

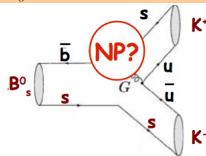
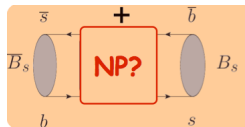
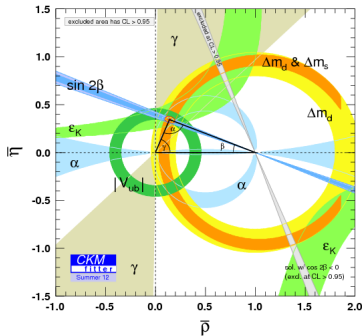


Violazione di CP nei mesoni B ai collider adronici

R. Cardinale

IFAE 2013
Cagliari, 3- 5 Aprile 2013

- Misure di violazione di CP sono un buon modo per testare lo SM
- Sistema dei mesoni B ideale
- Limiti sugli angoli CKM
- Evidenziare possibili contributi di nuova fisica (nuove particelle nei diagrammi a box e a pinguino)



Collider adronici

Tevatron

- Shut down nel 2011
- CDF and D0: precursori della fisica del B in un ambiente adronico
- Accessibilità al sistema dei B_s
- 10 fb^{-1} di dati

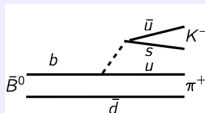
LHC

- Sorgente più copiosa di adroni b
- Collisioni dalla fine del 2009
- LHCb è l'esperimento dedicato alla fisica dei sapori pesanti
- ATLAS/CMS sono rivelatori "general purpose"



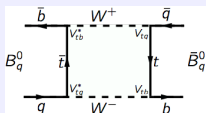
Diverse sorgenti di violazione di CP

Diretta



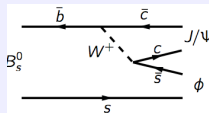
- $B_d^0, B_s^0 \rightarrow K\pi$
- $B^+ \rightarrow h^+h^-h^+$
- $B \rightarrow DK$ per misura γ

Mixing



- Misura a_{sl}
- $B_{(s)}^0 \rightarrow D\mu\nu$

Interferenza

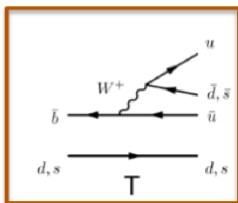


- Misura fase ϕ_s
- $B_s^0 \rightarrow J/\psi\phi$
- $B_s^0 \rightarrow J/\psi\pi\pi$
- $B_s^0 \rightarrow \phi\phi$

Violazione di CP in decadimenti charmless di mesoni B

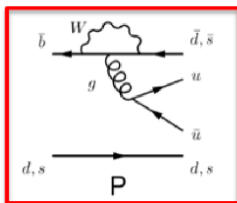
CP diretta nei decadimenti charmless a 2 corpi

- Esplorare meccanismo CKM
- CP dall'interferenza tra diagramma $b \rightarrow u$ a tree e diagramma $b \rightarrow s(d)$ a pinguino
- Sensibili a contributi di NP nei loops del diagramma a pinguino
- Determinazione angolo γ da loop



LHCb

- $B_d^0, B_s^0 \rightarrow K\pi$ con 0.37 fb^{-1}
PRL 108 (2012) 201601



CDF

- $B_d^0, B_s^0 \rightarrow K\pi$ e $\Lambda_b^0 \rightarrow p\pi$,
 $\Lambda_b^0 \rightarrow pK$ con 9.3 fb^{-1}
Public Note 10726

Analisi $B_{d,s} \rightarrow K\pi$ @ LHCb [PRL 108 (2012) 201601]

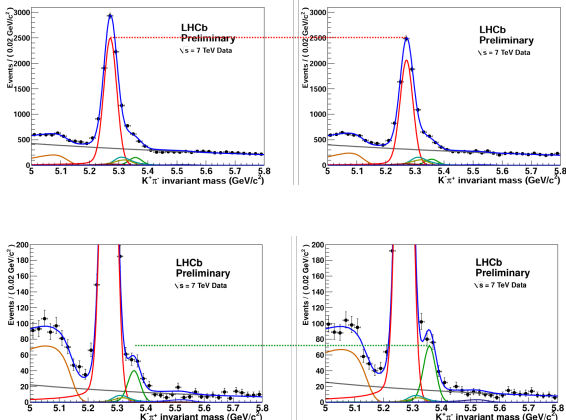
$$A_{\text{CP}}(B^0 \rightarrow K\pi) = \frac{\Gamma(\bar{B}^0 \rightarrow K^- \pi^+) - \Gamma(B^0 \rightarrow K^+ \pi^-)}{\Gamma(\bar{B}^0 \rightarrow K^- \pi^+) + \Gamma(B^0 \rightarrow K^+ \pi^-)}$$
$$A_{\text{CP}}(B_s^0 \rightarrow \pi K) = \frac{\Gamma(\bar{B}_s^0 \rightarrow \pi^- K^+) - \Gamma(B_s^0 \rightarrow \pi^+ K^-)}{\Gamma(\bar{B}_s^0 \rightarrow \pi^- K^+) + \Gamma(B_s^0 \rightarrow \pi^+ K^-)}$$

- Eccellente performance trigger adronico
- Per B_s , rate 14 volte minore, rate produzione 4 volte minore: selezione più stringente
- Selezione inclusiva, eventi ricostruiti come $\pi\pi$, suddivisi nei diversi stati finali grazie all'identificazione di particella dei RICH
- Asimmetrie raw:

$$A_{\text{CP}} = A_{\text{raw}} \pm A_D(K\pi) - \kappa_{d(s)} A_P(B_{(s)}^0)$$

- Asimmetria strumentale stato finale (A_D) da $D^* \rightarrow D^0(K^- \pi^+) \pi^+$
- Asimmetria produzione (A_P) da $B^0 \rightarrow J/\psi K^{*0}$
- κ tiene conto della diluizione del mixing dei $B_{(s)}^0$
- Sistematica dominante: diversa interazione K^+ / K^-

$B_{(s)}^0 \rightarrow K\pi$ @ LHCb - PRL 108 (2012) 201601

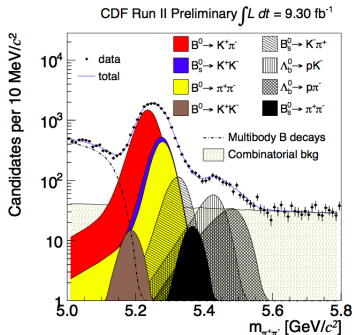


$$A_{CP}(B^0 \rightarrow K\pi) = -0.088 \pm 0.011(stat) \pm 0.008(syst), 6\sigma$$

$$A_{CP}(B_s^0 \rightarrow \pi K) = 0.27 \pm 0.08(stat) \pm 0.02(syst), 3.3\sigma$$

Prima evidenza di violazione CP nei B_s

$B^0_{(s)} \rightarrow K\pi$ @ CDF [Public Note 10726]



