γ/ϕ_3 at hadron colliders

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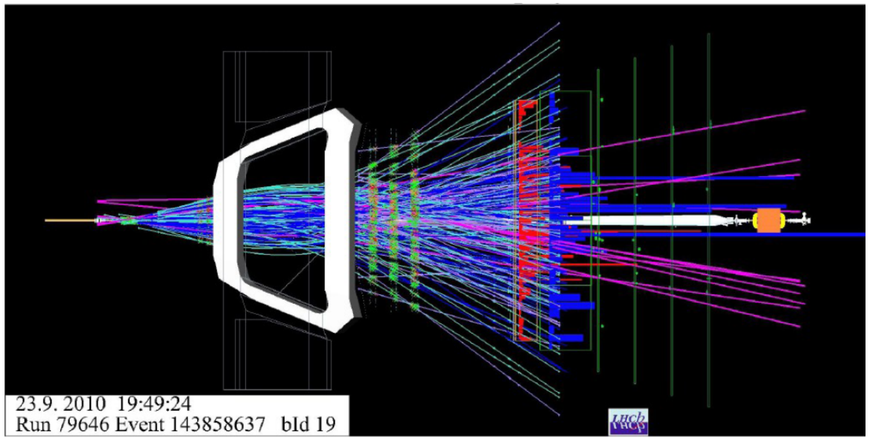
LHCb collaboration

- Introduction
- GLW and ADS results : CDF
- LHCb : first measurements preparing the road to $\boldsymbol{\gamma}$ /ϕ_3



Flavor Physics and CP Violation 2011

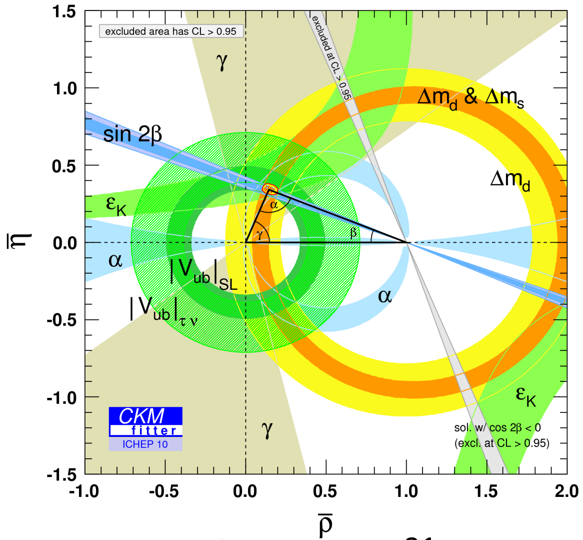
FPCP 2011 , May 23-27 Kibbutz Maale Hachamisha, Israel

Introduction

Why γ/ϕ_3 at hadron colliders ?

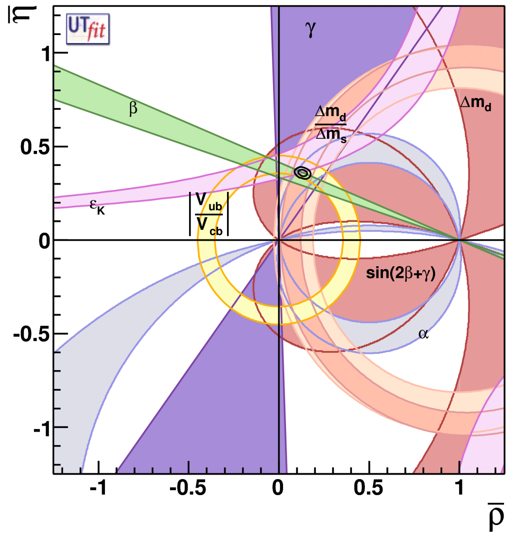
1. It is the most poorly measured angle :

http://ckmfitter.in2p3.fr/



$\gamma/\phi_3 = 71^{+21}_{-25}$

http://www.utfit.org/UTfit/



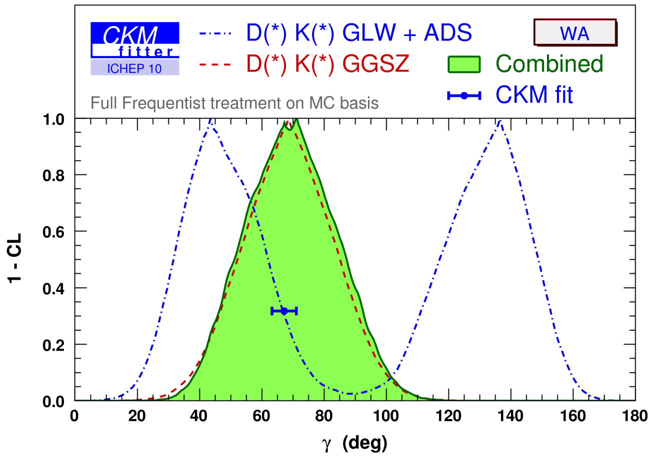
$\gamma/\phi_3 = 74 \pm 11$

σ_γ difference : statistical treatment

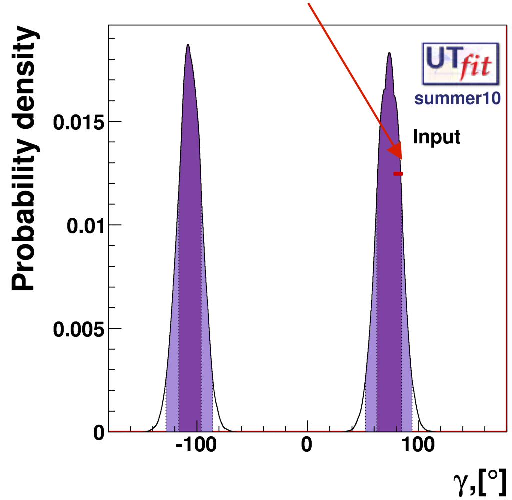
$\sigma_\alpha \sim 6°$

$\sigma_\beta \sim 1°$

2. The direct measurement is less precise than the SM prediction :



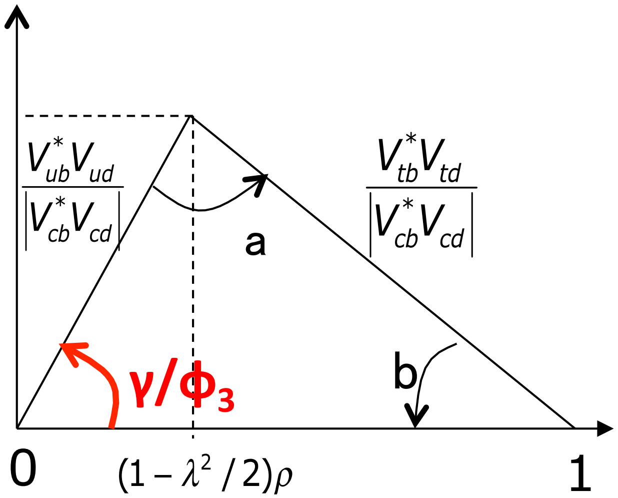
±3°



3. "SM candle"

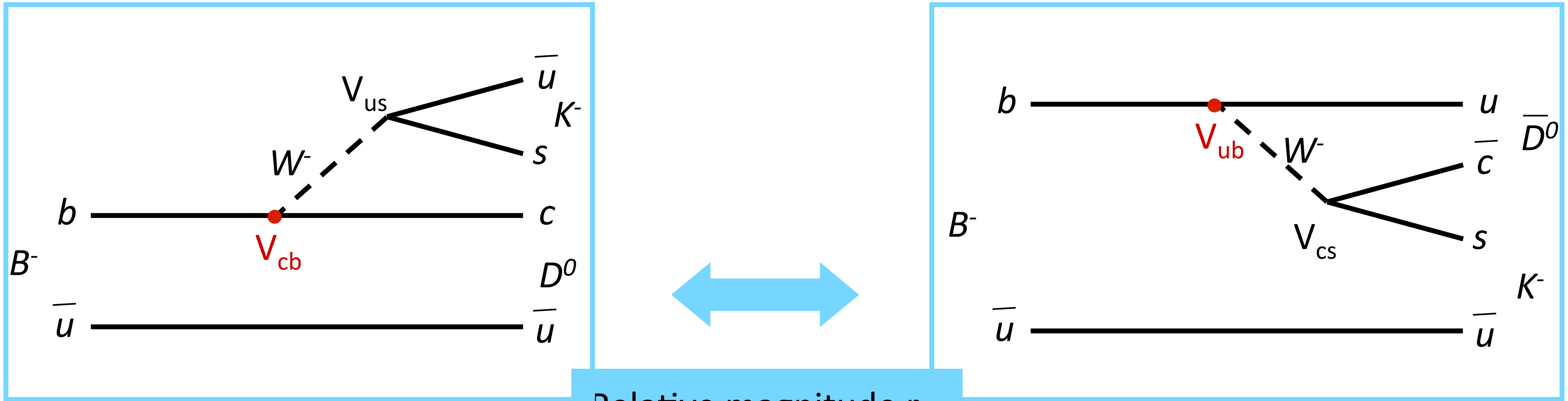
3. "SM candle"

$$\gamma / \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right)$$



Interferences between *b*➔*c* and *b*➔*u* transitions

NP in D^0 mixing is small



Relative magnitude r_B
relative phase δ_B-γ

Same final state : 3 techniques :

- GLW (Gronau, London, Wyler) : use a CP mode for the D^0 decay *Physics Letters B 265(1-2), 172 – 176*

  ADS (Atwood, Dunietz, Soni) : use D^0 CA($K^-\pi^+$) mode for the V_{ub} decay and D^0 DCS($K^+\pi^-$) for the V_{cb} decay *Phys. Rev. Lett. 78(17), 3257–3260*
- Dalitz GGSZ (Giri, Grossman, Soffer, Zupan) : use the D^0 ➔ $K_S\,\pi\,\pi$ or $K_S\,KK$ decays *Phys. Rev. D 68(5), 054018.*

Why γ/ϕ_3 at hadron colliders ?

