Prospects for γ measurements at LHCb

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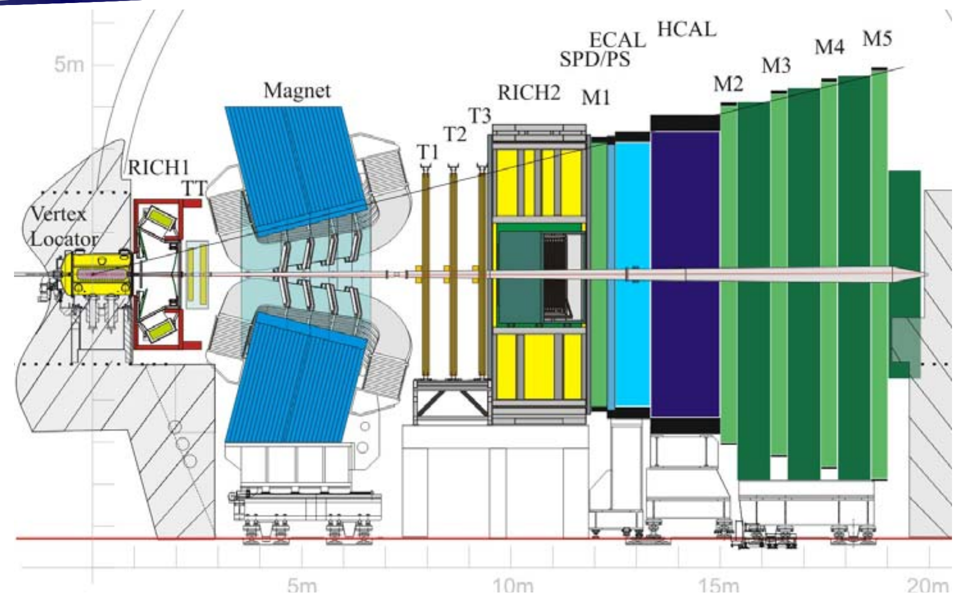
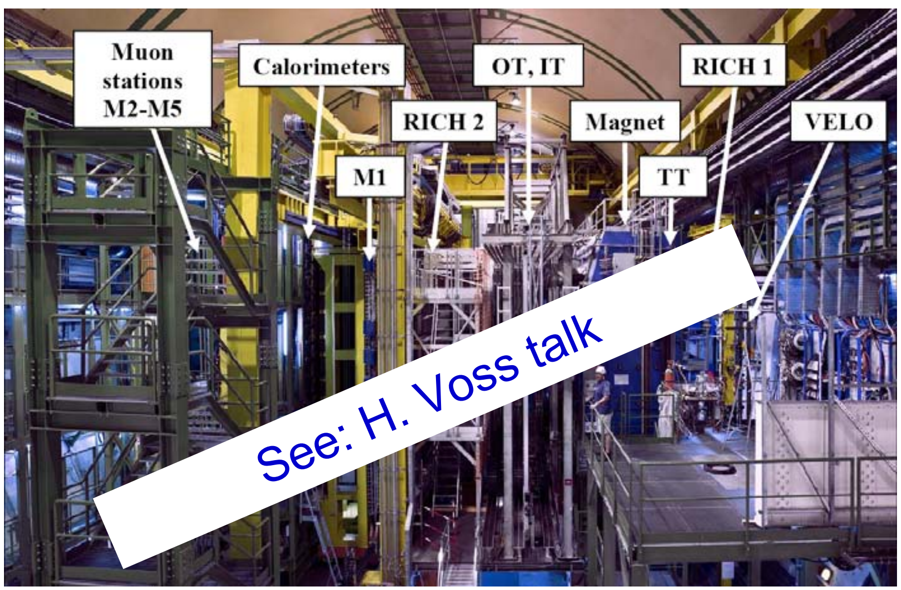
(on behalf of the LHCb collaboration)

LHCb detector

- LHC: 14 TeV → σ_{bb}= **500μb**
- **10^{12}** $b\bar{b}$ per year (2 fb^{-1})
- Special purpose detector to search for:
  - **New physics** - rare b quark decays   See: E. Lopez talk
  - **CP violation**
- $B^{\pm}$, B^0, B_s, B_c, Λ_b…





