B Physics with LHCb

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- Motivation
- Challenges of LHCb
- LHCb spectrometer
- Expected Results...

- Conclusions

- precise measurement of $B_s^0 - \overline{B}_s^0$ mixing
- precise determination of $\gamma$ and $\alpha$
- precise measurement of mixing parameters: $\Delta m_s, \Delta \Gamma_s$
- rare B-decays could yield new physics...
Motivation

- Sakharov: B, C and CP-violation essential to explain matter over anti-matter abundance in universe
- Level of Standard Model CP-violation seems insufficient (cf. Barr, Segrè & Weldon)
- Non SM sources of CP-violation necessary (SUSY?)
Large $b\bar{b}$ cross section of $\sigma_{b\bar{b}} = 500 \, \mu$ barn (0.5% of total $\sigma$) at $\sqrt{s} = 14$ TeV. pp-collisions at LHC produce $b\bar{b}$'s in forward direction:

- harsh environment from $p\bar{p}$ collisions
- many tracks
- pile up (multiple collisions per bunch crossing)
- select interesting b-physics events among $10^5 \, b\bar{b}/s$
- Use low luminosity \((2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1})\)
- trigger: reject minimum bias events
- good IP measurement: \(< \delta \text{IP} > = 40 \mu\text{m}\)
- Good proper time resolution \(\sim 40 \text{ fs}\)
- Good pion/kaon identification from \(p = 2 - 100 \text{ GeV}\)
21 layers of silicon
use $r, \phi$-sensor geometry
in close proximity to beampipe (8 mm)

used for primary vertex information in L1 trigger
used for IP calculation in HLT
Particle ID: RICH I & II

RICH systems use Hybrid Photo Diodes

Good separation of pions & kaons
Trigger

**Bunch crossing rate**

40 MHz

**Level 0**
- high Pt
- hardware trigger
- pile-up system

1 MHz

**Level 1**
- high IP
- software trigger
- high Pt tracks

40 kHz

**HLT**
- online tracking
- software trigger on complete event

2 kHz

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From consulting Pythia (MC calculations), based on $1 \text{ fb}^{-1}$

- $\Delta m_s$ from $B^0_s - B^0_s$ oscillations
- $\phi_s$ and $\Delta \Gamma_s$ from $B_s \rightarrow J/\psi \phi$
- $\gamma + \phi_s$ from $D^+_s K^- \text{ and } D^-_s K^+$ and CP-conjugates
- $\phi_d, \gamma$ from $B^0 \rightarrow \pi^+ \pi^- \text{ and } B^0_s \rightarrow K^+ K^-$
- $\gamma$ from $B^0 \rightarrow D^0 K^{*0}, B^0 \rightarrow D^0 K^{*0}, B^0 \rightarrow D^{0}_{CP} K^{*0}$ and CP-conjugates.
- $\alpha$ from $B \rightarrow \rho \pi \rightarrow \pi^+ \pi^- \pi^0$
$\Delta m_s$ from $B_s \rightarrow D_s^{\pm} \pi^{\mp}$

with $B_s \rightarrow D_s^{\pm} \pi^{\mp}$, $D_s^{\pm} \rightarrow \phi \pi^{\pm}$ and $\phi \rightarrow K^+ K^-$

\[ \mathcal{A}^{\text{flav}} = -D \frac{\cos(\Delta m_s t)}{\cosh(\Delta \Gamma_s t)} \]

- 80K events/year
- $S/B \approx 3.1$
- $5\sigma$ observation possible up to $\Delta m_s = 68 \text{ ps}^{-1}$
- Once measured: $\sigma(\Delta m_s) = 0.01 \text{ ps}^{-1}$. 
Gold-plated $B_S$ decay: $B_S \to J/\psi\phi$
- Measure three amplitudes, 2 CP-even, one CP-odd
- Disentangle flavour eigenstates by fitting angular distribution of daughter particles as a function of proper time

SM prediction:
- $\phi_S = -2\lambda^2 \eta \approx -0.04$; sensitive to NP in $B_S$ mixing
- $\Delta\Gamma_S = \Gamma(B_S^L) - \Gamma(B_S^H)$, SM: $\Delta\Gamma_S/\Gamma_S \approx 0.2$

LHCb 100K events/year for $B_S \to J/\psi\phi$ with $S/B > 3$
LHCb: $\sigma(\Delta\Gamma_S/\Gamma_S) = 0.018$