- $A_{CP} = \frac{N_{b \rightarrow f} - c_f N_{\bar{b} \rightarrow \bar{f}}}{N_{b \rightarrow f} + c_f N_{\bar{b} \rightarrow \bar{f}}}$
- Vantaggio: uguale produzione $b \bar{b}$
- Correzione effetti rivelatore c_f usando kaoni e pioni da decadimenti di c
- dE/dx per identificare particelle

$$A_{CP}(B^0 \rightarrow K\pi) = -0.083 \pm 0.013(stat) \pm 0.003(syst)$$

$$A_{CP}(B^0_s \rightarrow \pi K) = 0.22 \pm 0.07(stat) \pm 0.02(syst)$$

Risultati compatibili e con risoluzione confrontabile a quelli di LHCb

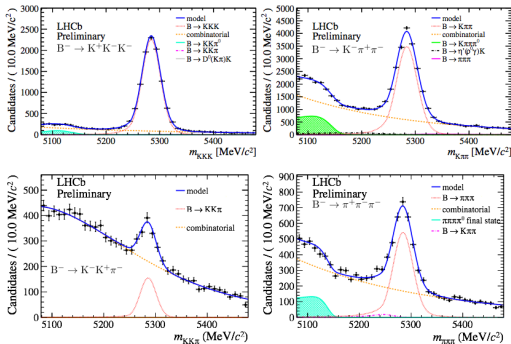
$$A_{CP}(\Lambda_b \rightarrow p\pi) = 0.07 \pm 0.07(stat) \pm 0.03(syst)$$

$$A_{CP}(\Lambda_b \rightarrow pK) = -0.09 \pm 0.08(stat) \pm 0.04(syst)$$

Misura delle asimmetrie di barioni b

Charmless a 3 corpi @ LHCb

- Studio CP nei pattern di interferenza tra risonanze a due corpi
- Misura di violazione CP integrata/diverse regioni del Dalitz plot con 1 fb^{-1}
- $B^\pm \rightarrow K^\pm K^+ K^-$ and $B^\pm \rightarrow K^\pm \pi^+ \pi^-$, Preliminary(LHCb-CONF-2012-018)
- $B^\pm \rightarrow \pi^\pm K^+ K^-$ and $B^\pm \rightarrow \pi^\pm \pi^+ \pi^-$, Preliminary(LHCb-CONF-2012-028)



- Stessa selezione cinematica, diverse richieste PID e veto per i fondi
- Canale di controllo $B^+ \rightarrow J/\psi K^+$ per estrarre violazione di CP dall'asimmetria raw (corregge for A_P e A_D)
- $\sim 20k$ di $B \rightarrow KKK$,
 $\sim 36k$ di $B \rightarrow K\pi\pi\pi$,
 $\sim 1.5k$ di $B \rightarrow KK\pi$,
 $\sim 5k$ di $B \rightarrow \pi\pi\pi$

Charmless a 3 corpi @ LHCb: Risultati

$$A_{CP}(KKK) = -0.046 \pm 0.009(stat) \pm 0.005(syst) \pm 0.007(J/\psi K), 3.7\sigma$$

$$A_{CP}(K\pi\pi) = 0.034 \pm 0.009(stat) \pm 0.004(syst) \pm 0.007(J/\psi K), 2.8\sigma$$

$$A_{CP}(\pi\pi\pi) = 0.120 \pm 0.020(stat) \pm 0.019(syst) \pm 0.007(J/\psi K), 4.2\sigma$$

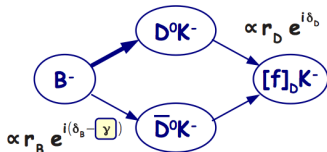
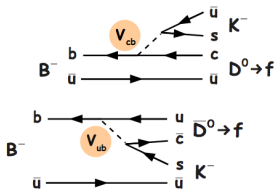
$$A_{CP}(KK\pi) = -0.153 \pm 0.046(stat) \pm 0.019(syst) \pm 0.007(J/\psi K), 3.0\sigma$$

- $A_{CP}(KKK)$: prima evidenza di CP diretta decadimenti charmless a tre corpi
- Evidenza di violazione CP in $\pi\pi\pi$, $K\pi\pi$
- Grandi asimmetrie locali in determinate regioni del Dalitz plot
- Incertezza sistematica maggiore dovuta alla correzione dell'asimmetria da $J/\psi K$
- Terza incertezza dovuta all'incertezza del PDG su $A_{CP}(B \rightarrow J/\psi K)$

Misura angolo γ

Misura angolo γ

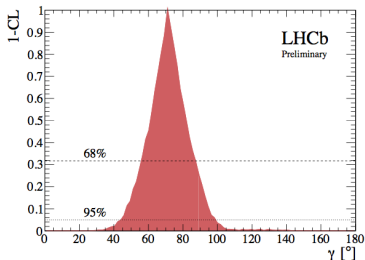
- $\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$
- Angolo meno conosciuto
- CKMfitter: $\gamma = (66 \pm 12)^\circ$
- UTfit: $\gamma = (76 \pm 10)^\circ$
- Decadimenti tree-level
 $B^\pm \rightarrow Dh^\pm$ ($h = K, \pi$): misura pulita (no loops)
- Interferenza tra transizioni $b \rightarrow c$ e $b \rightarrow u$ (stato finale D accessibile sia per il D^0 che il \bar{D}^0)



- Analisi con diversi stati finali @ LHCb

- $D^0 \rightarrow \pi\pi/KK$ GLW e $D^0 \rightarrow K\pi$ ADS [PLB 713 (2012) 351]
- $D^0 \rightarrow K3\pi$ ADS [LHCb-PAPER-2012-055]
- $D^0 \rightarrow K_s^0 hh$ GGSZ [LHCb-PAPER-2012-027]

Combinazione γ con $B^\pm \rightarrow DK^\pm$

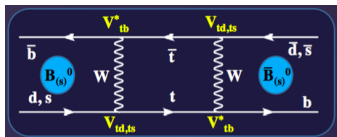


- $\gamma = (71.1^{+16.1}_{-15.2})^\circ$
- $[43.9^\circ - 98.9^\circ]$ @ 95% CL
- Preliminary [LHCb-CONF-2012-032]
- Precisione comparabile con valori delle B-factories

Violazione di CP nel mixing $B_s^0-\bar{B}_s^0$ in decadimenti semileptonici

Asimmetria semileptonica

- violazione di CP nel mixing $B_q^0 - \bar{B}_q^0$
se: $\phi_M = \arg(-M_{12}^q / \Gamma_{12}^q) \neq 0$



- Può essere misurata nell'asimmetria semileptonica:

$$a_{sl}^q = \frac{\bar{B}_q^0 \rightarrow \mu^+ X - B_q^0 \rightarrow \mu^- X}{\bar{B}_q^0 \rightarrow \mu^+ X + B_q^0 \rightarrow \mu^- X} = \frac{\Delta\Gamma_q}{\Delta M_q \tan(\phi_q)}$$