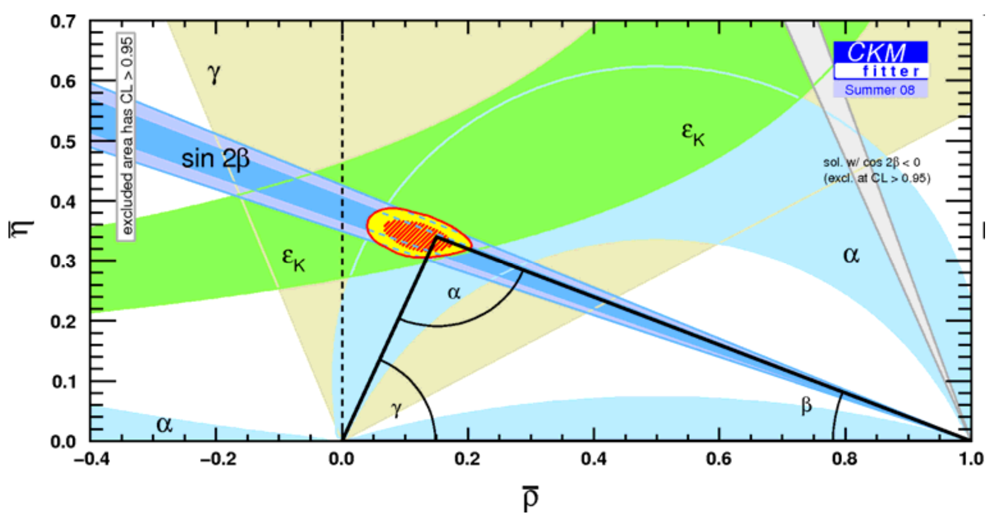
- Excellent tracking system (**VELO** retractable sensors: 5-35mm from beam)
  - t-resloution: **~40 fs**
    - B_s t-dependent studies
- RICH system – hadronic ID
  - K – π separation: **96%** (3σ)
    - 2-100GeV
- Trigger system: many B decay topologies

CKM angle γ

- CKM matrix in SM
  - Parameterisation of physical observables
  - Appears in SM Lagrangian
- LHCb: measure all angles and one-side+height independently
- γ – least well determined angle

$$\gamma = (70^{+27}_{-29})^{\circ}, [2\sigma] = (29^{\circ}, 113^{\circ})$$

- To disentangle 'new physics' in γ loop measurements
  - Need σ_γ **a few degrees** – from trees

