LHCb physics prospects for CP violation measurements with 0.2 and 1 fb^{-1}

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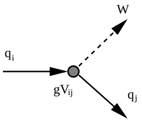
On behalf of the LHCb collaboration

CP violation in the Standard Model



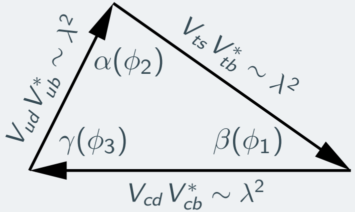
CKM matrix (Wolfenstein parametrization):

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Unitarity: $V_{ij}^* V_{jk} = \delta_{ik}$

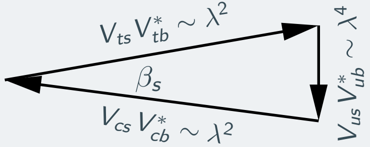
$b-d$ triangle ($i=b,\ k=d$)

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$



$b-s$ triangle ($i=b,\ k=s$)

$$V_{ub}^* V_{us} + V_{cb}^* V_{cs} + V_{tb}^* V_{ts} = 0$$



$\beta = 21.7^\circ \pm 0.9^\circ$
$\alpha = 89^\circ \pm 4^\circ$
$\gamma = 70^\circ{}^{+14^\circ}_{-21^\circ}$
$\beta_s = 0.01811 \pm 0.00085$ rad

CP violation in heavy flavors

The way to search for New Physics, complementary to direct high-energy searches.

- CP violation in B system (B^+, B^0)
  - Search for NP by comparing CPV parameters in loop- and tree-dominated decays.
- CP violation in B_s system
  - CPV phase ϕ_s: small in SM, large NP contribution possible.
- CP violation in charm
  - Mixing observed (in the combination, but no observation in the single experiment so far), no CPV visible (neither direct nor in mixing).

Flavor physics at the LHC

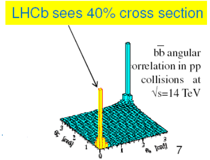
$b\bar{b}$ cross-section: 0.5 mb (14 TeV)
Flavor ratio: $B^+ : B^0 : B_s : \Lambda_b : B_c = 40\% : 40\% : 10\% : 10\% : 0.1\%$.

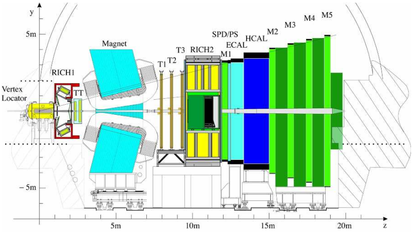
Altas, CMS

- Central detectors, $|\eta| < 2.5$
- High p_t trigger threshold

LHCb

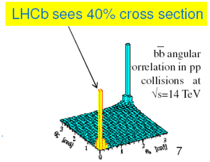
- Optimized B meson acceptance
- Forward spectrometer,
  $2 < \eta < 5$ $(15 - 300$ mrad$)$
- Softer low p_t triggers
- Efficient for hadronic B decays
- Design luminosity
  2×10^{32} cm^{-2}s^{-1},
  2 fb^{-1} per nominal year.

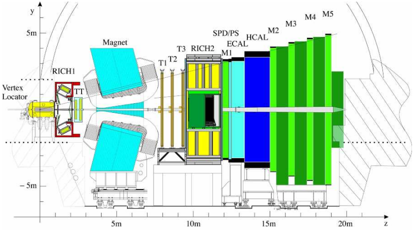




$b\bar{b}$ cross-section: 0.5 mb (14 TeV)
Flavor ratio: $B^+ : B^0 : B_s : \Lambda_b : B_c = 40\% : 40\% : 10\% : 10\% : 0.1\%$.