- valori SM molto piccoli:

$$a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5} \quad a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$$

- Sensibile a contributi di NP nei diagrammi a box

LHCb

Misura di a_{sl}^s con 1 fb^{-1}
Preliminary: LHCb-CONF-2012-022

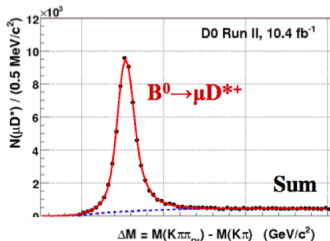
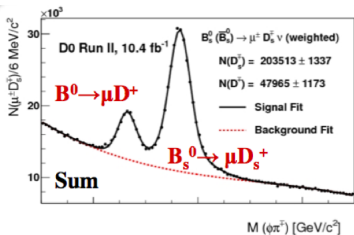
D0

Misura di a_{sl}^s [Phys.Rev. Lett. 110 (2013) 011801] e a_{sl}^d [Phys.Rev. D86, 072009 (2012)] con 10.4 fb^{-1}

Decadimenti semileptonici di B_d e B_s a D0

[Phys.Rev. Lett. 110 (2013) 011801 - Phys.Rev. D86, 072009 (2012)]

- 3 diversi canali di decadimento: $B_s^0 \rightarrow \mu^+ \nu D_s^- X$, $B^0 \rightarrow \mu^+ \nu D^- X$ e $B^0 \rightarrow \mu^+ \nu D^{*-} X$
- $a_{sl}^q = \frac{A - A_{BG}}{F^{osc} B_{(s)}^0}$ dove:
 - A asimmetria raw dagli yield $\mu D_{(s)}^{(*)\pm}$
 - A_{BG} asimmetria legata al rivelatore (efficienza di kaoni positivi più elevata)
 - F^{osc} è la frazione di $\mu D_{(s)}$ ricostruiti da B_s^0 che hanno oscillato

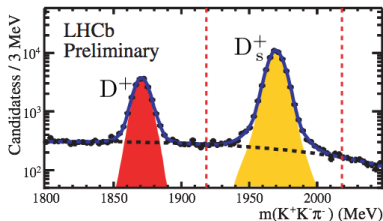
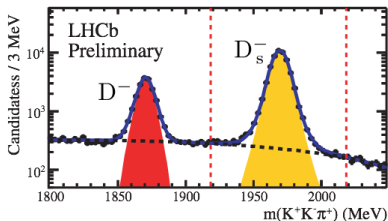


Asimmetria semileptonica di B_s a LHCb [LHCb-CONF-2012-022]

- $B_s^0 \rightarrow D_s \mu \nu X$ con $D_s \rightarrow \phi \pi$ e $\phi \rightarrow KK$

$$A_{\text{meas}} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-) \times \frac{\epsilon(D_s^- \mu^+)}{\epsilon(D_s^+ \mu^-)}}{N(D_s^- \mu^+) + N(D_s^+ \mu^-) \times \frac{\epsilon(D_s^- \mu^+)}{\epsilon(D_s^+ \mu^-)}} = \frac{a_{s,l}}{2} (1 - \kappa) + \kappa A_{\text{prod}} \sim \frac{a_{s,l}}{2}$$

- $\frac{\epsilon(D_s^- \mu^+)}{\epsilon(D_s^+ \mu^-)}$: asimmetria di rivelazione
- A_{prod} : asimmetria di produzione ($\sim 1\%$)
- κ : diluizione dovuto al mixing (0.2%)



- Diversi canali di controllo per determinare le efficienze
- Analisi dati in maniera separata per le due polarità del campo magnetico
- Maggiore sistematica: determinazione efficienze

Risultati a_{sl}

D0 [Phys.Rev. Lett. 110 (2013) 011801 -
Phys.Rev. D86, 072009 (2012)]

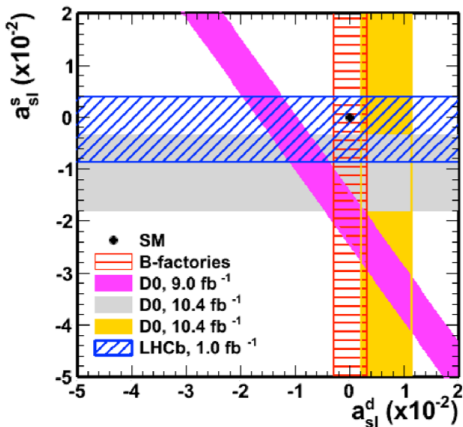
$$a_{sl}^s = [-1.12 \pm 0.74(stat) \pm 0.17(syst)]\%$$
$$a_{sl}^d = [0.68 \pm 0.45(stat) \pm 0.14(syst)]\%$$

LHCb [LHCb-CONF-2012-022]

$$a_{sl}^s = [-0.24 \pm 0.54(stat) \pm 0.33(syst)]\%$$

Consistenti con valore SM e compatibili tra loro

D0 ha misurato deviazione 2.9σ dallo SM nell'asimmetria di due muoni dello stesso segno [arXiv:1208.5813]



Fase ϕ_s da decadimenti $B_s^0 \rightarrow J/\psi\phi$ e
 $B_s^0 \rightarrow J/\psi\pi\pi$

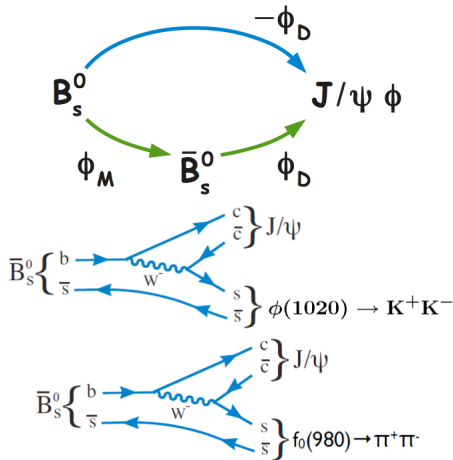
CP nell'interferenza

- CP nell'interferenza tra mixing e il decadimento dei mesoni B_s^0, \bar{B}_s^0 nello stesso stato finale
- Fase $\phi_s = \phi_M - 2\phi_D$ molto piccola

$$\phi_s^{SM} = -2\beta_s = (-0.0363 \pm 0.0016) \text{ rad}$$

[PRD 84 (2011) 033005]

- $\phi_s \rightarrow \phi_s^{SM} + \phi^{NP}$ sensibile a contributi di NP nel mixing
- I due modi più interessanti sono $B_s^0 \rightarrow J/\psi\phi (\rightarrow K^+K^-)$ e $B_s^0 \rightarrow J/\psi f_0 (\rightarrow \pi^+\pi^-)$



- Necessario studio asimmetria CP dipendente dal tempo:

$$A_{\text{CP}}(t) \sim (1 - 2\omega_{\text{tag}}) D(\sigma_t) \sin(\Delta m_s(t)) \sin(\phi_s)$$