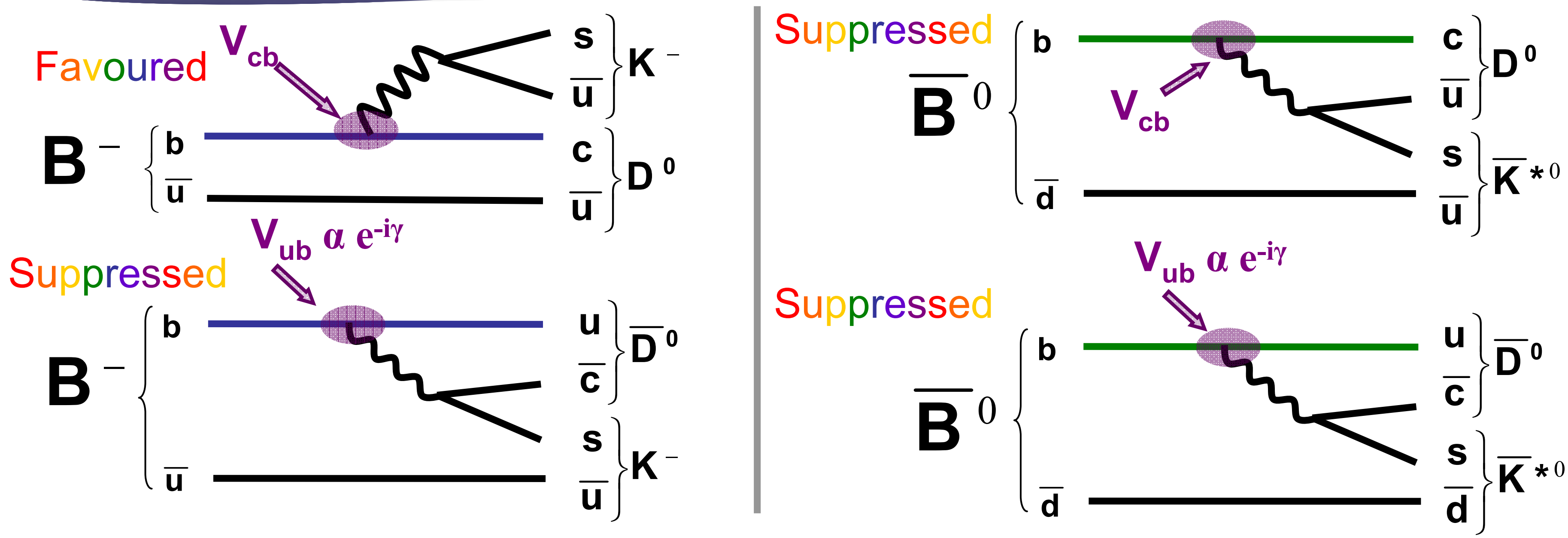


Hep-ph/0406184

Trees

Standard Model γ benchmark

B→DK strategy



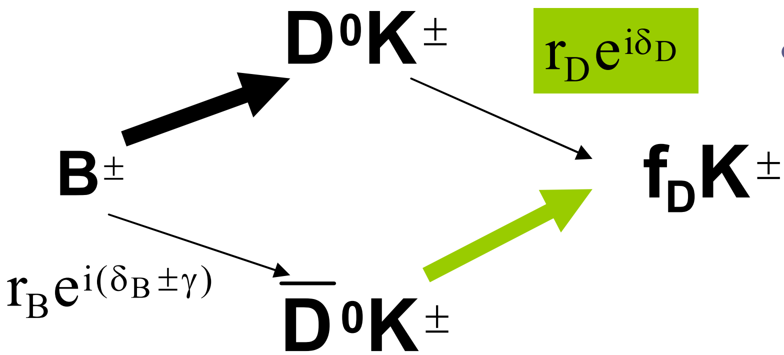
$r_{B^\pm} = 0.103^{+0.017}_{-0.023}$ ICHEP 2008 $r_{B^0} = [0.07, 0.41] @ 90\%$ c.l.

- **No loop** contribution – theoretically clean
  - **Baseline** γ measurement

$$\frac{A(B \to \bar{D}^0 K^-)}{A(B \to D^0 K^-)} = r_B e^{i\delta} e^{-i\gamma}$$

- $D^0/\bar{D}^0$ decay to **same final state**
  - γ extracted from **interference**
- **3 common parameters** – global fit
  - + D decay parameters

ADS/GLW



- **ADS**: f_D= D^0 DCS and CF (**$B^\pm$:** $K\pi$)
  - Low event rate, larger interference
- **GLW**: f_D = D^0 eigenstates (**$B^\pm$:** K^+K^-, $\pi^+\pi^-$)
  - High event rate, smaller interference

- $B^\pm \to D^0(hh)K^\pm$
- $B^0 \to D^0(hh)K^{*0}$
  - self tagged $K^{*0} \to K^+\pi^-$
- 6 rates, 5 parameters
- Constraint:

$$\delta_{K\pi} = (22^{+11+9}_{-12-11})^\circ$$

from CLEO-c

PRL 100(2008) 221801

	$B^\pm$	**B^0**
γ	60°	60°
r_B	0.10	0.40
δ_B	130° (PDG)	**Scan (0 – π)**
$r_{K\pi}$	0.0616 (PDG)	0.0616 (PDG)
$\delta_{K\pi}$	**-158°**	**-158°**

ADS formalism requires -180° phase shift

$B^{\pm(0)} \to D^0(hh)K^{\pm(*0)}$

2 fb^{-1}

- Yields:

$B^\pm$ Mode	Yield	B/S
$B^\pm \to D_{fav}(K\pi)K^\pm$	28k	0.6
$B^\pm \to D_{sup}(K\pi)K^\pm$	650	1.2
$B^\pm \to D_{CP}(KK)K^\pm$	3k	1.2
$B^\pm \to D_{CP}(\pi\pi)K^\pm$	1k	3.6

LHCb-2008-011

B^0 Mode	Yield	B/S (90%c.l)
$B^0 \to D_{fav}(K\pi)K^{*0}$	3.4k	[0.4,2.0]
$B^0 \to D_{sup}(K\pi)K^{*0}$	540	[2.0,13.0]
$B^0 \to D_{CP}(KK)K^{*0}$	470	[0,0.4]
$B^0 \to D_{CP}(\pi\pi)K^{*0}$	130	[0,14.0]

LHCb-2007-050

- Sensitivity:

$B^\pm \to D^0(hh)K^\pm$

$\delta_{K\pi}(^o)$	-190	-174	-158	-144	-130
$\sigma_\gamma(^o)$	12.7	10.8	13.8	12.6	10.8