- γ/ϕ_3 is not precisely measured, the result is dominated by Dalitz-GGSZ from B factories
- Sensitivity is obtained through $b \rightarrow u$ transition
- Effective BFs of the order of few 10^{-8} to few 10^{-7}

→ More statistics is needed

Challenges :

- Fully hadronic decay : trigger, background use of displaced vertices information
- PID is important : distinguish $D^0 \rightarrow K^- \pi^+$ from $D^0 \rightarrow K^+ \pi^-$

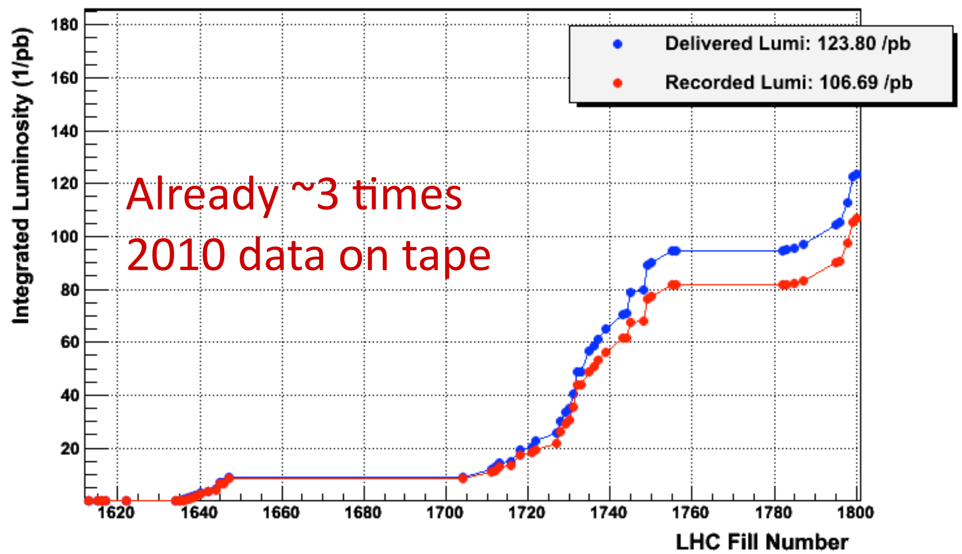
	$\sigma(b\bar{b})$	$\sigma(\text{inel})/\sigma(bb)$	$\int Ldt$	Yield ($B \rightarrow D^0_{CF} K-$)
CDF	~ 100 mb	1000	full dataset $10 fb^{-1}$ max	1500 (5 fb^{-1})
LHCb	~290 mb	~300	0.035 fb^{-1} ; ~1fb^{-1} (end of 2011)	440 (0.035 fb^{-1})
BaBar BELLE	~1 nb	~4	425 fb^{-1} (BaBar) 700 fb^{-1} (BELLE)	~1940 (BaBar) ~3400 (BELLE)

hep-ph/0201071 (CDF)
Physics Letters B 694 (2010) 209, Eur. Phys. J. C 71 (2011) 1645 (LHCb)
SLAC-R-0504 (B factories)

LHCb performances (in one slide !)

Luminosity

Last year : ~35 pb^{-1} , this year :



Geometrical resolution

Primary Vertex resolution (25 tracks) :

B flight ~1cm

	x,y (µm)	z (µm)
Data	16	76
MC	11	60

Impact parameter resolution :

	σ	High p_T
Data	14.4 +19.5/p_T (µm)	σ = ~15 µm
MC	13.1 +16.5/p_T (µm)	σ = ~15 µm

Slope : multiple scattering. Improvement on-going

Hadronic trigger

L0 (hardware) :

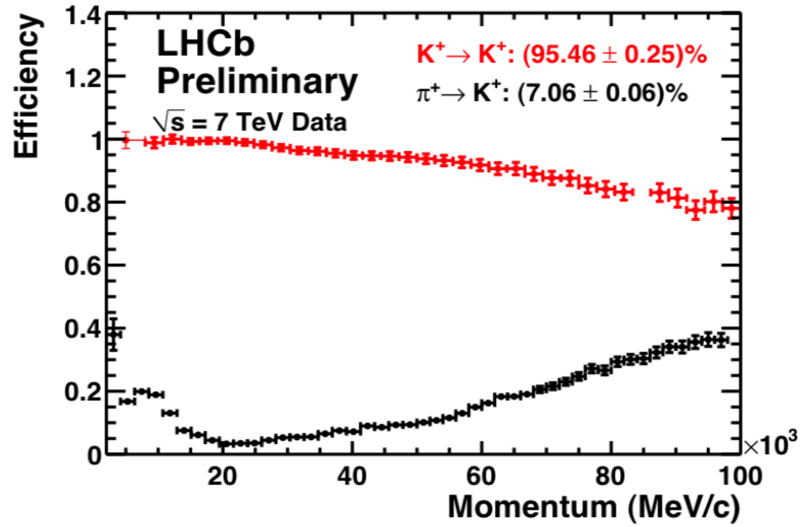
- "high" (>~3GeV) p_T tracks (~< 1MHz for the full L0)

High Level Trigger (HLT): (software)

- Hlt1 : Confirmation of L0 cand. with tracking info
- Hlt2 : Inclusive selections based on IP, p_T ; exclusive selection for key channels (2-3 kHz)

	ε(L0)	ε(Hlt1)	ε(Hlt2)
Hadronic	~50%	>~80%	~> 90%

PID



ADS and GLW results

GLW method

$B^{\pm} \rightarrow D_{\pm} K^{\pm}$ at hadron collider use only $D_{+} \rightarrow$ KK or ππ

$$A_{\pm} = \frac{\Gamma(B^- \to D_\pm K^-) - \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma},$$

$$R_{\pm} = 2\frac{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to D^0 K^+)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma,$$

- 3 unknowns : r_B , δ_B and **γ** / ϕ_3
- 3 independent quantities ($R_+ A_+ = - R_- A_-$)
- 2 measurements at hadron colliders

➔ should be combined with other methods

Could be also done using $B^0 \rightarrow D_{\pm} K^{*0}$
Different r_B , δ_B (r_B ~3 times larger)

	BR	r_B
$B^+ \rightarrow D^0 K^+$	$(3.7 \pm 0.3)\ 10^{-4}$	0.1
$B^0 \rightarrow D^0 K^{*0}$	$(4.2 \pm 0.6)\ 10^{-5}$	~0.3

ADS method

$B^{\pm} \rightarrow D K^{\pm}$ at hadron collider use only $D_{DCS} \rightarrow K^+ \pi^-$ and $D_{CF} \rightarrow K^- \pi^+$

$$A_{ADS} = \frac{\Gamma(B^- \to D_{DCS}K^-) - \Gamma(B^+ \to \bar{D}_{DCS}K^+)}{\Gamma(B^- \to D_{DCS}K^-) + \Gamma(B^+ \to \bar{D}_{DCS}K^+)} = \frac{2 r_B r_{K\pi} \sin(\delta_B + \delta_{K\pi}) \sin\gamma}{r_B^2 + r_{K\pi}^2 + 2 r_B r_{K\pi} \cos(\delta_B + \delta_{K\pi}) \cos\gamma}$$

$$R_{ADS} = \frac{\Gamma(B^- \to D_{DCS}K^-) + \Gamma(B^+ \to \bar{D}_{DCS}K^+)}{\Gamma(B^- \to D_{CF}K^-) + \Gamma(B^+ \to \bar{D}_{CF}K^+)} = r_B^2 + r_{K\pi}^2 + 2 r_B r_{K\pi} \cos(\delta_B + \delta_{K\pi}) \cos\gamma$$

- 3 unknowns (same as GLW) : r_B , δ_B and **γ** /ϕ_3

- $r_{K\pi}$, $\delta_{K\pi}$ known from elsewhere (CLEO-c)

  Phys Rev D80, 031105(R) (2009)

$$r_{K\pi} = \left| \frac{A(D^0 \to K^+ \pi^-)}{A(D^0 \to K^- \pi^+)} \right| = 0.0613 \pm 0.0010$$

- 2 independent quantities

Could be also done using $B^0 \rightarrow D K^{*0}$
Different r_B , δ_B (r_B ~3 times larger)