- rapida frequenza di mixing dei B_s^0 : necessario buona risoluzione temporale σ_t
- Necessario determinare il sapore del mesone B_s^0 a $t = 0$: algoritmo di tagging

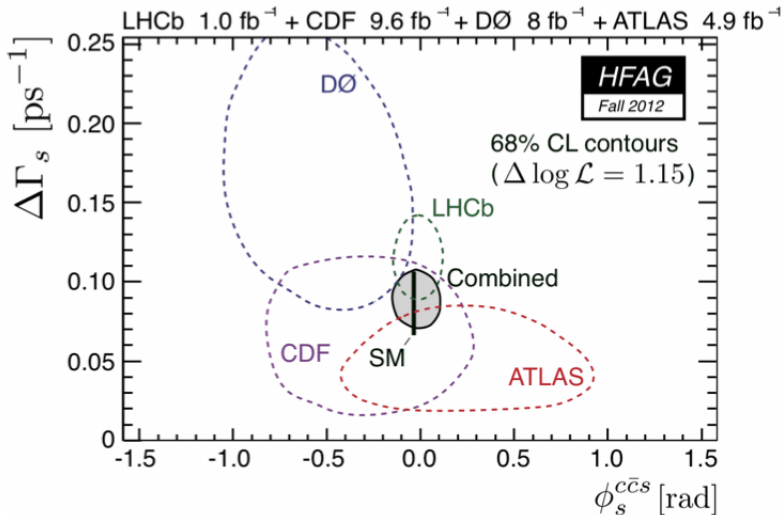
$$B_s^0 \rightarrow J/\psi\phi$$

- Risonanza ϕ stretta: decadimento sperimentalmente pulito
- Decadimento pseudoscalare in uno stato finale vettore-vettore: mix CP dispari e CP pari
- Analisi angolare per separare le ampiezze

$$B_s^0 \rightarrow J/\psi\pi\pi$$

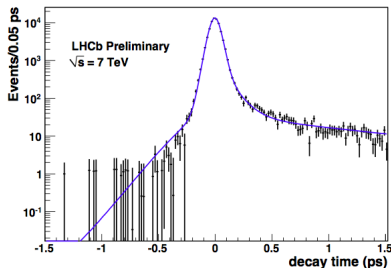
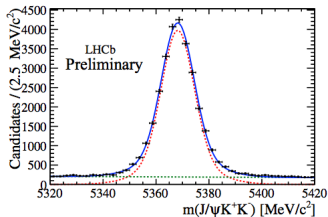
- dominato da $f_0 \rightarrow \pi^+\pi^-$
- BF $\sim 35\%$ di $B_s^0 \rightarrow J/\psi\phi$
- Stato finale CP-odd
[775 < $M(\pi\pi)$ < 1550 MeV]
[arXiv 1204.5643]

Combinazione misure ϕ_s

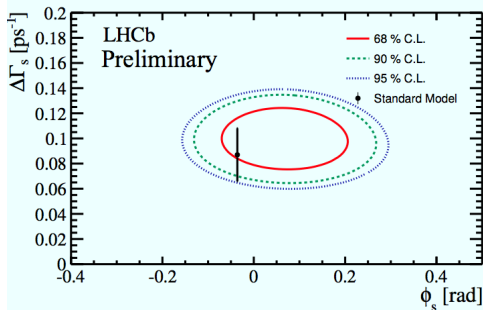


Nuova analisi

- Misura basata su ~ 27600 candidati, 1 fb^{-1}
- Usa “opposite side” e “same side” tagging: efficienza di tagging $(3.13 \pm 0.12 \pm 0.20)\%$
- Risoluzione temporale stimata usando prompt $J/\psi \rightarrow \mu\mu$: $\sim 45 \text{ fs}$
- Correzioni all'accettazione angolare dovuti alla geometria del rivelatore
- Correzioni per accettazione del tempo proprio
- Sistematiche principali su ϕ_s e $\Delta\Gamma$



Risultati LHCb - [LHCb-PAPER-2013-002, preliminary]



- Risultato più preciso attualmente disponibile!
- Consistente con valore SM

$B_s^0 \rightarrow J/\psi\phi$ - PRELIMINARY

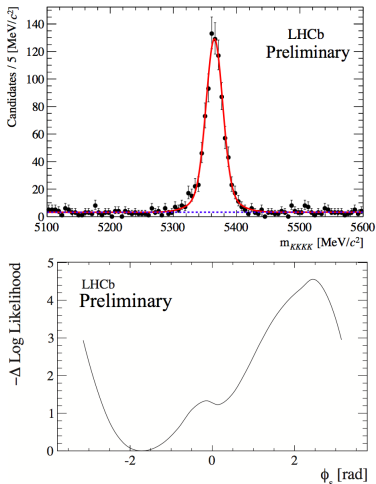
$$\begin{aligned}\phi_s &= 0.07 \pm 0.09(\text{stat}) \pm 0.01(\text{syst}) \text{ rad} \\ \Gamma_s &= 0.663 \pm 0.005(\text{stat}) \pm 0.006(\text{syst}) \text{ ps}^{-1} \\ \Delta\Gamma_s &= 0.100 \pm 0.016(\text{stat}) \pm 0.003(\text{syst}) \text{ ps}^{-1}\end{aligned}$$

Fit simultaneo: $B_s^0 \rightarrow J/\psi\phi$ e $B_s^0 \rightarrow J/\psi\pi\pi$ - PRELIMINARY

$$\begin{aligned}\phi_s &= 0.01 \pm 0.07(\text{stat}) \pm 0.01(\text{syst}) \text{ rad} \\ \Gamma_s &= 0.661 \pm 0.004(\text{stat}) \pm 0.006(\text{syst}) \text{ ps}^{-1} \\ \Delta\Gamma_s &= 0.106 \pm 0.011(\text{stat}) \pm 0.007(\text{syst}) \text{ ps}^{-1}\end{aligned}$$

$B_s \rightarrow \phi\phi$ @ LHCb [arXiv:1303.7125]

- Decadimento pinguino $P \rightarrow VV$ da transizione $b \rightarrow s\bar{s}s$
- Sensibile a NP
- SM ϕ_s attesa zero
- Analisi simile a $B_s^0 \rightarrow J/\psi\phi$
- 880 ± 31 eventi
- Γ_s e $\Delta\Gamma_s$ fissati ai valori misurati da $B_s^0 \rightarrow J/\psi\phi$
- Δm_s fissato
- Accettanze angolari e tempo stimate dalle simulazioni



ϕ_s in $[-2.46, -0.76]$ rad @ 68% CL
Precisione dominata dalla statistica

Conclusioni

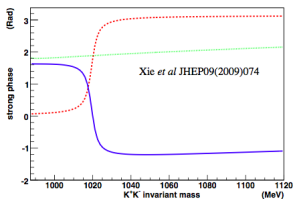
- Gli esperimenti a Tevatron hanno aperto la strada allo studio della fisica dei mesoni B a collider adronici
- Numerosi risultati complementari e con precisioni comparabili a quelli delle B-factories
- LHCb con la statistica collezionata a $\sqrt{s} = 7 \text{ TeV}$ di 1 fb^{-1} ha effettuato molte misure di violazione CP ottenendo precisioni migliori al mondo
- Nel 2012 ha raccolto $\sim 2 \text{ fb}^{-1}$ a $\sqrt{s} = 8 \text{ TeV}$, sono attesi nuove misure per le conferenze estive