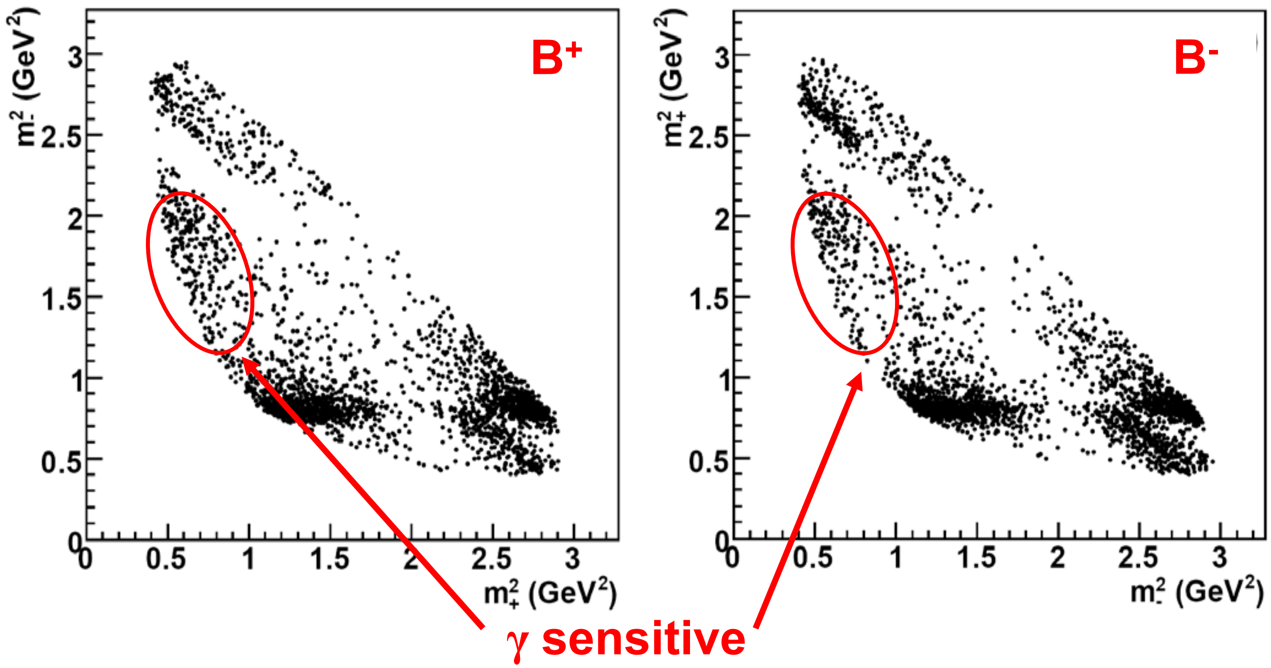
LHCb-2008-031

$B^0 \to D^0(hh)K^{*0}$

$\delta_{B^0}(^o)$	0	45	90	135	180
$\sigma_\gamma(^o)$	6.2	10.8	12.7	9.5	5.2

Dalitz

- $B^{\pm} \to D^0(K_s\pi^+\pi^-)K^{\pm}$



- Sensitivity to γ arises from interference between B^+ and B^-
- Two approaches to γ extraction
  - **Unbinned Isobar model** dependent method – Belle + BaBar
  - **Binned model independent** method – bins of δ_D

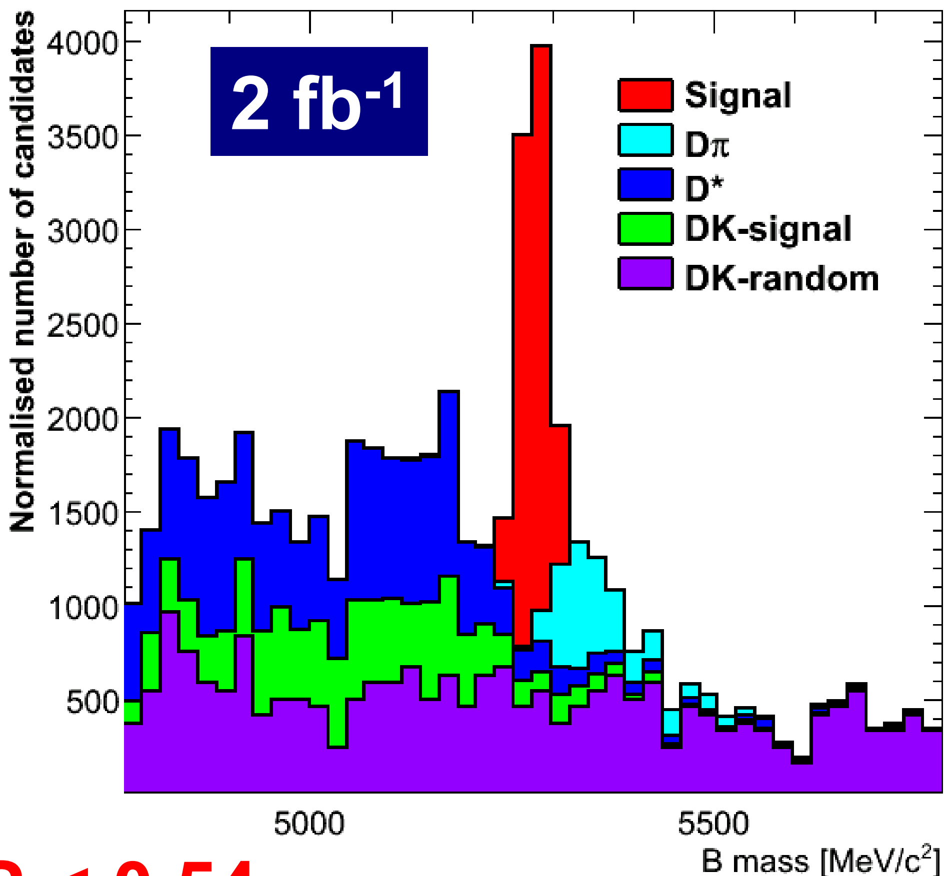
(Dalitz) $B^{\pm} \to D^0(K_s\pi\pi)K^{\pm}$