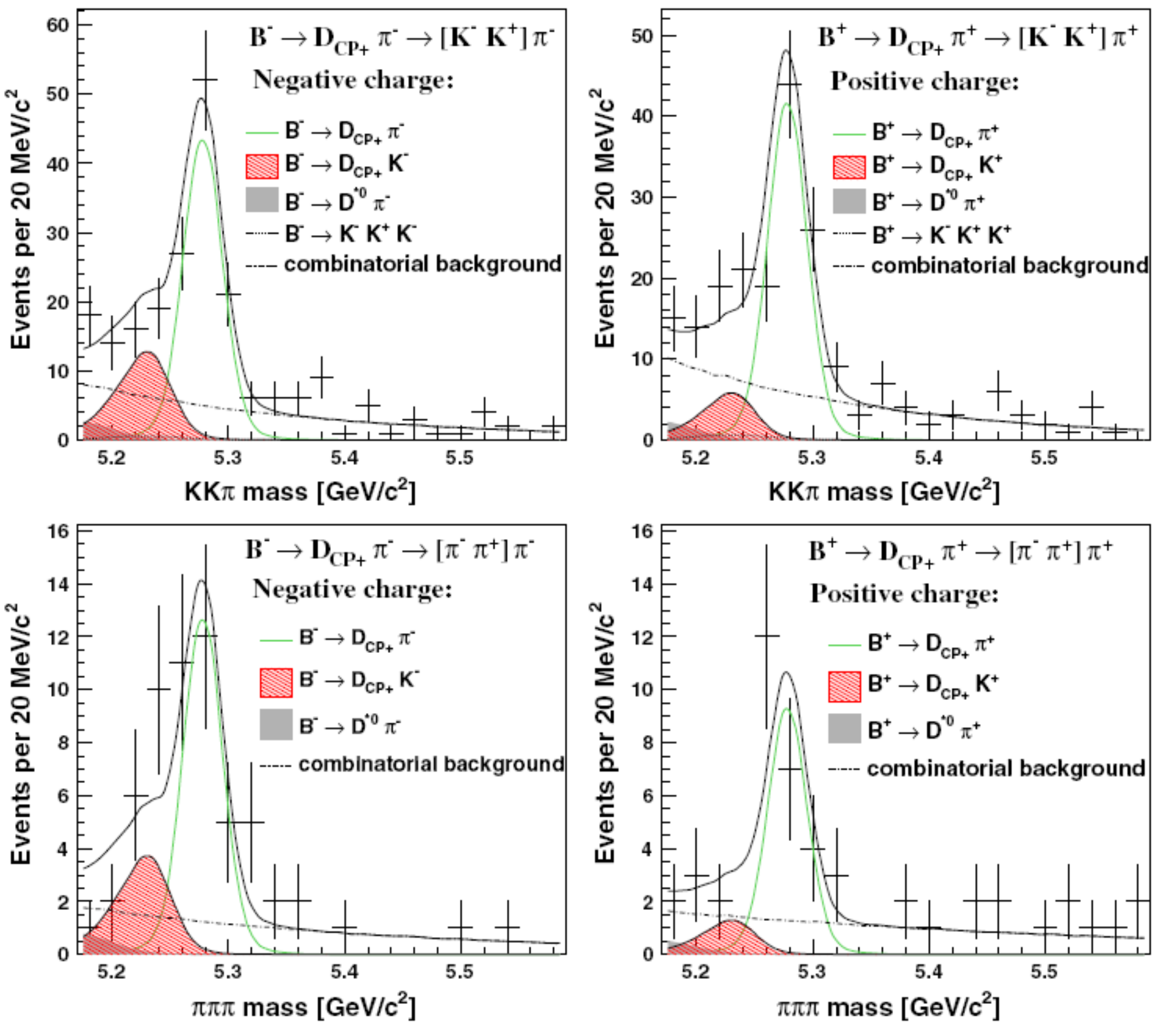
Could also be done with other D decay modes (quasi 2-body)

➔ should be combined with other methods to extract γ

CDF results 1/3

Published GLW analysis ($1fb^{-1}$) *Phys. Rev. D 81, 031105(R) (2010)*

PID cut to enhance the DK component



$D \rightarrow K^- K^+$

$D \rightarrow \pi^- \pi^+$

B^+ B^-

	$B^+ \rightarrow DK^+$	$B^- \rightarrow DK^-$
$D \rightarrow K^- \pi^+$	250 ± 26	266 ± 27
$D \rightarrow K^- K^+$	22 ± 8	49 ± 11
$D \rightarrow \pi^- \pi^+$	6 ± 6	14 ± 6

CDF results 2/3

Preliminary ADS analysis ($5fb^{-1}$) : *public note 10309, November 2010*

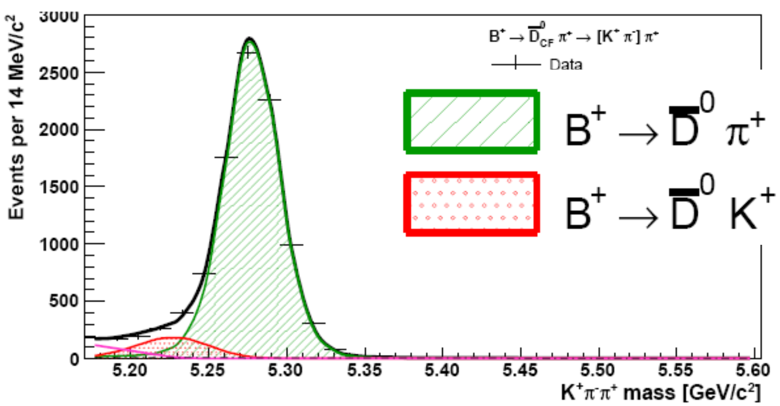
Use $B^{\pm} \rightarrow D\,\pi^{\pm}$ as a proxy (BF ~10 times larger) and optimize the cuts for the DCS D mode

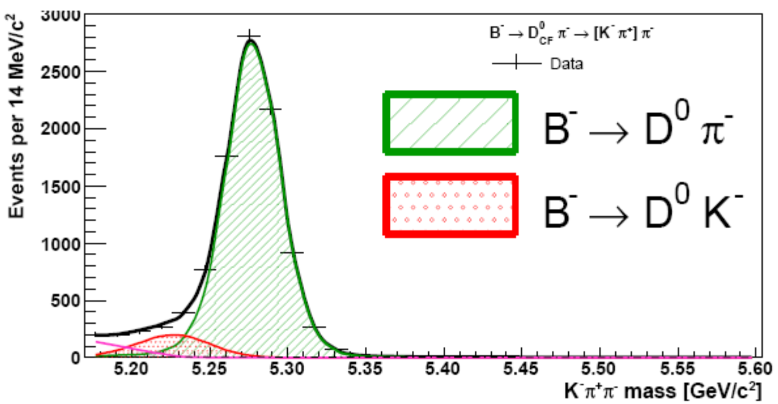
Topological cuts (vertices, flight length, flight angle)

K/π separation (1.5 σ at 2 GeV)

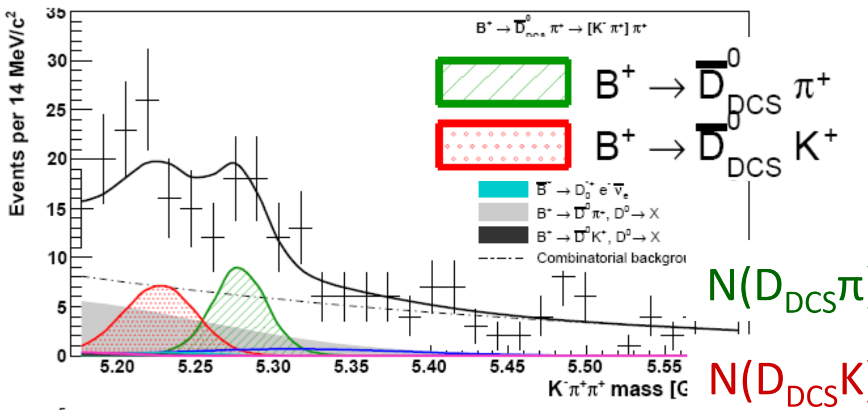
Unbinned maximum likelihood fits (m_B, PID) to extract the 8 components $B^{\pm} \rightarrow D_{DCS/CF}\,\pi\,/K^{\pm}$

CDF Run Cabibbo Favoured D mode



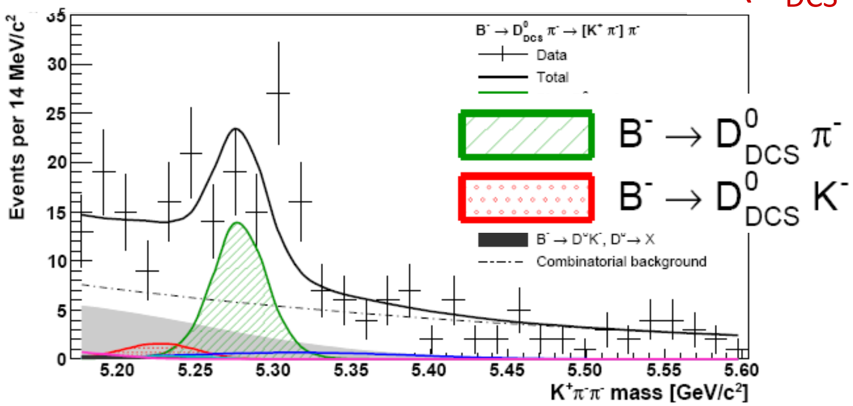


Doubly Cabibbo Suppressed D mode



N($D_{DCS}\pi$)= 73±16

N(D_{DCS}K)= 34±14



CDF results 3/3

ADS

<u>Main systematics</u>

R_{ADS} = 0.0225 ±0.0084 (stat) ±0.0079 (syst) — dE/dx, comb background

A_{ADS} = -0.63 ±0.40 (stat) ±0.23 (syst) — Comb background, fit bias, dE/dx

public note 10309, November 2010

Significance for all DCS signals ($D_{DCS}\pi$ and $D_{DCS}K$)>5σ

GLW

Phys. Rev. D 81, 031105(R) (2010)

<u>Main systematics</u>

R_{CP+} = 1.30 ±0.24 (stat) ±0.12 (syst) — Comb background, dE/dx

A_{CP+} = 0.39 ±0.17 (stat) ±0.04 (syst) — dE/dx, comb background

No significant constraint on **γ** /ϕ_3 yet
The precision ADS results is similar to the one from BaBar
Adds useful information

