Search for New Physics in Heavy Quark Decays at LHCb

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Introduction

- Data taking at LHCb has progressed rapidly

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- Collected $\sim 14 \text{ nb}^{-1}$
 - Significant strange, charm samples
 - Observations of beauty
- Expect $\sim 200 \text{ pb}^{-1}$ in 2010
 - $\Rightarrow O(10^{11})$ bb events
- $\sim 1 \text{ fb}^{-1}$ in 2011

- Will present in this talk:

- Overview of the detector performance
- Highlights of upcoming measurements in D and B decays
 - Charm: γ_{CP} in $D \rightarrow K\pi, KK, \pi\pi$
 - Beauty: $B_s \rightarrow \mu\mu, B_s \rightarrow J/\psi\phi, A_{\text{FB}}$ in $B_d \rightarrow K^*\mu\mu$

LHCb Detector

- Forward peaked, correlated $b\bar{b}$ -pair production
 - LHCb is a forward spectrometer
- Sophisticated trigger system (40MHz $\rightarrow$ 2kHz)
 - Currently run with reduced thresholds

Open Charm

- Lower trigger thresholds $\Rightarrow$ good prospects for charm
 - Large samples already collected
 - Cross-section measurements
 - Search for $D^0 \rightarrow \mu\mu$
 - Mixing, CPV etc

Charm measurements

- CP-violation weakly constrained
 - Negligible in SM, large NP contributions possible (O(1%) level)
 - eg: direct CPV in $D^+ \rightarrow K^+ K^- \pi^+$ ($D^+ \rightarrow K_S \pi^+$)

- Mixing in D^0 system
 - No single $>5\sigma$ observation
 - Many analyses in preparation at LHCb
 - For example: y_{CP} from CP eigenstates

$$y_{CP} = \frac{\tau(D^0 \rightarrow K^- \pi^+)}{\tau(D^0 \rightarrow K^+ K^-, \pi^+ \pi^-)} - 1$$

- Fit for event yields in bins of lifetime
- Plot ratio of yields $\rightarrow$ main systematics cancel
- Extract y_{CP}

Or extract y_{CP} directly from the lifetime distributions

Untagged $D^0 \rightarrow KK$ ($\sim 2.7 \text{ nb}^{-1}$)

Untagged $D^0 \rightarrow K\pi$ ($\sim 2.7 \text{ nb}^{-1}$)

$J/\psi \rightarrow \mu\mu$: Muon ID

- J/ψ "tag and probe"

- $\epsilon(\mu) = (97.3 \pm 1.2)\%$
- $\pi \rightarrow \mu$ mis-id (from K_S) in good agreement with MC
- $p \rightarrow \mu$ mis-id (from Λ) in good agreement with MC

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$J/\psi \rightarrow \mu\mu$: hints of beauty?

- Tail in J/ψ (pseudo) proper time $\Rightarrow$ B candidates?

Signal window & normalized sideband

Beauty

- Handful of B candidates observed
 - Hints in J/ψ channels (expect less than ~ 10 candidates)
- Fully reconstructed candidates

$B_s \rightarrow \mu\mu$

- Very rare SM branching ratio: $(3.35 \pm 0.32) \times 10^{-9}$ hep-ph/0604057
 - Sensitive to NP – could be enhanced by up to factor 100 in SUSY
 - An improved limit / observation should constrain potential NP

- LHCb: 3D binned likelihood analysis
 - Invariant mass, PID, geometric likelihoods
 - Uncorrelated variables lifetime, μ IP etc
 - Calibrated from control channels – little MC input
 - Loose selection to remove clear sources of background
 - Muon ID is crucial to suppress background from $B \rightarrow hh$
 - Remainder dominated by combinations semi-leptonic B-decays
 - Measure branching ratio with respect to $B \rightarrow J/\psi K$ and $B \rightarrow K\pi$

$B_s \rightarrow \mu\mu$

- Current studies suggest MC sensitivity is realistic
 - 200 pb⁻¹ (2010): improve on expected Tevatron limits (8fb⁻¹)
 - 1 fb⁻¹ (2011): exclusion down to $\sim 7 \times 10^{-9}$
 - 10fb⁻¹ for 5 σ SM observation (14TeV)

$B_d \rightarrow K^* \mu \mu$

- Rare FCNC decay $\rightarrow$ no signal observed at LHCb yet(!)