Backup Slides

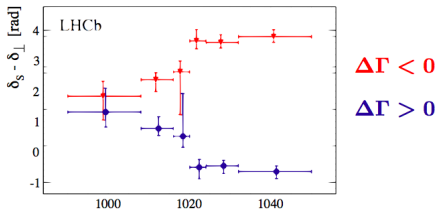
Sign of ϕ_s

$$(\phi_s, \Delta\Gamma_s, \delta_0, \delta_{\parallel}, \delta_{\perp}, \delta_s) \rightarrow (\pi - \phi_s, -\Delta\Gamma_s, -\delta_0, -\delta_{\parallel}, \pi - \delta_{\perp}, -\delta_s)$$

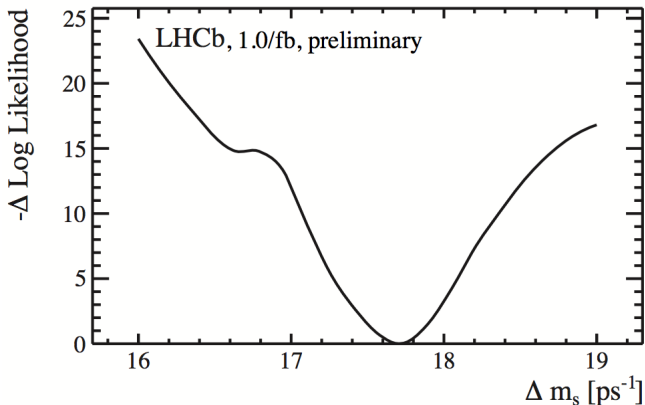
- soluzione: misurare la differenza di fase tra la componente onda S e onda P in funzione della massa [JHEP09(2009)074]



- P-wave
- S-wave
- difference
- La differenza diminuisce all'aumentare di $m(KK)$



ΔM_s come parametro libero del fit



$$\Delta M_s = 17.70 \pm 0.10(\text{sta}) \pm 0.01(\text{syst}) \text{ ps}^{-1}$$

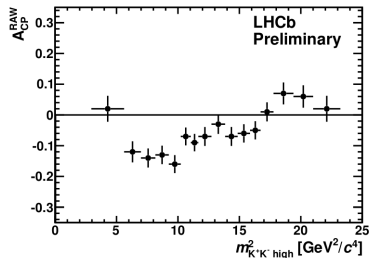
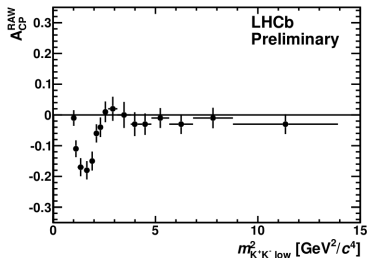
in accordo con il valore di ΔM_s misurato da $B_s \rightarrow D_s \pi$

Systematic uncertainties $B_s^0 \rightarrow J/\psi\phi$

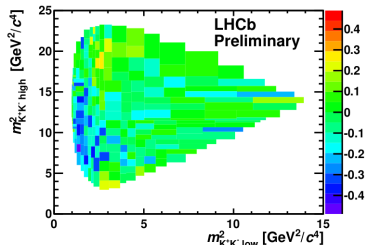
Source	Γ_s [ps ⁻¹]	$\Delta\Gamma_s$ [ps ⁻¹]	$ A_{\perp} ^2$	$ A_0 ^2$	δ_{\parallel} [rad]	δ_{\perp} [rad]	ϕ_s [rad]	$ \lambda $
Stat. uncertainty	0.0048	0.016	0.0086	0.0061	^{+0.13} _{-0.21}	0.22	0.091	0.031
Background subtraction	0.0041	0.002	-	0.0031	0.03	0.02	0.003	0.003
$B^0 \rightarrow J/\psi K^{*0}$ background	-	0.001	0.0030	0.0001	0.01	0.02	0.004	0.005
Ang. acc. reweighting	0.0007	-	0.0052	0.0091	0.07	0.05	0.003	0.020
Ang. acc. statistical	0.0002	-	0.0020	0.0010	0.03	0.04	0.007	0.006
Lower decay time acc. model	0.0023	0.002	-	-	-	-	-	-
Upper decay time acc. model	0.0040	-	-	-	-	-	-	-
z + p scale	0.0009	-	-	-	-	-	-	-
Fit bias	-	-	0.0010	-	-	-	-	-
Quadratic sum of syst.	0.0063	0.003	0.0064	0.0097	0.08	0.07	0.009	0.022
Total uncertainties	0.0079	0.016	0.0107	0.0114	^{+0.15} _{-0.23}	0.23	0.091	0.038

CP asymmetry in phase space:

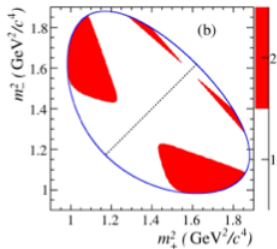
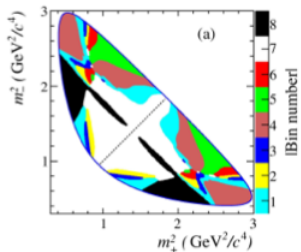
$$B^+ \rightarrow K^+ K^+ K^-$$



- Raw asymmetries in bins of the two body invariant mass projections
- Signal yield in each bin from simplified mass fit
- Dalitz plot in bins with equal number of entries, no background subtraction, $A_{CP}^{N} = \frac{N^- - N^+}{N^- + N^+}$
- No clear asymmetry around $\phi(1020)$ or $f_2(1525)$, large between the two resonances



$B \rightarrow DK$: GGSZ

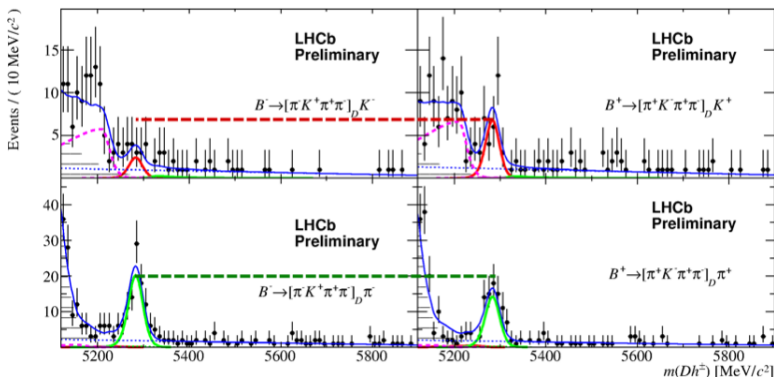


- Model-independent analysis of $D^0 \rightarrow K_s^0 hh$
- Strong phase variation from CLEO measurements
- Binning scheme to maximise sensitivity to γ for $K_s^0 \pi \pi$ (top) and $K_s^0 K K$ (bottom)

$$N_i^+ \propto [K_{-i} + (x_+^2 + y_+^2)K_{+i} + 2\sqrt{K_{+i} + K_{-i}}(x_+c_{+i} - y_+s_{+i})]$$

$$x_+ = r_B \cos(\delta_B + \gamma) \quad y_+ = r_B \sin(\delta_B + \gamma)$$

Suppressed ADS $K3\pi$



- First observation of $B^{\pm} \rightarrow D(\pi^{\pm} K^{\mp} \pi^+ \pi^-) \pi^{\pm}$ mode ($> 10\sigma$)
- First observation of $B^{\pm} \rightarrow D(\pi^{\pm} K^{\mp} \pi^+ \pi^-) K^{\pm}$ mode ($> 5.1\sigma$)