- $\sqrt{s} = 7$ TeV, $b\bar{b}$ cross-section reduced by $\sim 50\%$ compared to 14 TeV. Can partially compensate by lower background, lower thresholds.
- Integrated luminosity milestones:
  - 0.2 fb^{-1} by the end of 2010
  - 1 fb^{-1} in 2011.
- > 200 nb^{-1} collected, ~ 10 nb^{-1} analysed (first results next week at ICHEP!).





LHCb detector: features

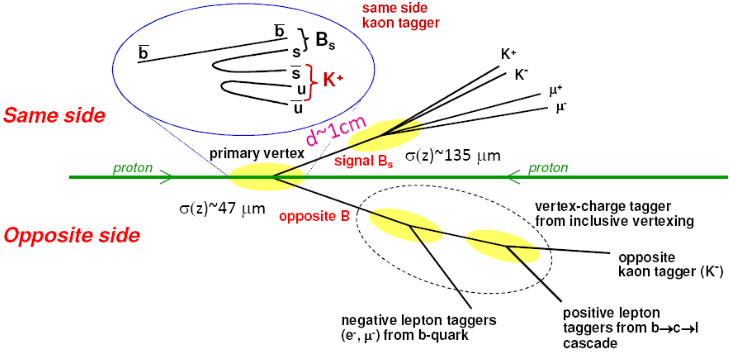
Needed for efficient B physics:

Good PID ($\pi/K/p/\mu$ separation):

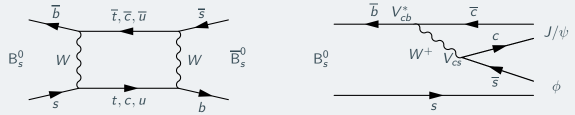
- B decay products separation
- Flavor tagging ($p < 100$ GeV)

Good vertexing ($\sigma_t \simeq 40$ fs):

- Decay time measurement, esp. for fast B_s oscillations
- Background suppression (vertex separation)



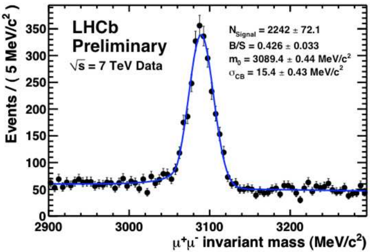
CPV in mixing of B_s: ϕ_s phase



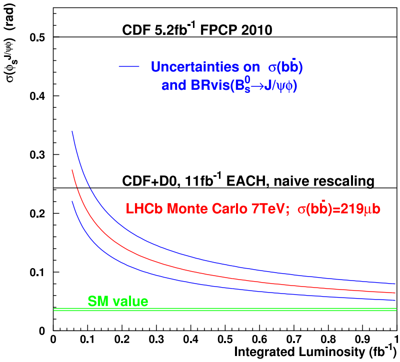
- Interference between decays $B_s \to J/\psi(\mu\mu)\phi(KK)$ with and without mixing. $\phi_s(SM) = -2\beta_s = -0.036 \pm 0.002$.
- Measured from the time-dependent asymmetry

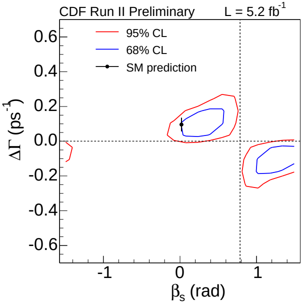
$$A_{CP}(t) = -\frac{\eta_f \sin\phi_s \sin\Delta m_s t}{\cosh\Delta\Gamma_s t/2 - \eta_f \cos\phi_s \sinh\Delta\Gamma_s t/2}$$

- P$\to$VV decay. Angular analysis to separate CP-odd and CP-even states.
- Flavor tagging needed for time-dependent asymmetry.
- First 13 nb^{-1}: do not expect signal, observe components: $J/\psi \to \mu\mu$, $\phi \to KK$.



CP violation in mixing of B_s: ϕ_s phase





Expect ~ 30000 $B_s \to J/\psi\phi$ decays with 1 fb^{-1}.
$B/S \sim 2$ (mostly prompt component, easy to separate by proper time).

