\rightarrow DK^-) \propto A_D(m_{K\pi^-},m_{K\pi^+}) + r_B e^{i(\delta_B - \gamma)} A_D(m_{K\pi^+},m_{K\pi^-})$

$A(B^\rightarrow DK^+) \propto A_D(m_{K\pi^+},m_{K\pi^-}) + r_B e^{i(\delta_B + \gamma)} A_D(m_{K\pi^-},m_{K\pi^+})$

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (2 fb$^{-1}$)</th>
<th>B/S (90%CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow D(K_s\pi^+\pi^-)K$</td>
<td>5000</td>
<td>&lt; 0.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\sigma(\gamma)$ 2 fb$^{-1}$</th>
<th>Systematic error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow D(K_s\pi^+\pi^-)K$ model-dependent</td>
<td>7°-12°</td>
<td>~5-10° (model dependence)</td>
</tr>
<tr>
<td>$B \rightarrow D(K_s\pi^+\pi^-)K$ model-indep.</td>
<td>9°-13°</td>
<td>3°-4° (Cleo-c statistics)</td>
</tr>
</tbody>
</table>

Sensitivity spread due to different background scenarios
\[ \gamma \text{ from } B^0 \to \pi^+ \pi^- \text{ and } B_s \to K^+ K^- \]

Sensitive to NP in penguins. Measure:

\[ A_{CP}(t) = \frac{A_{dir} \cos(\Delta m \ t) + A_{mix} \sin(\Delta m \ t)}{\cosh (\Delta \Gamma \ t / 2) - A_{\Delta \Gamma} \sinh (\Delta \Gamma \ t / 2)} \]

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield 2 fb(^{-1})</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^0 \to \pi^+ \pi^-)</td>
<td>36k</td>
<td>(\sim 0.5)</td>
</tr>
<tr>
<td>(B_s \to K^+ K^-)</td>
<td>36k</td>
<td>(\sim 0.15)</td>
</tr>
</tbody>
</table>

Competitive with final Tevatron luminosity already for \(L=0.5\)fb\(^{-1}\)

Advantage of strong PID system to separate \(B \to h^+ h^- \) modes.

- \(A_{dir}\) and \(A_{mix}\) depend on \(\beta_d, \beta_s, \gamma, \delta e^{i\theta}\) (P/T ratio)
- Exploit U-spin symmetry (Fleischer):
  Assume: \(d_{\pi \pi} = d_{KK}\) and \(\theta_{\pi \pi} = \theta_{KK}\): 4 meas. and 3 unknowns → can solve for \(\gamma\) (taking \(\beta_d, \beta_s\) from other modes)
- Can relax U-spin requirements:
  \(0.8 < d_{KK}/d_{\pi \pi} < 1.2\), \(\theta_{\pi \pi}, \theta_{KK}\) free

\[ \sigma_{\text{stat}}(\gamma) = 10^\circ + \text{fake solution} \]

\[ \sigma_{\text{stat}}(\gamma) = 5^\circ + \text{decreased fake} \]
$R_K \text{ in } B^+ \rightarrow K^+\ell\ell$

$$R_K = \frac{\int q_{\text{max}}^2 4m_{\mu}^2 d\Gamma (B \rightarrow K_{\mu^+\mu^-}) ds}{\int q_{\text{max}}^2 4m_{\mu}^2 d\Gamma (B \rightarrow Ke^{+e^-}) ds} = 1 \pm 0.001 \text{ in SM (Hiller,Kr"uger PRD69 (2004) 074020)}$$

- Large corrections $O(10\%)$ possible in models that distinguish between lepton flavours (eg. MSSM at large $\tan\beta$). Constraints to NP also from $R_K$ and $BR(B_s \rightarrow \mu\mu)$ combined.

**LHCb 10 fb$^{-1}$**

- $B_u \rightarrow eeK$ 9.2 k events
- $B_u \rightarrow \mu\muK$ 19 k events

\[ \sigma_{\text{stat}}(R_K) = 0.043 \]

- Trigger eff $\sim 70\%$ on ee channel under study - not included.
- Similar sensitivity expected for $R_{K^*} = B_d \rightarrow \mu\muK^*/ B_d \rightarrow eeK^*$.

\[ 4m_{\mu^2}^2 < m_{ll}^2 < 6 \text{ (GeV/c}^2\text{)}^2 \]