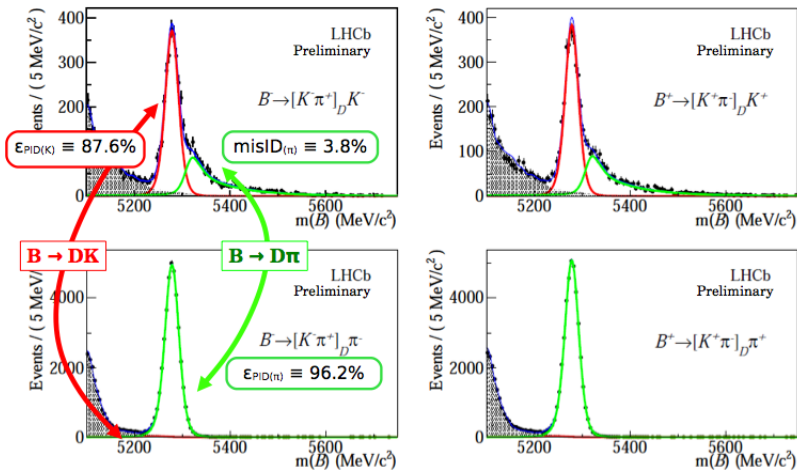
Analysis and observables: $B \rightarrow DK$

- Consider every combination $B \rightarrow [h' h'']_D h'''$ where $h = \pi, K$
- Extract Ratios and Asymmetries with simultaneous fit

13 measured observables

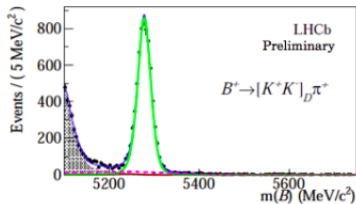
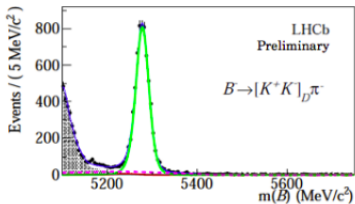
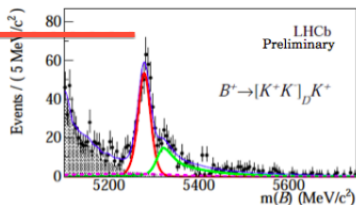
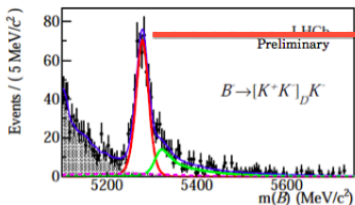
- 3 ratios of partial widths: $R_{K/\pi}^f = \frac{\Gamma(B^- \rightarrow [f]_D K^-) - \Gamma(B^+ \rightarrow [f]_D K^+)}{\Gamma(B^- \rightarrow [f]_D \pi^-) - \Gamma(B^+ \rightarrow [f]_D \pi^+)}$
 - 6 CP asymmetries: $A_h^f = \frac{\Gamma(B^- \rightarrow [f]_D h^-) - \Gamma(B^+ \rightarrow [f]_D h^+)}{\Gamma(B^- \rightarrow [f]_D h^-) + \Gamma(B^+ \rightarrow [f]_D h^+)}$
 - 4 charge-separated partial widths of the suppressed mode relative to the favoured: $R_h^\pm = \frac{(\Gamma(B^\pm \rightarrow [\pi^\pm K^\mp]_D h^\pm))}{(\Gamma(B^\pm \rightarrow [K^\pm \pi^\mp]_D h^\pm))}$
 - Considered final states $[f]_D = KK, \pi\pi, K\pi, \pi K$
- Multivariate analysis to suppress combinatorial backgrounds
 - Simultaneous fit of 16 slices:
2 (charges) \times 4 (D modes) \times 2 ($DK/D\pi$)

$B^\pm \rightarrow [K\pi]_D h^\pm$: favoured ADS mode

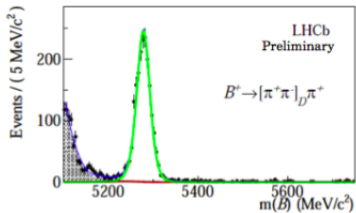
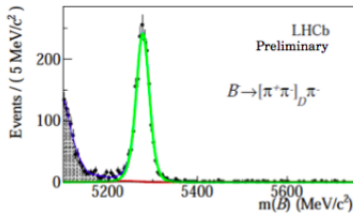
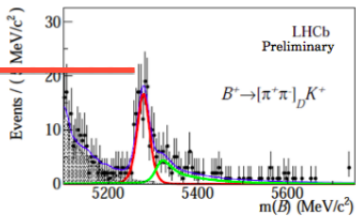
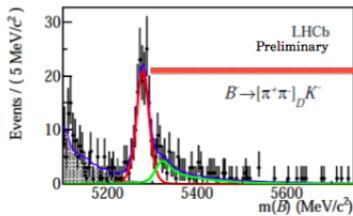


- Not CP violation expected in these most abundant modes

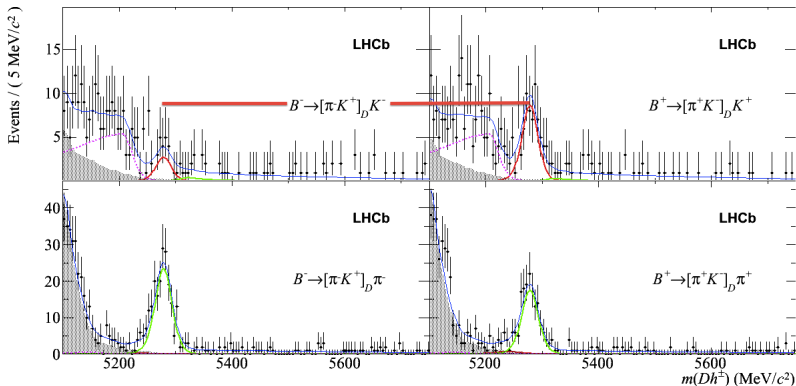
$B^\pm \rightarrow [KK]_D h^\pm$: GLW CP mode