- CDF 5.2 fb^{-1}: now consistent with SM (0.8σ).
- Expect sensitivity competitive to Tevatron with 0.2 fb^{-1}
- $\sigma(\phi_s) \sim 0.07$ with 1 fb^{-1}
- If NP $\sim$ CDF measurement, 5σ discovery with 1 fb^{-1}.

Flavor-specific CP-asymmetry

Charge asymmetry in semileptonic b decays: $a^q_{sl} = \frac{\Gamma(\overline{B}^0_q \to \mu^+ X) - \Gamma(B^0_q \to \mu^- X)}{\Gamma(\overline{B}^0_q \to \mu^+ X) + \Gamma(B^0_q \to \mu^- X)}$

D0 [arXiv:1005.2757]: Using like-sign dimuon asymmetry and inclusive charge asymmetry, $A^b_{sl} = a^b_{sl} + a^s_{sl} = (-0.96 \pm 0.25 \pm 0.15)\%$

$A^b_{sl}(SM) = -2.3^{+0.5}_{-0.6} \times 10^{-4}$.

Need good control of systematic factors:

- Background asymmetry
- Detector asymmetry δ_c (flip B-field)
- Production asymmetry δ_p (difficult at pp-machine!)

Time-dependent charged asymmetry:

$$A^q_{sl}(t) = \frac{a^q_{sl}}{2} - \frac{\delta^q_c}{2} - \left(\frac{a^q_{sl}}{2} + \frac{\delta^q_p}{2}\right)\frac{\cos \Delta m_q t}{\cosh \Delta\Gamma_q t/2}.$$

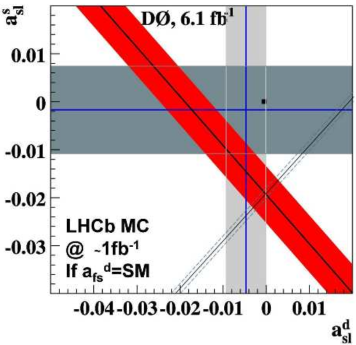
Take time-independent component:

$\rightarrow$ get rid of δ_p

Measure difference $\Delta A^{s,d}_{sl} = A^s_{sl} - A^d_{sl}$:

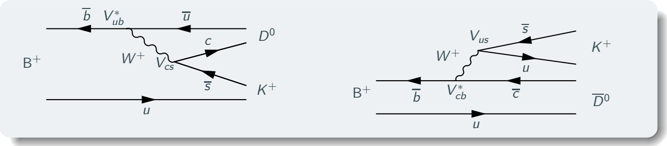
$\rightarrow$ cancel δ_c

Aᵇ central value and no NP in Bd



Using $B^0_{s,d} \to D_{s,d}(KK\pi)\mu\nu$

$\sigma(\Delta A_{fs}) \simeq 10^{-3}$ with 1 fb^{-1}



Provides SM reference for loop-induced decays.

Angle γ appears in the interference of amplitudes with V_{ub} and another CKM element.

- Interference between decays with D^0 and $\overline{D}^0$ ($B^{\pm}$, B^0 self-tagged). Need D^0 and $\overline{D}^0$ to decay into the same final state: $D^0 \to KK, K\pi, K_S\pi\pi$, ...
- Interference between decays with and without mixing (for B^0, B_s time-dependent). Can use charged D.

Many decay modes involved with comparable sensitivity.