LHCb

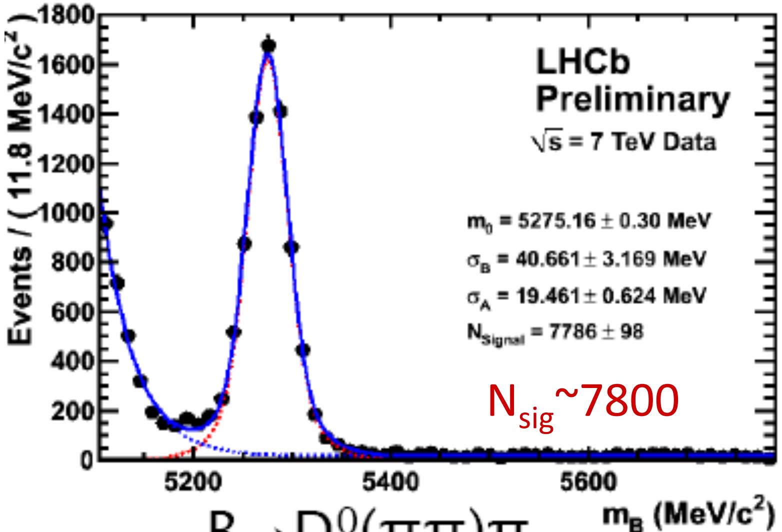
- Not enough statistics (yet)
- First plots are encouraging
- As a first step : few measurements

LHCb : towards B→DK (GLW and ADS)

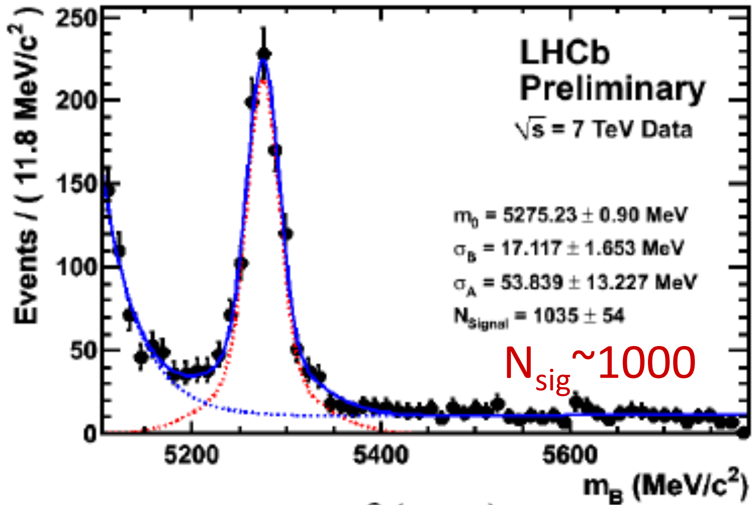
Data 2010 : 35 pb^{-1}

N_{sig}~780 CDF (1fb^{-1})

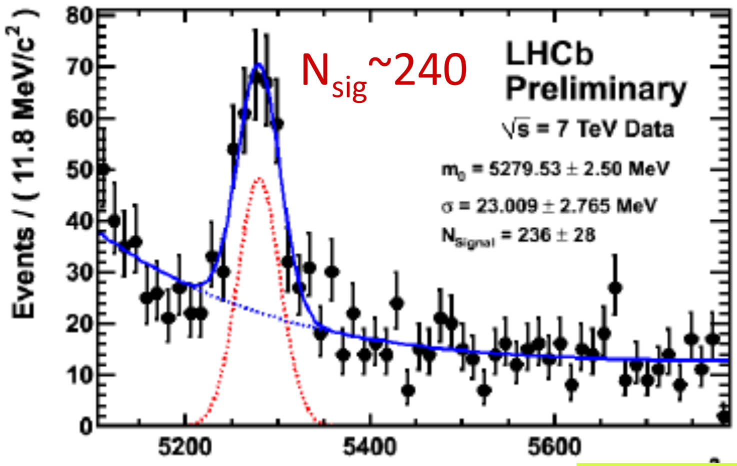
$B \to D^0(K\pi)\pi$ | N_{sig}~17700 CDF (5fb^{-1})



$B \to D^0(KK)\pi$

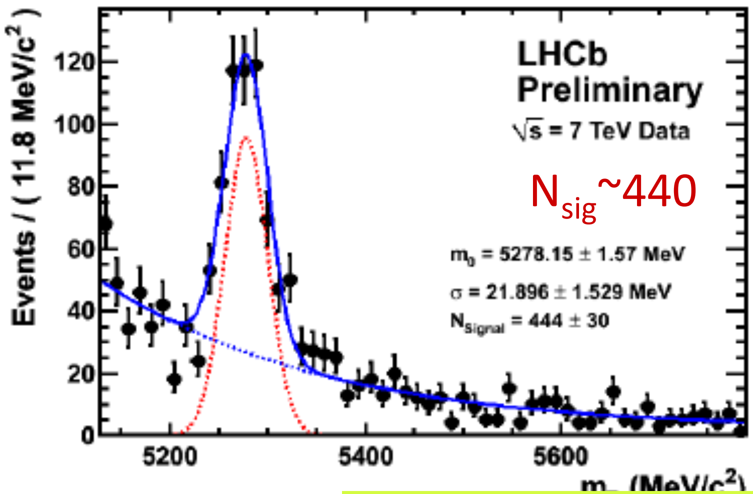


$B \to D^0(\pi\pi)\pi$



N_{sig}~220 CDF (1fb^{-1})

$B \to D^0(K\pi)K$



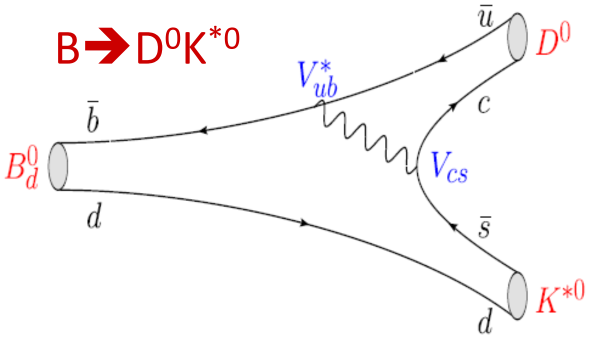
N_{sig}~1500 CDF (5fb^{-1})

LHCb : towards B→DK* (GLW and ADS)

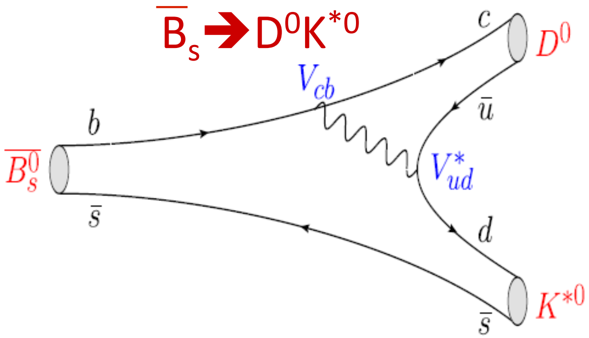
LHCb-CONF-2011-008

Data 2010 : 35 pb^{-1}

B→D^0K^{*0}



$\overline{B}_s$→D^0K^{*0}



BR ~300 times smaller

Diagram sensitive to **γ** /ϕ_3

V_{cb} ; not yet observed ; large BR(B_s→D^0K^{*0}) = 3 - 9 10^{-4}

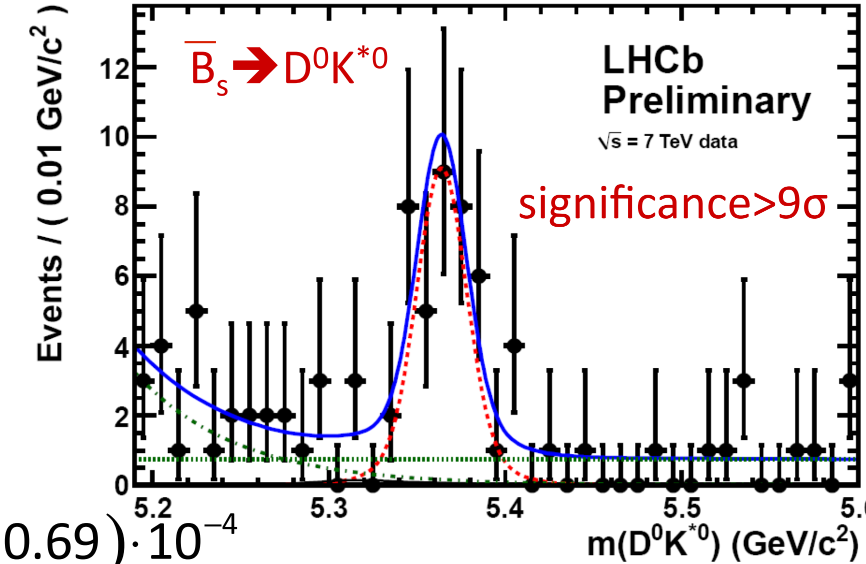
potentially large background (D^{*0}) :
5000-5340 MeV (the worst is D^{*0} →$D^0\gamma$)

Measurement of $\frac{BR(\overline{B}_s \to D^0 K^{*0})}{BR(\overline{B}_d \to D^0 \rho^0)}$

(similar final state)

$$\frac{BR(\overline{B}_s \to D^0 K^{*0})}{BR(\overline{B}_d \to D^0 \rho^0)} = 1.39 \pm 0.31 \pm 0.17 \pm 0.18$$

f_s/f_d



$$BR(\overline{B}_s \to D^0 K^{*0}) = (4.44 \pm 1.00 \pm 0.55 \pm 0.56 \pm 0.69) \cdot 10^{-4}$$

f_s/f_d | B→$D^0\rho$

f_d/f_s=3.71 ± 0.47(HFAG)