Can also use $B_S \to J/\psi\eta$ and $B_S \to \eta c\phi$
Determining $\gamma + \phi_s$ and strong phase $\Delta$

- Need to reconstruct 4 time-dependent decay rates
  - $B_s \rightarrow D_s^{\pm} K^\mp$ and CP-conjugates
  - phase extracted from $D_s^+ K^-$: $\Delta - (\gamma + \phi_s)$
  - phase extracted from $D_s^- K^+$: $\Delta + (\gamma + \phi_s)$

- use $\phi_s$ from $B_s \rightarrow J/\psi \phi$

- results in $\gamma$ independent of NP, since only tree-diagrams contribute
- good pion-kaon separation imperative
- LHCb yield: 5.4K events/year with $S/B > 1.0$

LHCb: $\sigma_\gamma = 14^\circ$ with one year of data
Measure 6 time-integrated decay rates: \( B^0 \rightarrow D^0 K^{*0} \), \( D^0 \rightarrow \bar{D}^0 K^{*0} \), \( B^0 \rightarrow D_{CP}^0 K^{*0} \) and CP conjugates. Use the Dunietz variant of the Gronau-Wyler method:

\[
\begin{align*}
A_1 &= A(B^0 \rightarrow \bar{D}^0 K^{*0}) \\
A_2 &= A(B^0 \rightarrow D^0 K^{*0}) \\
A_3 &= \sqrt{2}A(B^0 \rightarrow D_{CP}^0 K^{*0}) \\
A_4 &= \sqrt{2}A(\bar{B}^0 \rightarrow D_{CP}^0 \bar{K}^{*0})
\end{align*}
\]

\( A_3 = (|A_1| + |A_2| e^{i(\Delta + \gamma)}) \)

Result: in 1 year of datataking, \( \sigma(\gamma) \approx 7^\circ - 8^\circ \)
\[ A_{\text{CP}}(t) = A_{\text{dir}} \cos(\Delta m t) + A_{\text{mix}} \sin(\Delta m t) \]
\[ = \frac{2d \sin \theta \sin \gamma}{1 - 2d \sin \theta \sin \gamma + \frac{d^2}{2}} \]

- Assuming U-spin flavour symmetry holds for QCD
- \( \phi_s, \phi_d \) taken from other measurements

Asymmetries depend on

- \( \phi_d, \phi_s \) and \( \gamma \)
- Ratio of penguin and tree amplitudes: \( P/T = de^{i\theta} \)
- 4 measurements, three variables \( \rightarrow \) determine \( \gamma \)
- Apply unbinned extended likelihood fit to asymmetries including background
- 17 free parameters, including 6 for mass and proper time resolutions of background

26k \( B^0 \rightarrow \pi^+\pi^- \), 37k \( B^0_s \rightarrow K^+K^- \) \( \Rightarrow \sigma(\gamma) = 4^\circ - 6^\circ + \sigma(\text{theory}) \)
Determining $\alpha$ from $B \to \rho\pi$

- time-dependent Dalitz plot analysis cf. Snyder & Quinn
- extraction of $\alpha$ and strong phases
- multi-parameter fit including (non-)resonant background
- $s^- = M(\pi^0, \pi^-)$ and $s^+ = M(\pi^0, \pi^+)$

10.8k events, S/B > 0.3 in one year
- $\sigma(\alpha) < 10^\circ$
Rare decays

Standard Model prediction for $\text{Br}(B_s \rightarrow \mu^+\mu^-) = 3.5 \times 10^{-9}$

- sensitive to New Physics
- for instance: channel is enhanced in SUSY models

In one year: 17 SM events...
- $S/B \sim 0.2$
- 18 MeV resolution

$B^0 \rightarrow \phi K_s$

- challenging for trigger
- 1k events per year
- if NP, then also study $B_s \rightarrow \phi\phi, KK, \phi\gamma$ etc.

![Graph showing five years of LHCb data taking](image-url)
LHCb offers great opportunity for an extensive program on B-physics
- excellent vertex resolution and particle identification
- efficient trigger
- Precise measurements of
  - $B_s^0$-$\bar{B}_s^0$ mixing: $\Delta \Gamma_s$, $\Delta m_s$ and $\phi_s$
  - compare different measurements on $\gamma$ to identify possible NP
  - possible NP can be detected in BR measurements of rare decays
  - overconstrain unitarity triangle