$B^\pm \to DK^\pm$ time-integrated measurements

CPV magnitude determined by $r_B = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \overline{D}^0 K^+)|}$, strong phase difference δ_B

$D \to \pi\pi, KK, K\pi$

Observables - charge asymmetries and allowed-suppressed ratios:

$$\mathcal{A}_{ADS} \equiv \frac{\mathcal{B}(B^- \to D(K^+\pi^-)K^-) - \mathcal{B}(B^+ \to D(K^-\pi^+)K^+)}{\mathcal{B}(B^- \to D(K^+\pi^-)K^-) + \mathcal{B}(B^+ \to D(K^-\pi^+)K^+)}$$

$$\mathcal{R}_{ADS} = \frac{Br(B^\pm \to [K^\mp\pi^\pm]_D K^\pm)}{Br(B^\pm \to [K^\pm\pi^\mp]_D K^\pm)}$$

$D \to K_S\pi\pi, K_S KK$

Observable - D decay Dalitz plot density (different for B^+ and B^-):

$$|A_\pm|^2 = \Bigg| \quad [\text{plot}] \quad + re^{i\delta_B \pm i\gamma} \quad [\text{plot}] \quad \Bigg|^2$$

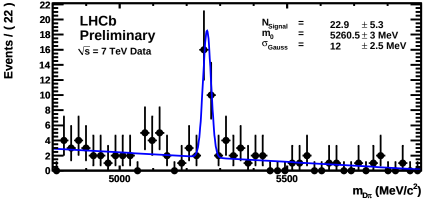
Input from charm studies (D amplitude ratios, strong phase differences — CLEO).

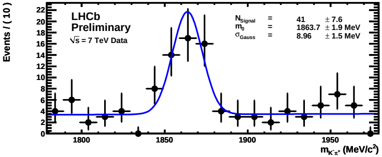
Practically no theoretical uncertainty.

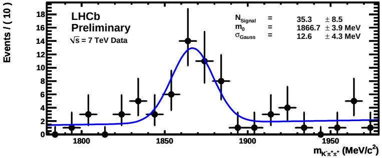
Measured parameters: r_B, δ_B, γ.

γ sensitivity depends on r_B, δ_B values.

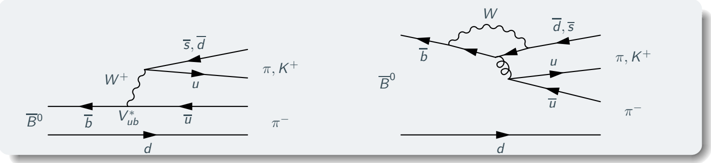
- Today (13 nb^{-1}): $B \to D\pi$ signal is seen.







- 2010 (0.2 fb^{-1}): Precision comparable to B factories ($\sigma_\gamma \sim 12 - 15^\circ$)
- 2011 (1 fb^{-1}):
  - $B \to D(hh)K$: $N_{signal} \sim 3000$ events
  - $B \to D_{\text{sup}}(K\pi)K$: $N_{signal} \sim 400$ events
  - $D \to D(K_s\pi\pi)K$: $N_{signal} \sim 1500$ events.
  - Combined $\sigma_\gamma \sim 6 - 8^\circ$

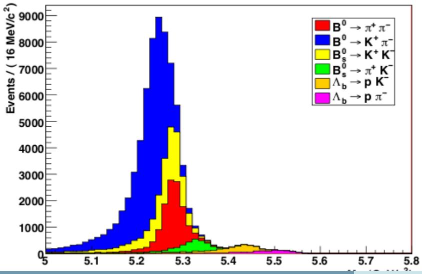


- Charmless two-body decays can probe γ.
- Observables: time-dependent asymmetries

$$A_f^{CP}(t) = \frac{A_f^{dir}\cos\Delta m t + A_f^{mix}\sin\Delta m t}{\cosh\Delta\Gamma t/2 - A_f^{\Delta}\sinh\Delta\Gamma t/2}$$

Need flavor tagging and B decay time measurements.