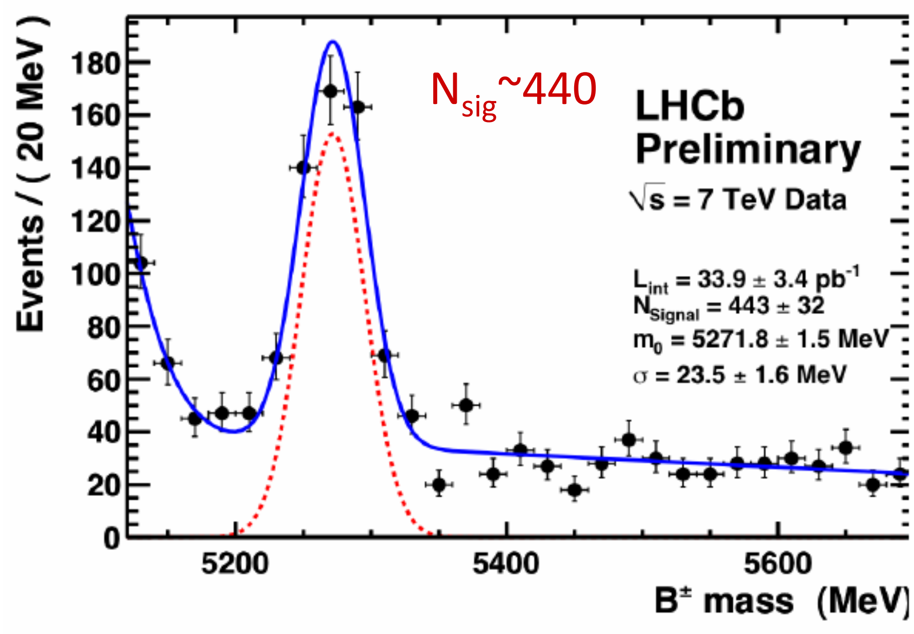
See Walter's Bonivento talk for LHCb f_d/f_s measurements

LHCb : towards B➔D(➔K_s ππ) K (GGSZ)

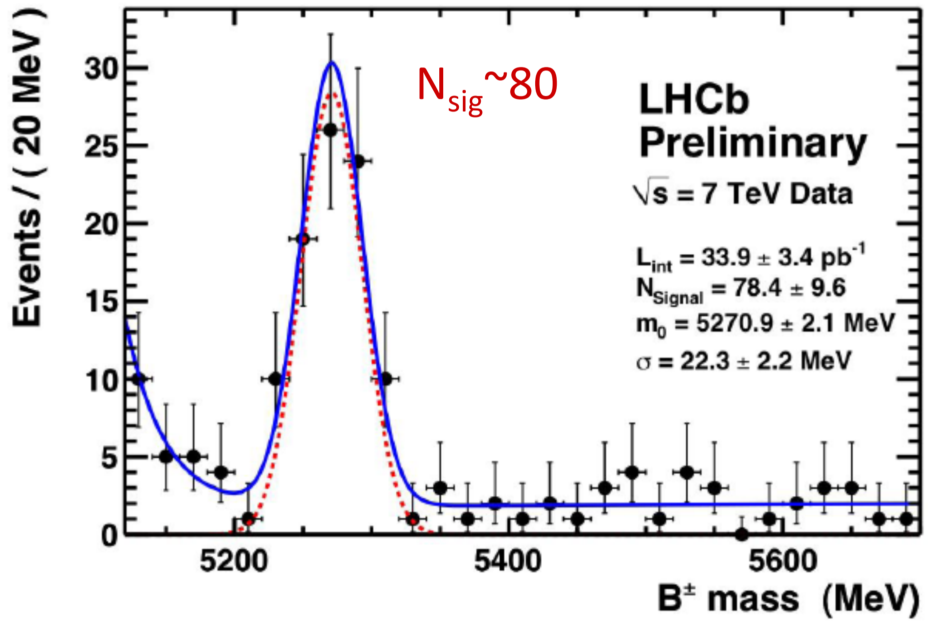
From the method itself : no strong phase ambiguities (B-Factories : measures γ/ϕ_3)
Can also be done at LHCb (but K_s reconstruction is not easy)

Not yet the CS modes : Data 2010 : 35 pb^{-1}

B^- ➔D^0 (K_s ππ) π



B^- ➔D^0 (K_s KK) π



Can expect ~1000 B^- ➔D^0 (K_s ππ) K at the end of 2011 (about the size of BaBar or BELLE)

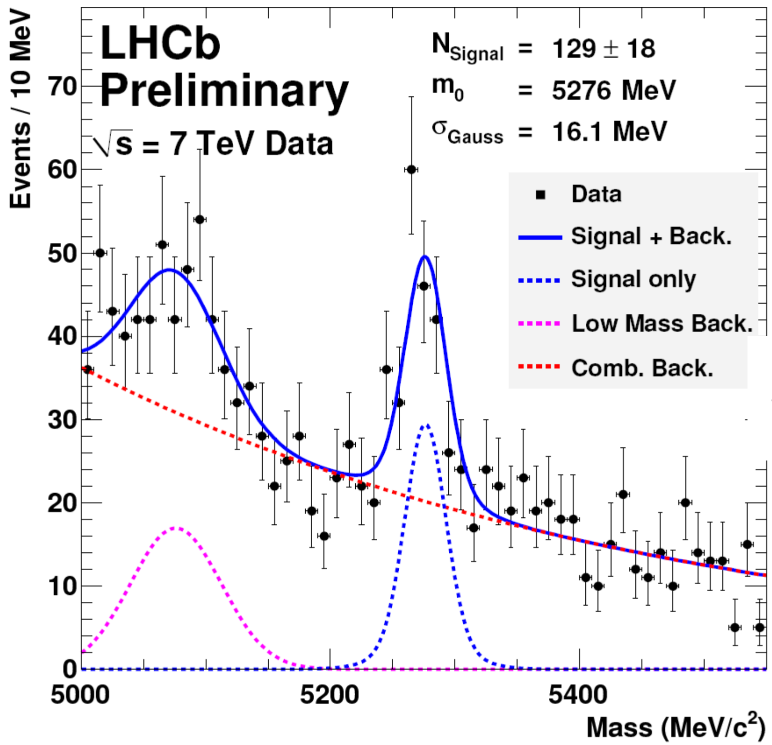
LHCb : measurements of $X_b \rightarrow X_c hhh$

X_b : B^0, B^-, Λ_b , h= K or π

LHCb-CONF-2011-007, LHCb-CONF-2011-024

$B^- \rightarrow D^0 K^- \pi\pi$

Data 2010 : 35 pb^{-1}



First observation

Could be used for **γ** /ϕ_3 measurements

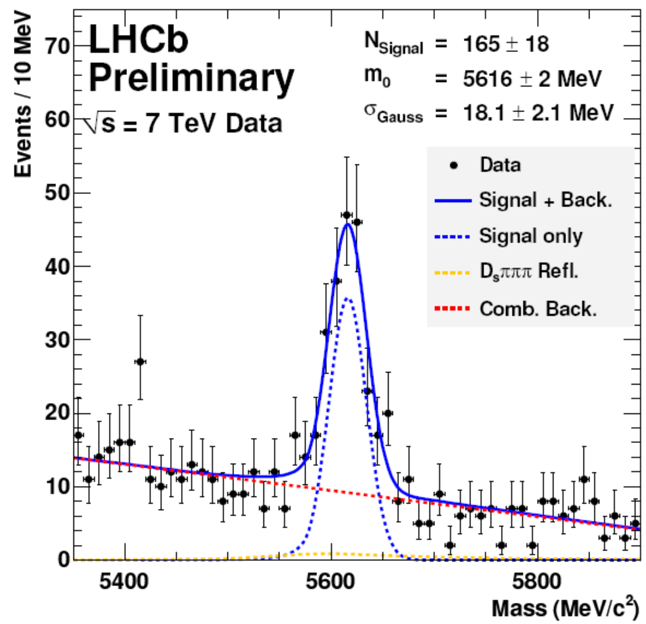
$$\frac{\mathcal{B}(B^- \to D^0 K^- \pi^+ \pi^-)}{\mathcal{B}(B^- \to D^0 \pi^- \pi^+ \pi^-)} = (9.9 \pm 1.4(\text{stat}) \pm 0.8(\text{syst})) \times 10^{-2}$$

But also :

$$\frac{\mathcal{B}(\bar{B}^0 \to D^+ K^- \pi^+ \pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+ \pi^- \pi^+ \pi^-)} = (5.2 \pm 0.9(\text{stat}) \pm 0.5(\text{syst})) \times 10^{-2}$$

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)} = 1.32 \pm 0.15(\text{stat}) \pm 0.14(\text{syst})$$

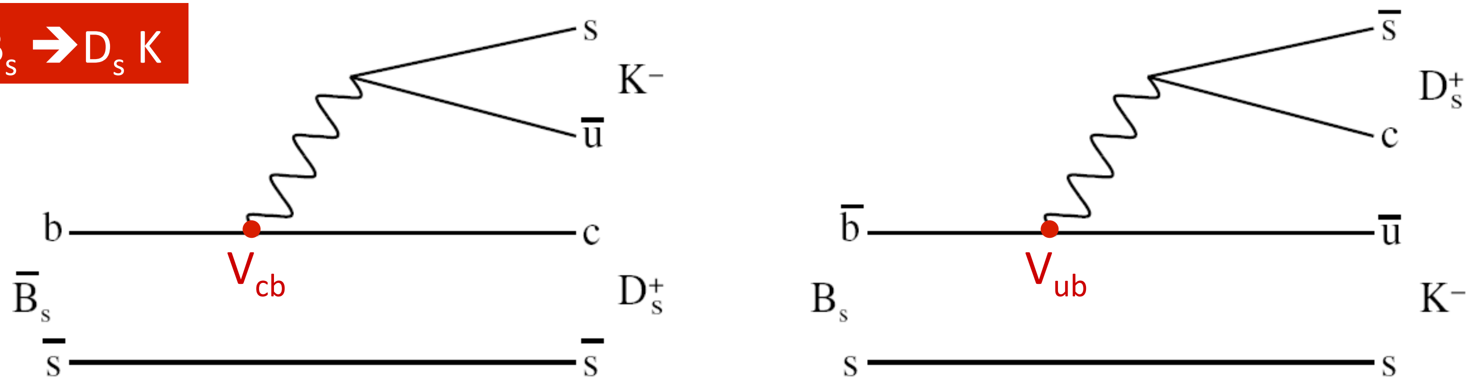
(first measurement)