- **Signal yield:**

  ~ 5k per year

Bkg type	B/S (*@ 90% c.l.)
DK-random	0.35±0.03
$B^{\pm} \to D^0\pi^{\pm}$	< 0.095*
DK-signal	< 0.09*
$B \to D^*X + K$	< 0.05*

LHCb-2008-028



Total B/S < 0.54 @ 90% c.l.

(Dalitz) $B^{\pm} \to D^0(K_s\pi\pi)K^{\pm}$

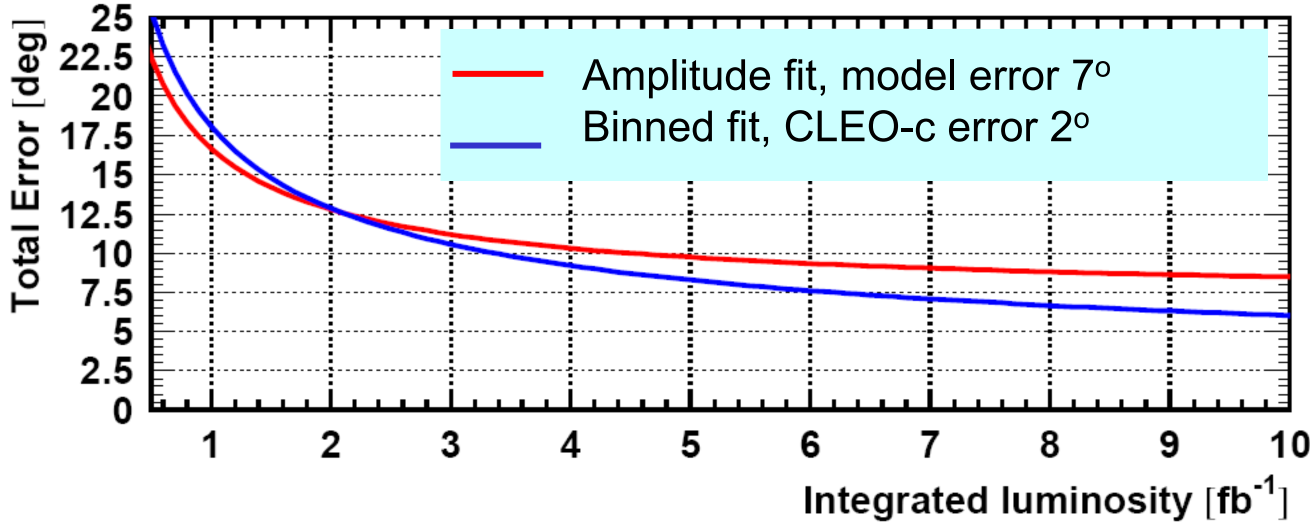
- Unbinned **isobar model** fit (Belle+BaBar)
  - 17-19 intermediate resonances
  - Carries model error **~7°**

$2fb^{-1}$	σ_γ (°)	σ_{r_B}	σ_{δ_B} (°)
Amp. Fit	**9.8**	0.018	9.3
Binned Fit	**12.8**	0.020	12.6

- Binned **model independent** method – binned according to δ_D
  - Slight loss on statistical power from binning
  - Input from $\psi(3770)$ on D decays – **CLEO-C**
  - Residue error from CLEO-C statistics **~1-2°**