$B^\pm \rightarrow [\pi\pi]_D h^\pm$: GLW CP mode



$B^\pm \rightarrow [\pi K]_D h^\pm$: suppressed ADS mode



- Suppressed ADS mode (kaon with wrong sign)
- $B^- \rightarrow D_{\text{ADS}} K^- = 23$ events, $B^+ \rightarrow D_{\text{ADS}} K^+ = 73$ events
- First observation of $B^+ \rightarrow D_{\text{ADS}} K^+$

Results

$$\begin{aligned}R_{K/\pi}^{K\pi} &= 0.0774 \pm 0.0012 \pm 0.0018 \\R_{K/\pi}^{KK} &= 0.0773 \pm 0.0030 \pm 0.0018 \\R_{K/\pi}^{\pi\pi} &= 0.0803 \pm 0.0056 \pm 0.0017 \\A_{\pi}^{K\pi} &= -0.0001 \pm 0.0036 \pm 0.0095 \\A_K^{K\pi} &= 0.0044 \pm 0.0144 \pm 0.0174 \\A_K^{KK} &= 0.1480 \pm 0.0369 \pm 0.0097 \\A_K^{\pi\pi} &= 0.1351 \pm 0.0661 \pm 0.0095 \\A_{\pi}^{KK} &= -0.0199 \pm 0.0091 \pm 0.0116 \\A_{\pi}^{\pi\pi} &= -0.0009 \pm 0.0165 \pm 0.0099 \\R_K^- &= 0.0073 \pm 0.0023 \pm 0.0004 \\R_K^+ &= 0.0232 \pm 0.0034 \pm 0.0007 \\R_{\pi}^- &= 0.00469 \pm 0.00038 \pm 0.00008 \\R_{\pi}^+ &= 0.00352 \pm 0.00033 \pm 0.00007\end{aligned}$$

Total significance of 5.8σ :
direct CP violation in
 $B^+ \rightarrow DK^+$ is observed

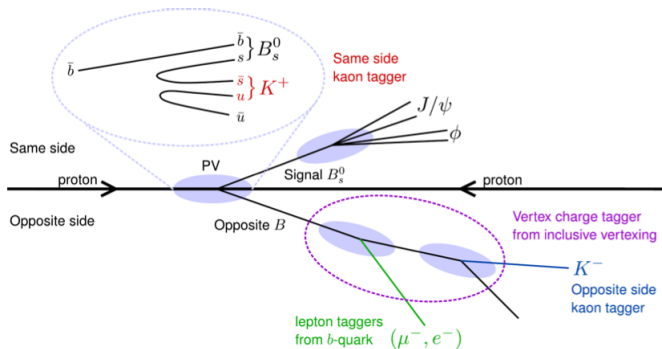
GLW observables

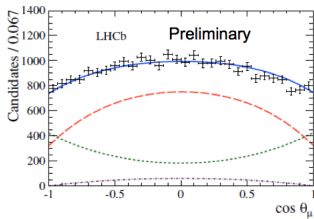
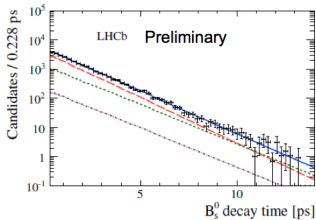
- $R_{CP^+} = \langle R_{K/\pi}^{KK}, R_{K/\pi}^{\pi\pi} \rangle / R_{K/\pi}^{K\pi} = 1.007 \pm 0.038 \pm 0.012$
- $A_{CP^+} = \langle A_K^{KK}, A_K^{\pi\pi} \rangle = 0.145 \pm 0.032 \pm 0.010$
- Both KK and $\pi\pi$ modes show positive asymmetries
- The combined asymmetry significance is 4.5σ

ADS observables

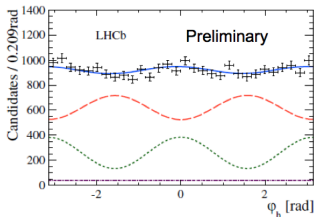
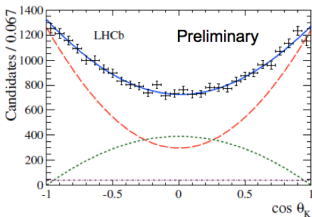
- $R_{ADS(K)} = 0.0152 \pm 0.0020 \pm 0.0004$
- $A_{ADS(K)} = -0.520 \pm 0.150 \pm 0.021$
- $R_{ADS(\pi)} = 0.00410 \pm 0.00025 \pm 0.00005$
- $A_{ADS(\pi)} = 0.143 \pm 0.062 \pm 0.011$
- $B \rightarrow D_{ADS}K$ observed with 10σ and evidence (4σ) of negative asymmetry
- $B \rightarrow D_{ADS}\pi$ shows hint of positive asymmetry (2.4σ)

Flavour tagging

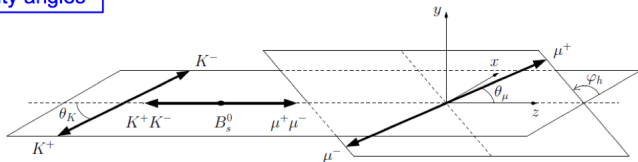




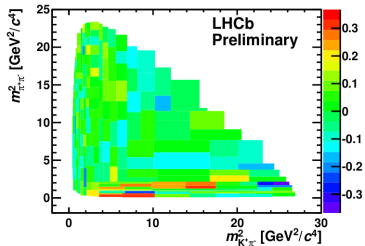
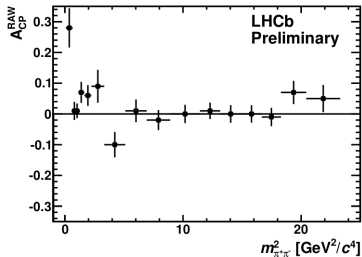
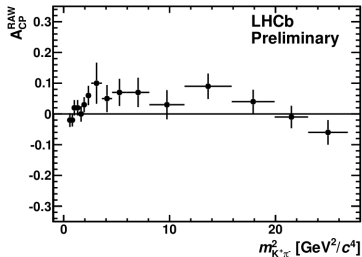
--- CP-even --- CP-odd --- S-wave



Helicity angles



CP asymmetry in phase space: $B^+ \rightarrow K^+ \pi^+ \pi^-$



- Raw asymmetries in bins of the two body invariant mass projections
- Signal yield in each bin from simplified mass fit
- Dalitz plot in bins with equal number of entries, no background subtraction, $A_{CP}^N = \frac{N^- - N^+}{N^- + N^+}$
- Clear asymmetry around $\rho(770)$

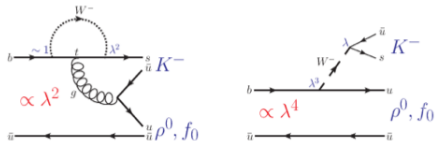
Study of three-body charmless B^\pm decays