LHCb : time dependent measurements for γ /ϕ_3 (1/2)

$B_s \rightarrow D_s K$

LHCb-CONF-2011-005



Sensitive to γ /ϕ_3 -ϕ_s (ϕ_s should be obtained from elsewhere)
Requires tagging and proper time measurement
Untagged events : sensitive to γ /ϕ_3 through $\Delta\Gamma_s \neq 0$
First step : Δms measurement using Bs → Ds π (+ Ds 3π)

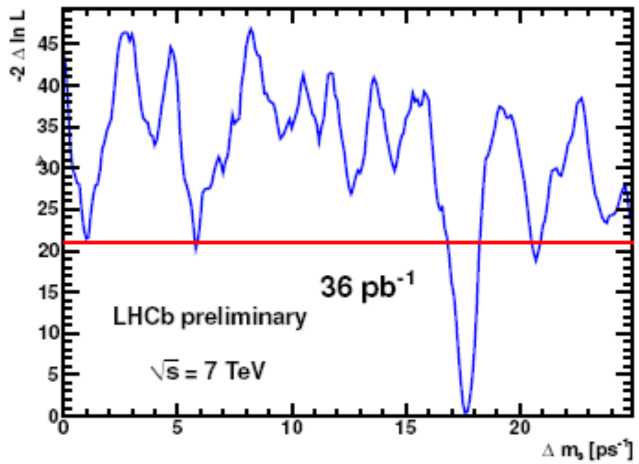
See Marta's Calvi talk for more details

Clear dip at $\Delta m_s \sim 17.6 ps^{-1}$ the observed mixing signal has 4.6σ significance.

Proper time resolution directly measured on 2010 data : 50 fs

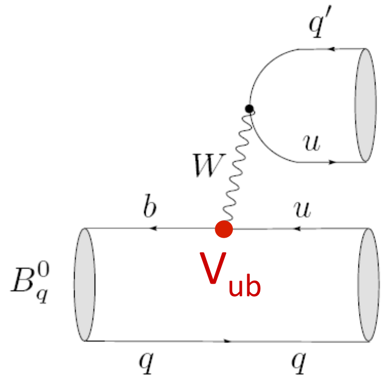
Opposite Side tagging power : $\varepsilon \times (1-2\omega)^2 = 3.8 \pm 2.1\%$
(Same Side tagging : work on going)

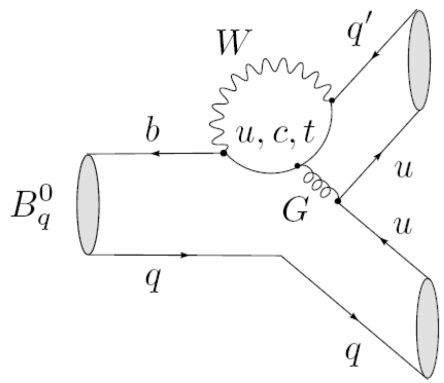
$$\Delta m_s = (17.63 \pm 0.11 \pm 0.04) \cdot \text{ps}^{-1}$$



LHCb : time dependent measurements for **γ** /ϕ_3 (2/2)

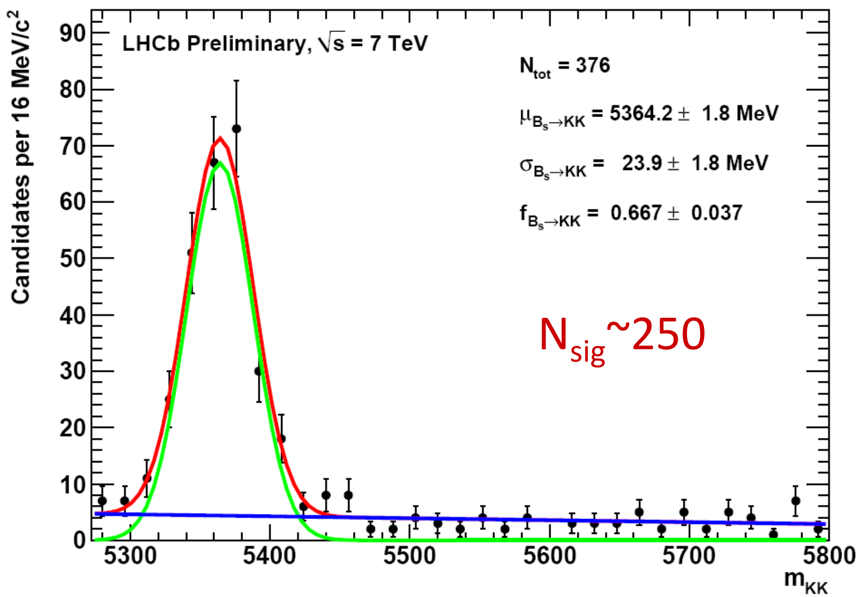
Time-dependent measurements exploiting U-spin symmetry (B→hh)





See Marta's Calvi talk for a first measurement of the B_s → KK effective lifetime

Data 2010 : 35 pb^{-1}

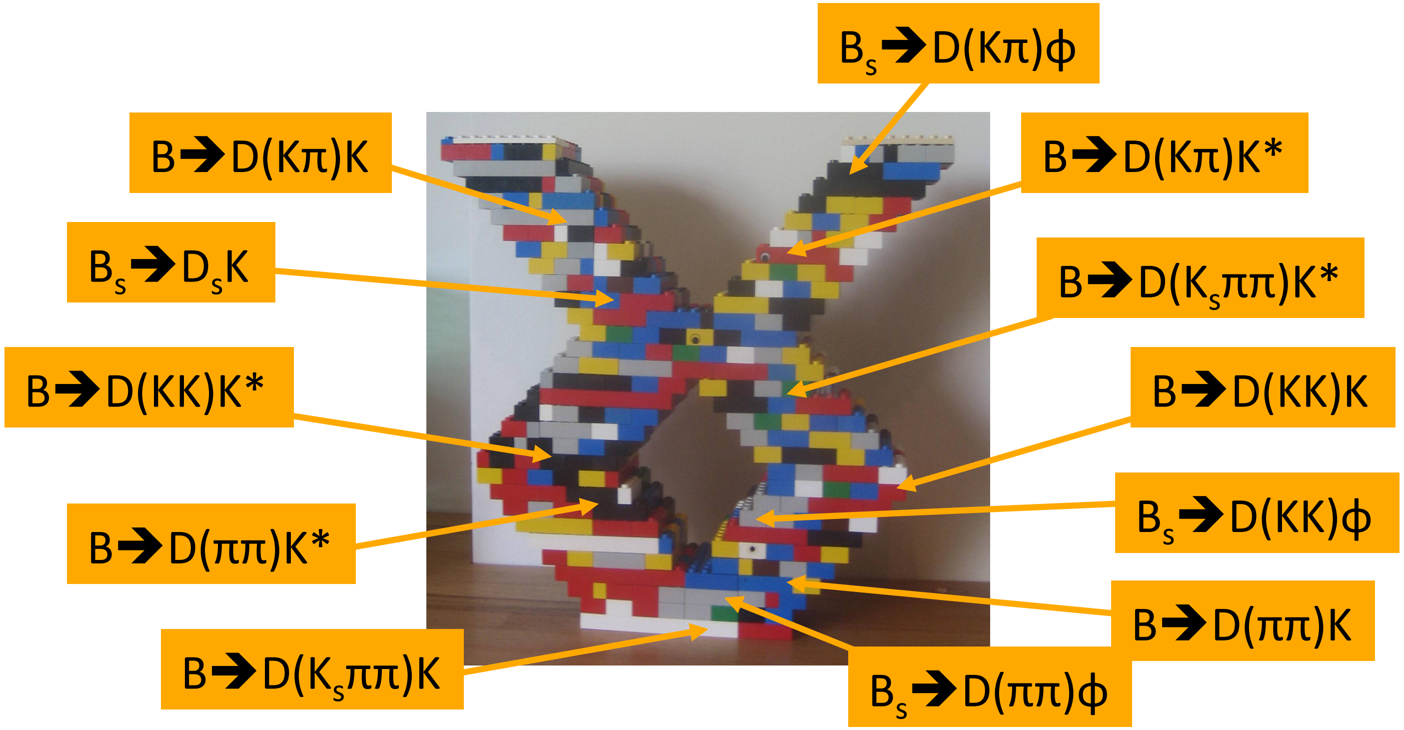


Time-dependent CP asymmetries in view of **γ** /ϕ_3 measurement (assuming U-spin) will take time

Summary

• Challenges at hadronic colliders : fully hadronic channels : trigger and background rejection (displaced vertices and PID)