- PDG branching ratio: $(9.8 \pm 2.1) \times 10^{-7}$
 - In broad agreement with SM predictions
- Possibility to discover NP in angular distributions
 - Many angular observables sensitive to NP
 - Focus on forward-backward asymmetry (A_{FB}) as a function of q^2 (di-muon mass squared)

$$A_{FB} = \frac{N_{\theta < \pi/2} - N_{\theta > \pi/2}}{N_{\theta < \pi/2} + N_{\theta > \pi/2}}$$

$B_d \rightarrow K^* \mu \mu : A_{FB}$

- Full angular fit (θ_L , θ_K and ϕ) requires $> 2\text{fb}^{-1}$
- Projection fits to $\theta_L, \theta_K \rightarrow$ still measure A_{FB} (F_L)
- LHCb statistical precision (assume Belle central value)

Data (fb^{-1})	SM exclusion
0.1	1.5σ
0.3	2.4σ
0.5	3.1σ

Green band – SM curve
Purple band – SM average
Red points – BaBar
Blue points – Belle
Black points – LHCb (MC)

$B_s \rightarrow J/\psi \phi$

- Measure mixing-induced CP-violation in $b \rightarrow ccs$ decay

- Mixing phase $\phi_s = \phi_s^{\text{SM}} + \phi_s^{\text{NP}}$
 - $\phi_s^{\text{SM}} = -2\beta_s = 0.036 \pm 0.002$ (CKM fitter)
 - Sensitive to NP – eg new particles in box-mixing

- Measurement requires
 - Flavour tagging
 - Time dependent analysis
 - Angular analysis
- Good prospect for NP
 - $\sigma(\phi_s) = 0.14$ (200 pb^{-1})
 - $\sigma(\phi_s) = 0.07$ (1 fb^{-1})

Conclusions

- LHCb physics program progressing well
 - Measurements in charm sector
 - Direct CPV
 - Y_{CP}
 - Observation of B particles
 - Good prospects for NP discovery in $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow J/\psi\phi$
- Await more data!

Backup

Strangeness

- Large sample of strange particles
 - K_S cross section, Λ /anti- Λ ratio etc (see talk by F. Dettori)

RICH PID performance

- ϕ is useful to measure the kaon PID performance
 - 2009 data (450 GeV) – add PID information → see a ϕ peak

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RICH PID performance

- ϕ is useful to measure the kaon PID performance
 - 2010 data (7 TeV) – “tag and probe” to extract PID performance

$$\Delta \log \mathcal{L}(K - \pi) > 0$$

- Work still ongoing with alignment / calibration
 - Cherenkov angle resolutions close to expectations

LHCb Trigger

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L0 (hardware)

- high P_T single and di-muons
- high E_T single and di-electrons
- photon
- pile-up veto

2010 Trigger

- reduced L0 thresholds (P_T)
- reduced HLT1 thresholds (IP)
- HLT2 in pass-through (current)
 - phase in HLT2 as rate increases

Cuts for plots

- $K_S \rightarrow \pi\pi$
 - $\Lambda \rightarrow p\pi$ veto (8 MeV)
 - Vertex $\chi^2/\text{dof} < 15$
 - Vertex-z < 200cm
 - $v > 3.0$
 - $\Lambda \rightarrow p\pi$
 - $v > 2.0$
 - Vertex $\chi^2/\text{dof} < 15$
 - Vertex-z < 200cm
 - $K_S \rightarrow \pi\pi$ veto (17.5 MeV)
- $$v = \log_{10} \left(\frac{IP_+ IP_-}{IP_{V0}} \right)$$
- $K^*(892) \rightarrow K\pi$
 - $IP\chi^2 (K^*) < 10$
 - $FD\chi^2 (K^*) < 20$
 - $p_T (K^*) > 400 \text{ MeV}$
 - $IP\chi^2 (K,\pi) < 4$
 - Kaon $\Delta_{LL} (K-\pi) > 30$
 - Pion $\Delta_{LL} (K-\pi) < -30$
 - $\phi \rightarrow KK$
 - Vertex $\chi^2/\text{dof} < 25$
 - $FD\chi^2 (\phi) < 15$
 - Kaon $\Delta_{LL} (K-\pi) > 30$

Cuts for plots

- $J/\psi \rightarrow \mu\mu$ efficiency
 - Tag μ :
ID(μ)
 $p_T > 1.5$ GeV
 $p > 6$ GeV
 - Probe μ :
Calo(mips)
1 hit in M2 FoI