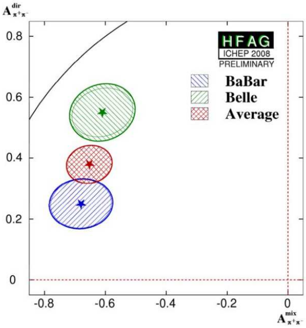
- Measurable A_f^{mix} and A_f^{dir} contain information about γ. Can be extracted by measurements with B^0 and B_s decays to $f = \pi\pi, KK, K\pi$, using U-spin symmetry ($d - s$ SU(3) subgroup).



CPV in charmless B decays

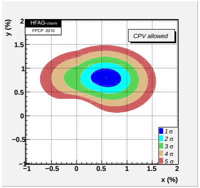
- Measurements with B^0 performed by B factories. 1.9σ disagreement between Belle and BaBar measurements.
- LHCb competitive with B factories for $A_{\pi\pi}$ measurement with 1 fb^{-1}, can measure A_{KK} from B_s.

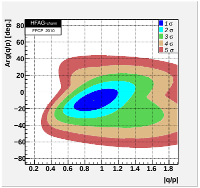
	Current value	0.2 fb^{-1}	1 fb^{-1}
$A_{\pi\pi}^{dir}$	0.38 ± 0.06	0.13	0.06
$A_{\pi\pi}^{mix}$	-0.65 ± 0.07	0.13	0.06
A_{KK}^{dir}	-	0.15	0.07
A_{KK}^{mix}	-	0.11	0.05



D mixing: $D_{1,2} = pD^0 \pm q\overline{D}^0$

- $x = (M_2 - M_1)/\Gamma$,
  $y = (\Gamma_2 - \Gamma_1)/2\Gamma$.
- $q/p \neq 1 \Rightarrow$ CPV in mixing.





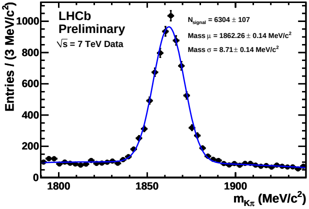
Example of a first-year measurement for LHCb: CPV in $D \to hh$.

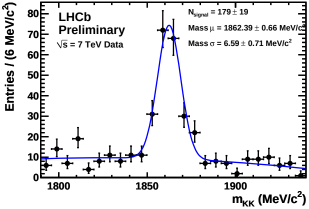
Observables:

- $y_{CP} = \tau(K\pi)/\tau(KK) - 1$,
- $A_\Gamma = \frac{\tau(D^0 \to KK) - \tau(\overline{D}^0 \to KK)}{\tau(D^0 \to KK) + \tau(\overline{D}^0 \to KK)}$

Can reach $\sigma(y_{CP}), \sigma(A_\Gamma) \sim 0.1\%$ ($\times 3$ better than current limit) with only 0.1 fb^{-1}.

Flavor-tagged signals $D^{*\pm} \to D^0\pi^\pm$, $D^0 \to KK, K\pi$ already seen:





Conclusion

- Many possibilities to search for CPV at LHCb with first data:
  - $B_s \to J/\psi\phi$ — competitive with CDF/D0 with 0.2 fb^{-1}.
  - Flavor-specific charge asymmetry: measurement complementary to D0: $\sigma(\Delta A_{fs}) \simeq 10^{-3}$ with 1 fb^{-1}.
  - γ measurements with $B \to DK$ (different D decay modes), time-dependent $B_s \to D_s K$ (not covered here) — precision comparable to B factories with 0.2 fb^{-1} ($\sigma_\gamma \sim 15^\circ$), $\sigma_\gamma \sim 6-8^\circ$ with 1 fb^{-1}.
  - CPV in charmless decays: $B \to \pi\pi, K\pi, KK$ — comparable to B factories with 1 fb^{-1} for B^0 (solve Belle-BaBar disagreement), best constraint for B_s.
  - CPV in charm mixing (*e.g.* y_{CP} from $D \to hh$) — ~ 3 times improvement possible with 0.1 fb^{-1}.
- Excellent detector performance confirmed, analyses using first O(10 nb^{-1}) to be reported at ICHEP.