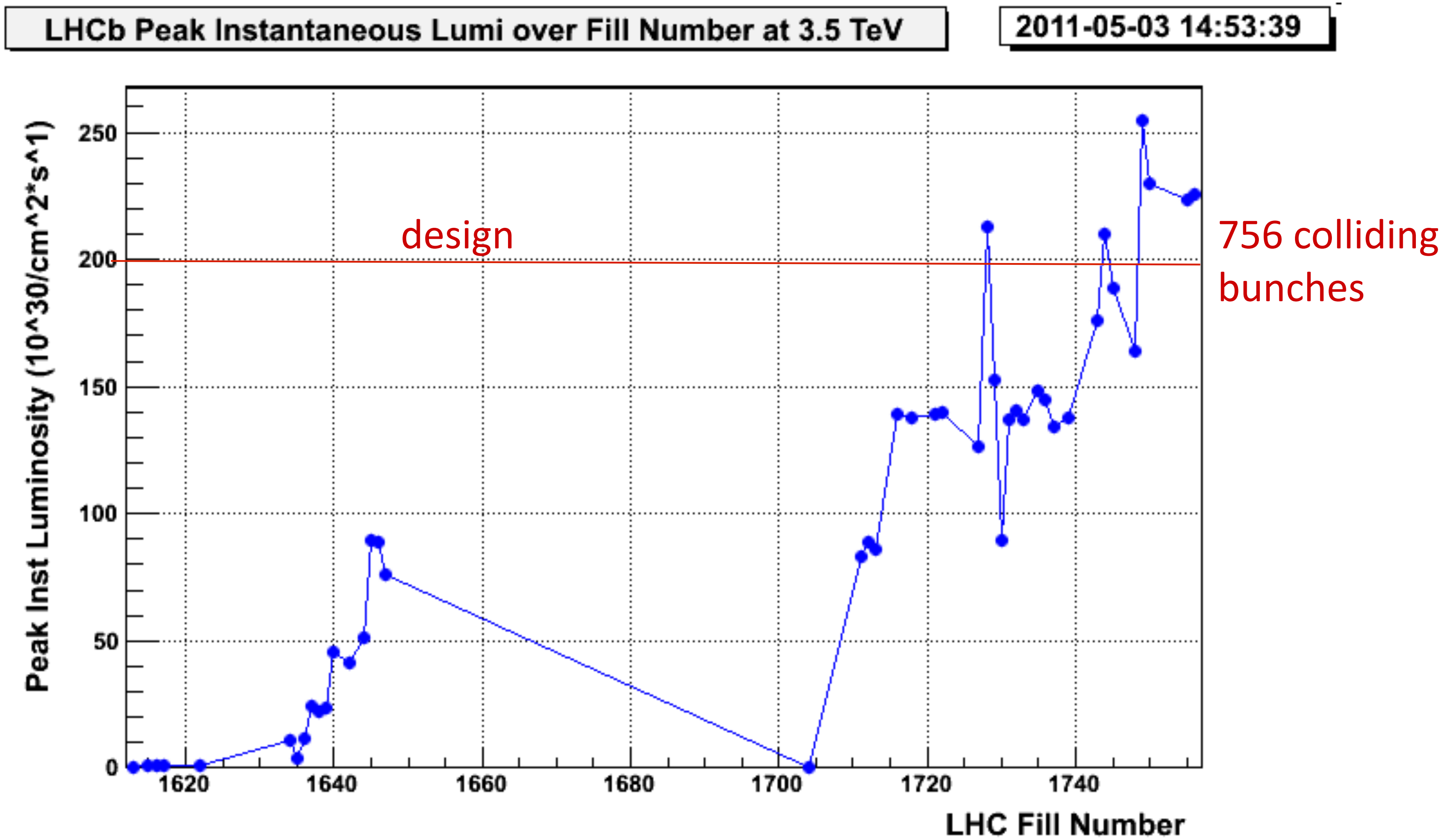
• LHCb should be taking over CDF this year



•At the end of 2012 : sensitivity on **γ** /ϕ_3 from LHCb should be between 5-10°

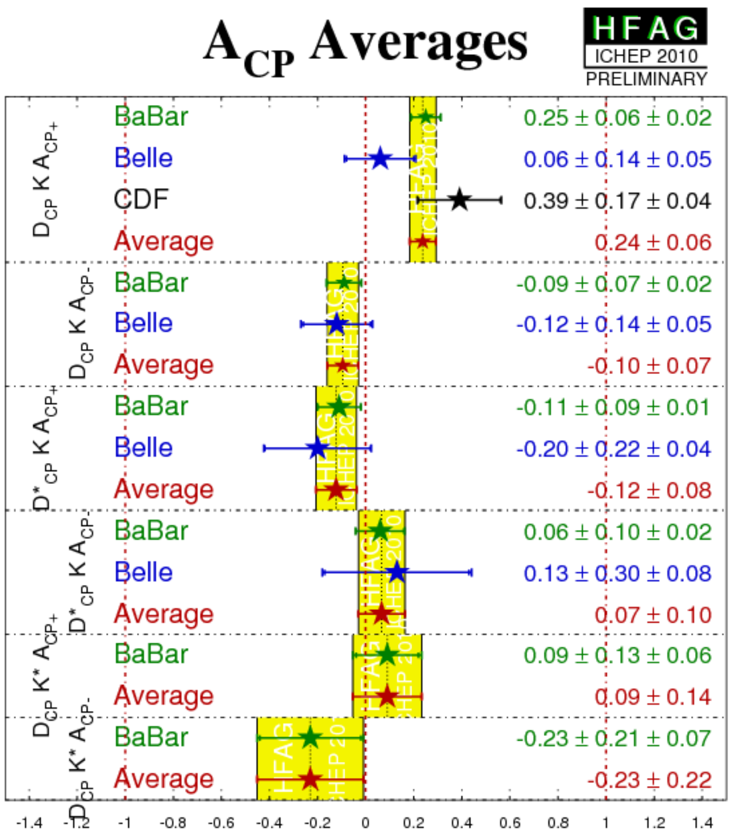
Thank you for your attention !

Back up slides

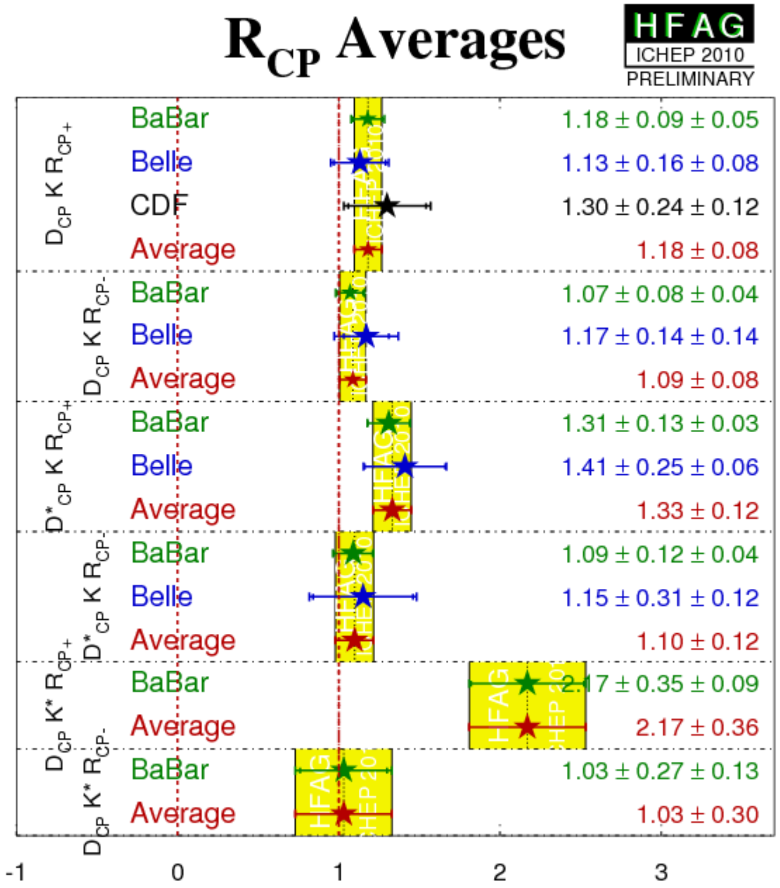


LHCb Peak Instantaneous Lumi over Fill Number at 3.5 TeV
2011-05-03 14:53:39
Peak Inst Luminosity (10^30/cm^2*s^1)
LHC Fill Number
0
50
100
150
200
250
1620
1640
1660
1680
1700
1720
1740
design
756 colliding
bunches