- Possibility to study the weak phase in interference patterns between two-body resonance in the Dalitz plot
- Leading diagrams: $b \rightarrow s$ penguin and $b \rightarrow u$ tree

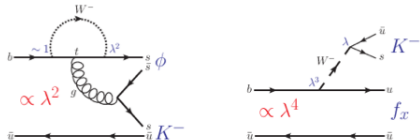
Current knowledge

- $A_{CP}(B^+ \rightarrow K^+\pi^+\pi^-) = 0.038 \pm 0.022$
- Belle¹ and BaBar² claimed evidence of CP violation in $B^+ \rightarrow \rho^0 K^+$
- $A_{CP}(B^+ \rightarrow K^+K^+K^-) = -0.017 \pm 0.030$
- BaBar³ claimed evidence of CP violation in $B^+ \rightarrow \phi(1020)K^+$

$$B^\pm \rightarrow K^\pm \pi^+ \pi^-$$



$$B^\pm \rightarrow K^\pm K^+ K^-$$

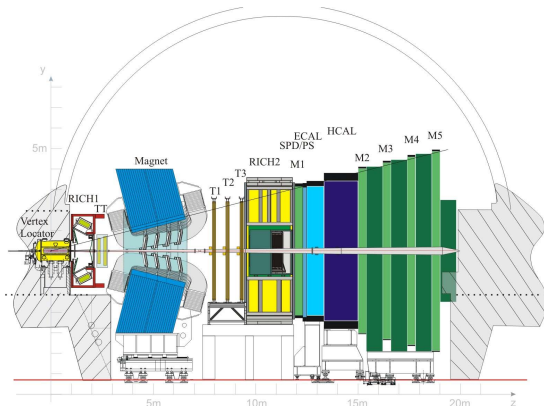


¹ Phys.Rev.Lett. 96 (2006) 251803

² Phys.Rev.Lett. D78 (2008) 012004

³ arXiv: 1201.5897

LHCb



- Momentum resolution: $\Delta p/p = 0.4\%$ at $5 \text{ GeV}/c$ to 0.6% at $100 \text{ GeV}/c$
- ECAL resolution: $1\% + \frac{10\%}{\sqrt{E[\text{GeV}]}}$
- Impact parameter resolution: $20 \mu\text{m}$
- Invariant mass resolution: $\sim 22 \text{ MeV}/c^2$ for two-body B decays

Selection for $A_{CP}(B^0 \rightarrow K\pi)$ and $A_{CP}(B_s^0 \rightarrow K\pi)$

Variable	$A_{CP}(B^0 \rightarrow K\pi)$	$A_{CP}(B_s^0 \rightarrow K\pi)$
Track quality χ^2/ndf	< 3	< 3
Track p_T [GeV/c]	> 1.1	> 1.2
Track d_{IP} [mm]	> 0.15	> 0.20
$\max(p_T^K, p_T^\pi)$ [GeV/c]	> 2.8	> 3.0
$\max(d_{IP}^K, d_{IP}^\pi)$ [mm]	> 0.3	> 0.4
d_{CA} [mm]	< 0.08	< 0.08
p_T^B [GeV/c]	> 2.2	> 2.4
d_{IP}^B [mm]	< 0.06	< 0.06
$t_{\pi\pi}$ [ps]	> 0.9	> 1.5

B mixing dilution factor

$$\kappa_{d(s)} = \frac{\int_0^\infty e^{-\Gamma_{d(s)}t} \cos(\Delta m_{d(s)}t) \epsilon(B_{(s)}^0 \rightarrow K\pi; t) dt}{\int_0^\infty e^{-\Gamma_{d(s)}t} \cosh\left(\frac{\Delta\Gamma_{d(s)}}{2}t\right) \epsilon(B_{(s)}^0 \rightarrow K\pi; t) dt}$$

where ϵ are the acceptances as functions of the decay time for the two reconstructed decays.

- $\Delta\Gamma_d = 0$
- $\Gamma_d, \Gamma_s, \Delta m_d, \Delta m_s, \Delta\Gamma_s$ world averaged (PDG)
- $\kappa_d = 0.303 \pm 0.05$
- $\kappa_s = -0.033 \pm 0.003$, small since B_s^0 oscillation frequency is large

Systematic uncertainties for $A_{CP}(B^0 \rightarrow K\pi)$ and $A_{CP}(B_s^0 \rightarrow K\pi)$

Systematic uncertainty	$A_{CP}(B^0 \rightarrow K\pi)$	$A_{CP}(B_s^0 \rightarrow K\pi)$
^(a) PID calibration	0.0012	0.001
^(b) Final state radiation	0.0026	0.010
^(b) Signal model	0.0004	0.005
^(b) Combinatorial background	0.0001	0.009
^(b) 3-body background	0.0009	0.007
^(b) Cross-feed background	0.0011	0.008
^(c) Instr. and prod. asym. (A_Δ)	0.0078	0.005
Total	0.0084	0.019

$B \rightarrow DK$

- $A_{\text{prod}} = (-0.8 \pm 0.7)\%$ (simulation suggests a small excess of B^+ over B^-), observed raw asymmetry of $B^+ \rightarrow J/\psi K^+$
- $A_K = (-0.5 \pm 0.7)\%$ in the detection of K^\pm due to their different interaction lengths (assigned for each occurrence of strangeness in the final state)
- $A_\pi = (0.0 \pm 0.7)\%$

Systematic uncertainties

$\times 10^{-3}$	PID	PDFs	Sim	$A_{\text{instr.}}$	Total
$R_{K/\pi}^{K\pi}$	1.4	0.9	0.8	0	1.8
$R_{K/\pi}^{KK}$	1.3	0.8	0.9	0	1.8
$R_{\pi/\pi}^{K\pi}$	1.3	0.6	0.8	0	1.7
$A_{\pi}^{K\pi}$	0	1.0	0	9.4	9.5
$A_K^{K\pi}$	0.2	4.1	0	16.9	17.4
A_K^{KK}	1.6	1.3	0.5	9.5	9.7
$A_{\pi}^{\pi\pi}$	1.9	2.3	0	9.0	9.5
A_{π}^{KK}	0.1	6.6	0	9.5	11.6
$A_{\pi}^{\pi\pi}$	0.1	0.4	0	9.9	9.9
R_K^-	0.2	0.4	0	0.1	0.4
R_K^+	0.4	0.5	0	0.1	0.7
R_π^-	0.01	0.03	0	0.07	0.08
R_π^+	0.01	0.03	0	0.07	0.07

Systematic uncertainties for $B^+ \rightarrow K^+ K^+ K^-$ and $B^+ \rightarrow K^+ \pi^+ \pi^-$

Contribution	$K^\pm \pi^+ \pi^-$	$K^\pm K^+ K^-$
Signal fixed parameters	0.002	0.002
Signal model	0.0001	0.0001
Signal shape	0.0012	0.0001
Background model	0.0003	0.00002
Background asymmetry	0.0002	0.0001
Acceptance	0.001	0.0015
Trigger correction	0.0011	0.001
Subtraction method	0.003	0.004
Total	0.004	0.005