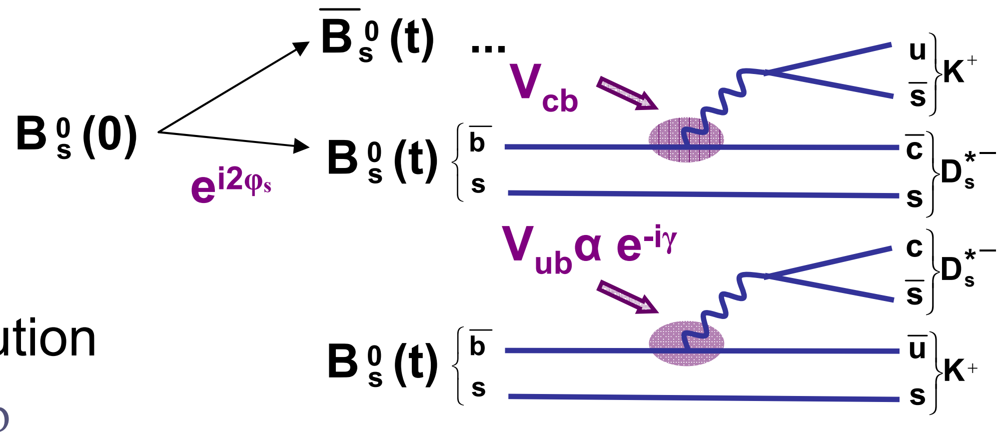
LHCb-2007-048

LHCb-2007-141



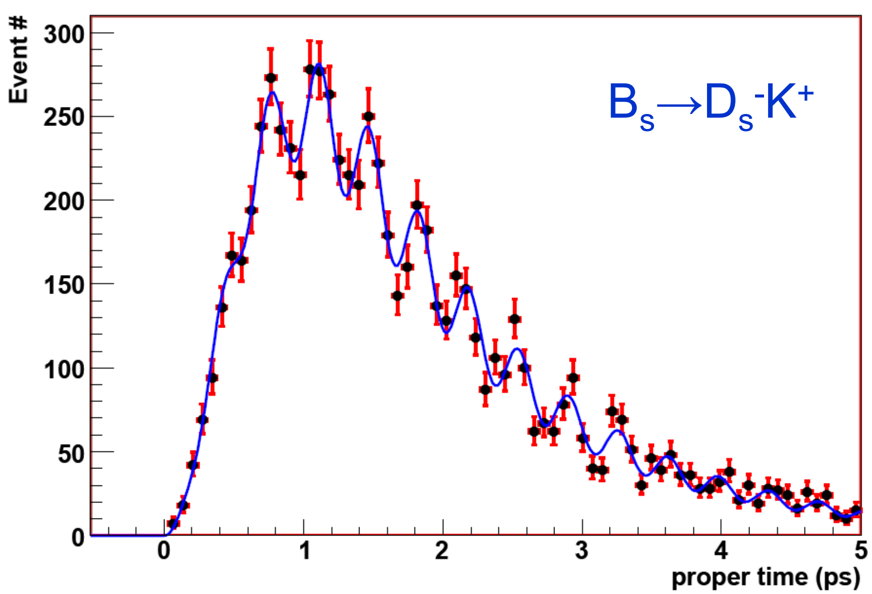
Time dependent $B_s \to D_s K$

- Measurement $\gamma + \varphi_s$ from decay amp + mixing
- Flavour tag for $\overline{B}_s^0, B_s^0$
- Fit to $B_s \to D_s K$ decay time distribution
  - $\varphi_s \sim 0.03$ input from $B_s \to J/\psi\varphi$
  - $\gamma = 60^o$