GLW
|A|~.15
R~1

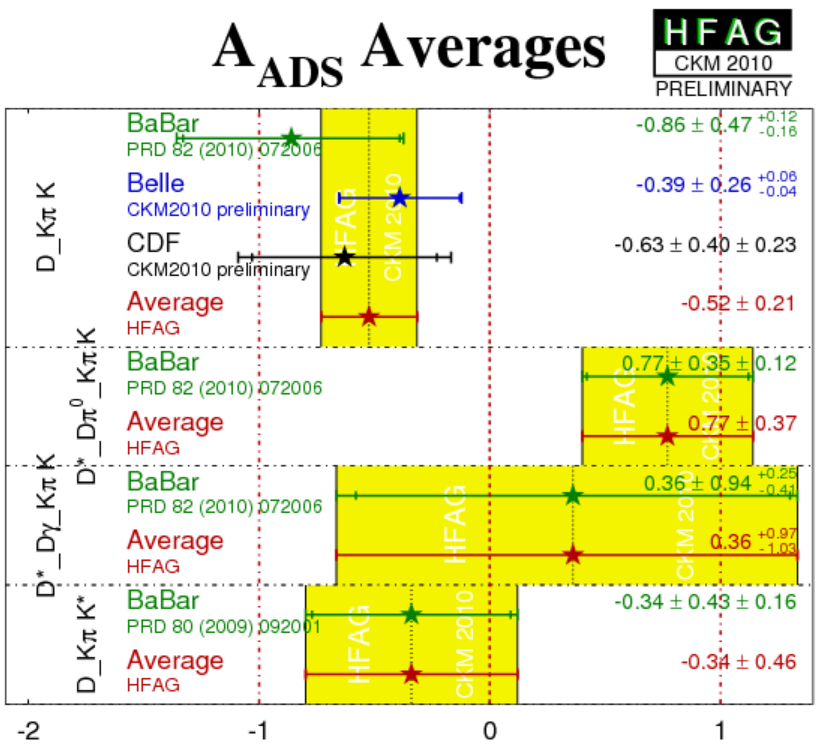


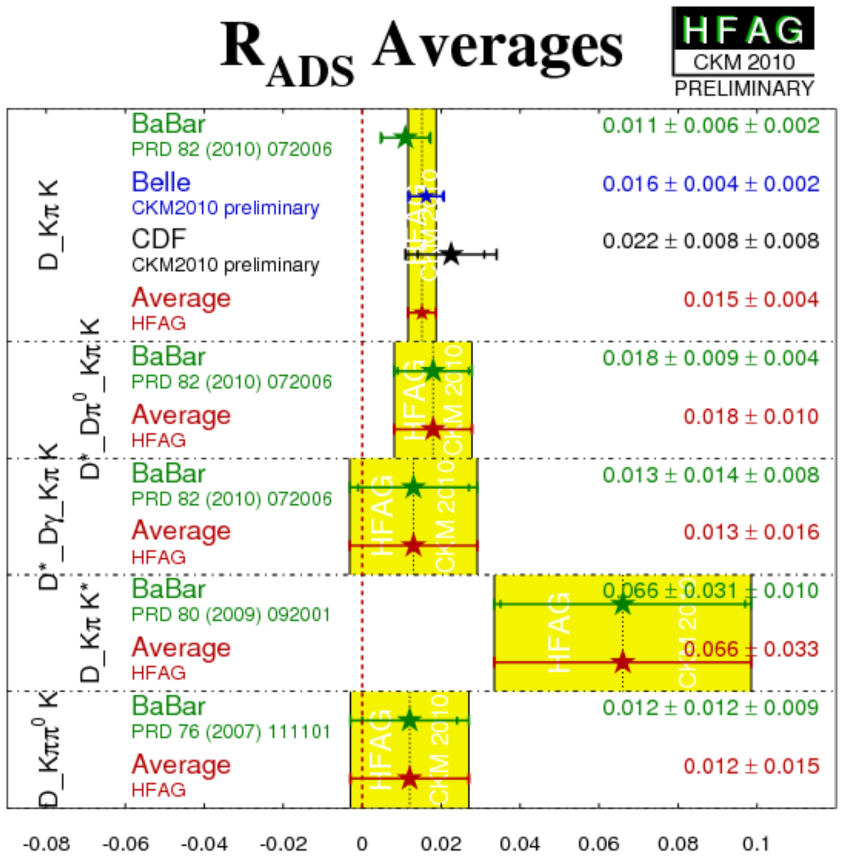
ACP Averages
HFAG
ICHEP 2010
PRELIMINARY
BaBar 0.25 ± 0.06 ± 0.02
Belle 0.06 ± 0.14 ± 0.05
CDF 0.39 ± 0.17 ± 0.04
Average 0.24 ± 0.06
BaBar -0.09 ± 0.07 ± 0.02
Belle -0.12 ± 0.14 ± 0.05
Average -0.10 ± 0.07
BaBar -0.11 ± 0.09 ± 0.01
Belle -0.20 ± 0.22 ± 0.04
Average -0.12 ± 0.08
BaBar 0.06 ± 0.10 ± 0.02
Belle 0.13 ± 0.30 ± 0.08
Average 0.07 ± 0.10
BaBar 0.09 ± 0.13 ± 0.06
Average 0.09 ± 0.14
BaBar -0.23 ± 0.21 ± 0.07
Average -0.23 ± 0.22

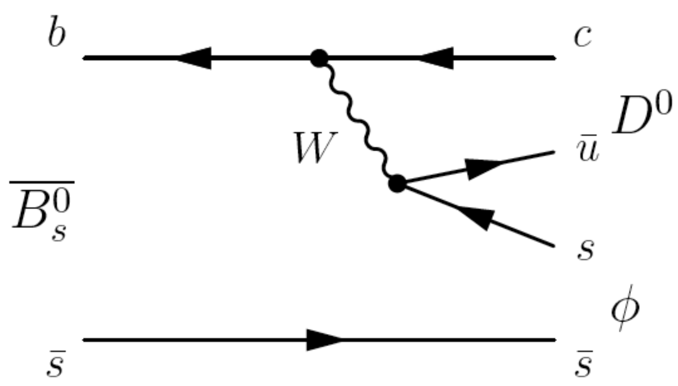


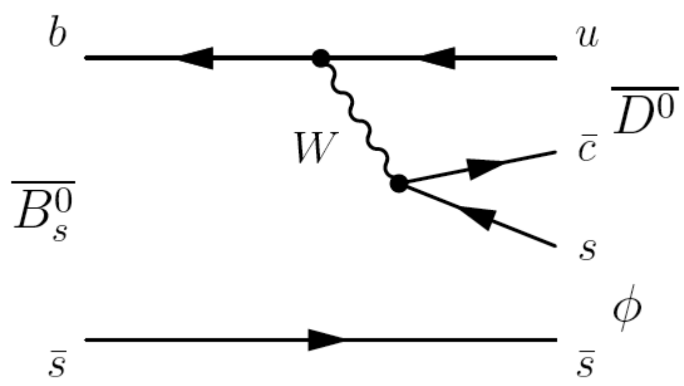
RCP Averages
HFAG
ICHEP 2010
PRELIMINARY
BaBar 1.18 ± 0.09 ± 0.05
Belle 1.13 ± 0.16 ± 0.08
CDF 1.30 ± 0.24 ± 0.12
Average 1.18 ± 0.08
BaBar 1.07 ± 0.08 ± 0.04
Belle 1.17 ± 0.14 ± 0.14
Average 1.09 ± 0.08
BaBar 1.31 ± 0.13 ± 0.03
Belle 1.41 ± 0.25 ± 0.06
Average 1.33 ± 0.12
BaBar 1.09 ± 0.12 ± 0.04
Belle 1.15 ± 0.31 ± 0.12
Average 1.10 ± 0.12
BaBar 2.17 ± 0.35 ± 0.09
Average 2.17 ± 0.36
BaBar 1.03 ± 0.27 ± 0.13
Average 1.03 ± 0.30

ADS
|A|~.2-.3
R~.02-.03



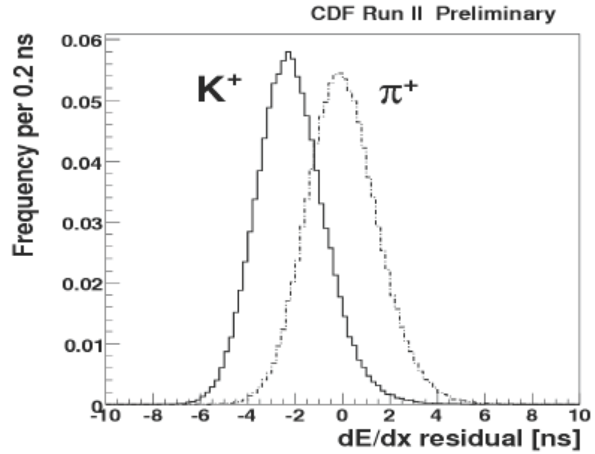






$$
\begin{aligned}
\Gamma[D(K^-\pi^+)\phi] &= N_{K\pi}[(1+r_B^2)(1+(r_D^{K\pi})^2)+4r_B r_D^{K\pi}\cos(\delta_{K\pi}+\gamma)\cos\delta_B] \\
\Gamma[D(K^+\pi^-)\phi] &= N_{K\pi}[(1+r_B^2)(1+(r_D^{K\pi})^2)+4r_B r_D^{K\pi}\cos(\delta_{K\pi}-\gamma)\cos\delta_B] \\
\Gamma[D(K^-3\pi)\phi] &= N_{K3\pi}[(1+r_B^2)(1+(r_D^{K3\pi})^2)+4R_{K3\pi}r_B r_D^{K3\pi}\cos(\delta_{K3\pi}+\gamma)\cos\delta_B] \\
\Gamma[D(K^+3\pi)\phi] &= N_{K3\pi}[(1+r_B^2)(1+(r_D^{K3\pi})^2)+4R_{K3\pi}r_B r_D^{K3\pi}\cos(\delta_{K3\pi}-\gamma)\cos\delta_B] \\
\Gamma[D(hh)\phi] &= 4N_{hh}[(1+r_B^2)+2r_B\cos\gamma\cos\delta_B]
\end{aligned}
$$

mode not yet seen.



K – π separation: 1.5 σ for p > 2 GeV/c

ADS: Systematics

Source	$R_{ADS}(\pi)$	$R_{ADS}(K)$	$A_{ADS}(\pi)$	$A_{ADS}(K)$
dE/dx	0.0001	0.0050	0.0560	0.070
combinatorial background	0.0003	0.0037	0.0073	0.153
$B^- \to [X]_D \pi^-$ shape	0.0002	0.0025	0.0067	0.057
$B^- \to [X]_D K^-$ shape	-	0.0001	0.0003	0.003
$B^- \to K^- \pi^+ \pi^-$ shape	0.0001	0.0004	0.0049	0.009
$B^0 \to D_0^{*-} e^+ \nu_e$ shape	-	0.0003	0.0020	0.007
$B^- \to D^{*0} \pi^-$ shape	-	0.0005	0.0009	0.013
efficiency	-	0.0001	-	0.003
bias	0.0001	0.0042	0.0159	0.148
Total	**0.0004**	**0.0079**	**0.059**	**0.232**

- dE/dx we varied the shapes of the PID pdfs
- Combinatorial and physics background: we varied the shapes used in the fit
- efficiency of K+/K- reconstruction
- Fit bias: checked with pseudo-experiments MC