CPV in $D^+ \rightarrow K_S \pi$

$$D^+ \rightarrow K_S \pi^+$$

$$D_s^+ \rightarrow K_S K^+$$

Cabbibo Allowed

Cabbibo Suppressed

Doubly Cabbibo Suppressed

$$B_s \rightarrow \mu\mu$$

- 3 variables:
 - Invariant-mass
 - Geometric likelihood:
 - B_s lifetime
 - μ impact parameter significance
 - B_s impact parameter
 - Distance of closest approach of muons
 - Isolation
 - PID likelihood
 - Combination of probabilities as μ , K , π

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 - Branching ratio (PDG) measured to be $(9.8 \pm 2.1) \times 10^{-6}$
 - In broad agreement with SM predictions
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 - Transverse asymmetry $A_T^{(2)}$ [Egede, Reece]

$B_d \rightarrow K^* \mu \mu$: Signal Selection

- Exploit good vertex resolution and PID
 - Monte-Carlo Fisher discriminant selection
 - 2fb^{-1} : $S = 6200$ and $B = 1550$, at 7+7 TeV

- 2010/11 run:
 - Hope to collect statistics comparable to other experiments
 - Also collect sample of $\sim 64\text{k}$ $B_d \rightarrow J/\psi K^*$ events
 - Control channel for $K^* \mu \mu$ (eg selection validation / acceptance correction)

$B_d \rightarrow K^* \mu \mu$: Acceptance effects

- Acceptance varies with θ_L and $q^2 \rightarrow$ bias in A_{FB}
 - Sensitive to $\mu^\pm$ p_T cuts (avoided in selection)
- Dominated by detector geometry
 - Requirement of $P(\mu) > 3$ GeV to reach muon stations

- Shift in A_{FB} expected to be less than statistical precision for 2010/11 run
 - Acceptance correction using $J/\psi K^*$ under investigation

$B_d \rightarrow K^* \mu \mu : A_{FB}$

- Full angular fit (θ_L , θ_K and ϕ) requires $> 2\text{fb}^{-1}$
- Just use $\theta_L \rightarrow$ can still measure A_{FB}
- Current results favour flipped $C_7^{(SM)}$: more stats needed

BABAR [PRD79:031102,2009]

BELLE [PRL103:171801,2009]

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$B_s \rightarrow J/\psi \phi$

$$\frac{d^4\Gamma(B_s^0 \rightarrow J/\psi \phi)}{dt d\cos\theta d\varphi d\cos\psi} \equiv \frac{d^4\Gamma}{dt d\Omega} \propto \sum_{k=1}^6 h_k(t) f_k(\Omega)$$

$$\frac{d^4\Gamma(\bar{B}_s^0 \rightarrow J/\psi \phi)}{dt d\cos\theta d\varphi d\cos\psi} \equiv \frac{d^4\bar{\Gamma}}{dt d\Omega} \propto \sum_{k=1}^6 \bar{h}_k(t) f_k(\Omega)$$

Angular analysis to disentangle the
CP-even and CP-odd states

k	$h_k(t)$	$\bar{h}_k(t)$	$f_k(\theta, \psi, \varphi)$
1	$ A_0(t) ^2$	$ \bar{A}_0(t) ^2$	$2 \cos^2 \psi (1 - \sin^2 \theta \cos^2 \varphi)$
2	$ A_{ }(t) ^2$	$ \bar{A}_{ }(t) ^2$	$\sin^2 \psi (1 - \sin^2 \theta \sin^2 \varphi)$
3	$ A_{\perp}(t) ^2$	$ \bar{A}_{\perp}(t) ^2$	$\sin^2 \psi \sin^2 \theta$
4	$\Im\{A_{ }^*(t) A_{\perp}(t)\}$	$\Im\{\bar{A}_{ }^*(t) \bar{A}_{\perp}(t)\}$	$-\sin^2 \psi \sin 2\theta \sin \varphi$
5	$\Re\{A_0^*(t) A_{ }(t)\}$	$\Re\{\bar{A}_0^*(t) \bar{A}_{ }(t)\}$	$\frac{1}{\sqrt{2}} \sin 2\psi \sin^2 \theta \sin 2\varphi$
6	$\Im\{A_0^*(t) A_{\perp}(t)\}$	$\Im\{\bar{A}_0^*(t) \bar{A}_{\perp}(t)\}$	$\frac{1}{\sqrt{2}} \sin 2\psi \sin 2\theta \cos \varphi$