$$r_{DK} \sim \frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

LHCb-2007-017
LHCb-2007-041



2 fb^{-1}

Mode	Sig. yield	B/S
$B_s \to D_s K$	6.2k	0.7

Sensitivity	2 fb^{-1}	10 fb^{-1}
σ_γ (^{o})	10.3	4.6

Loops

Sensitive to new physics

$B^0 \to \pi\pi$ and $B_s \to KK$

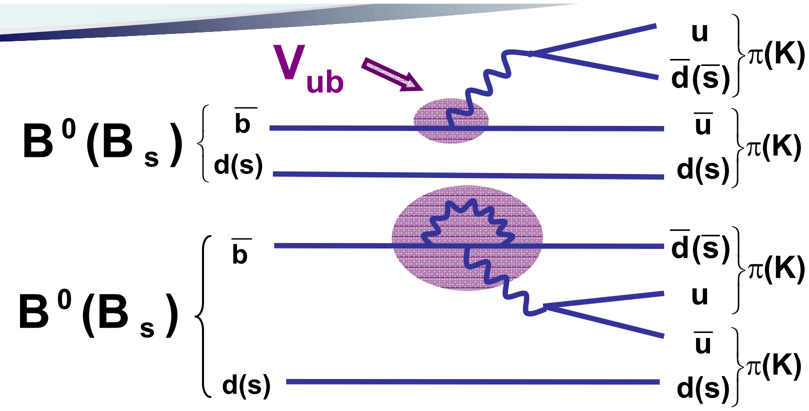
LHCb-2007-059

- γ sensitivity from interference
  - Mixing
  - Tree and penguin diagrams
- Fit t-dependent CP asymmetries

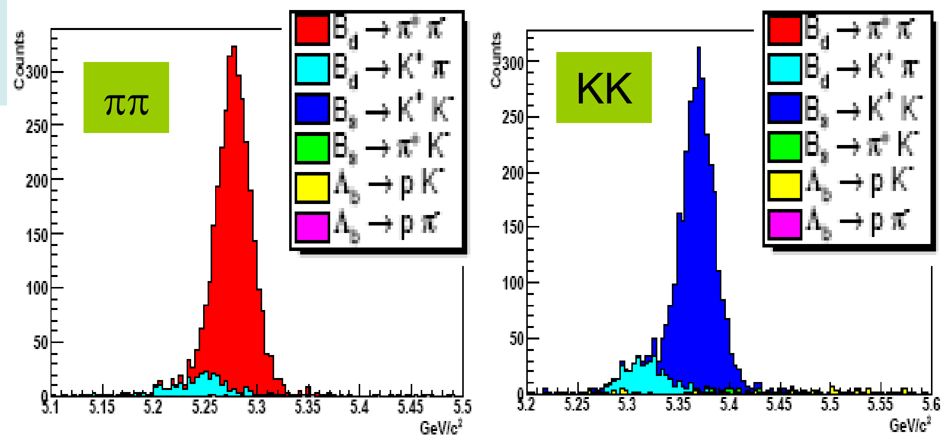
$$A_f^{CP}(\tau) = \frac{A_f^{dir}\cos(\Delta m\cdot\tau) + A_f^{mix}\cdot\sin(\Delta m\cdot\tau)}{\cosh\left(\frac{\Delta\Gamma}{2}\cdot\tau\right) - A_f^{\Delta\Gamma}\cdot\sinh\left(\frac{\Delta\Gamma}{2}\cdot\tau\right)}$$

- 4 U-spin asymmetry observables:

$$A_{\pi\pi}^{dir}, A_{KK}^{dir}, A_{\pi\pi}^{mix}, A_{KK}^{mix}$$



RICH particle ID:



Mode	Sig. yield (untagged)	B/S
$B^0 \to \pi\pi$	36k	0.5
$B_s \to KK$	36k	0.15
$B^0 \to K\pi$	140k	< 0.06
$B_s \to \pi K$	10k	1.9

$2\ fb^{-1}$

γ $(de^{i\theta})_{\pi\pi,KK}$ Input: φ_d and φ_s

Weak Uspin constraint:

$d_{\pi\pi} = d_{KK} \pm 20\%$, $\theta_{\pi\pi}, \theta_{KK}$ indep.

Sensitivity	$2\ fb^{-1}$	$10\ fb^{-1}$
σ_γ (°)	10	5
$\sigma_{d_{\pi\pi}}$	0.18	0.09
$\sigma_{\theta_{\pi\pi}}$ (°)	9	5

Summary

- LHCb has a rich γ measurement program
  - Measurement from trees and loops with an aim to **combine and disentangle NP**
- **Trees**
  - **'Standard candle'** γ measurement
  - CLEO-c D decay constraints key to LHCb γ sensitivities **See C. Thomas talk**
  - Combined tree γ sensitivity: $\sigma_\gamma \sim$ **4-5** (2-3)^o 2 (10) fb^{-1} **LHCb-2008-031**
  - Other channels: $D \to K\pi\pi^0$, $D \to K_s KK$, $D \to K_s K\pi$, $B \to D^{(*)}K^{(*)}$, $B_s \to D_s^{(*)}K_1$ …
- **Loops**
  - Sensitive to **NP**
  - $B \to hh$ γ sensitivity: $\sigma_\gamma \sim$ **10** (5)^o 2 (10) fb^{-1}
  - Promising first studies of $B \to hhh$ $\sigma_\gamma \sim 5^o$ ($2fb^{-1}$) **G.Guerrer CKM 2008**
  - Other channels: $B_d \to KK$, $B_s \to \pi\pi$, $B_s \to K\pi\pi^0$…

1st LHC collisions Oct 2009 + 1st physics data early 2010

Backup Slides

(ADS) $B^{\pm} \to D^0(K\pi\pi\pi)K^{\pm}$

LHCb-2008-031

- $B^{\pm} \to D^0(K\pi\pi\pi)K^{\pm}$
  - 4 decay rates
- Integrate over all phase space
  - Coherence factor $R_{K3\pi}$(= 0-1)
  - $\delta_D^{K3\pi}$ – averaged over all amp

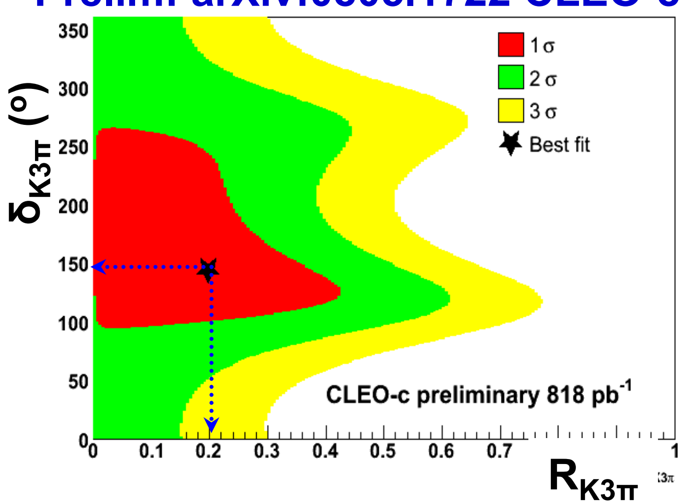
Mode	Sig. Yield	B/S
$B^+ \to D(K^+3\pi)K^+$	31k	0.7
$B^+ \to D(K^-3\pi)K^+$	530	2.3

$$\Gamma(B^+ \to D(K^-\pi^+\pi^+\pi^-)K^+) \propto r_B^2 + (r_D^{K3\pi})^2 + 2 r_B r_D^{K3\pi} R_{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} + \gamma)$$

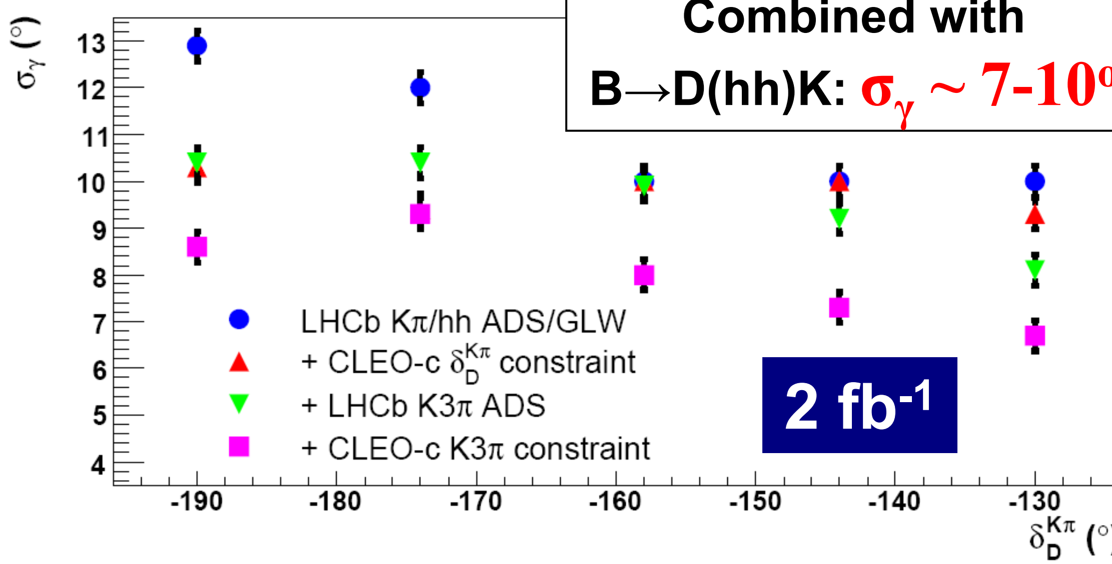
CLEO-c constraints

- $r_{K3\pi}$=0.0568 (PDG)
- Interference effects ∫PS – small
  - Global analysis + contribution to determination of r_B

Prelim: arXiv:0805.1722 CLEO-c



Combined with B→D(hh)K: $\sigma_\gamma \sim$ 7-10°

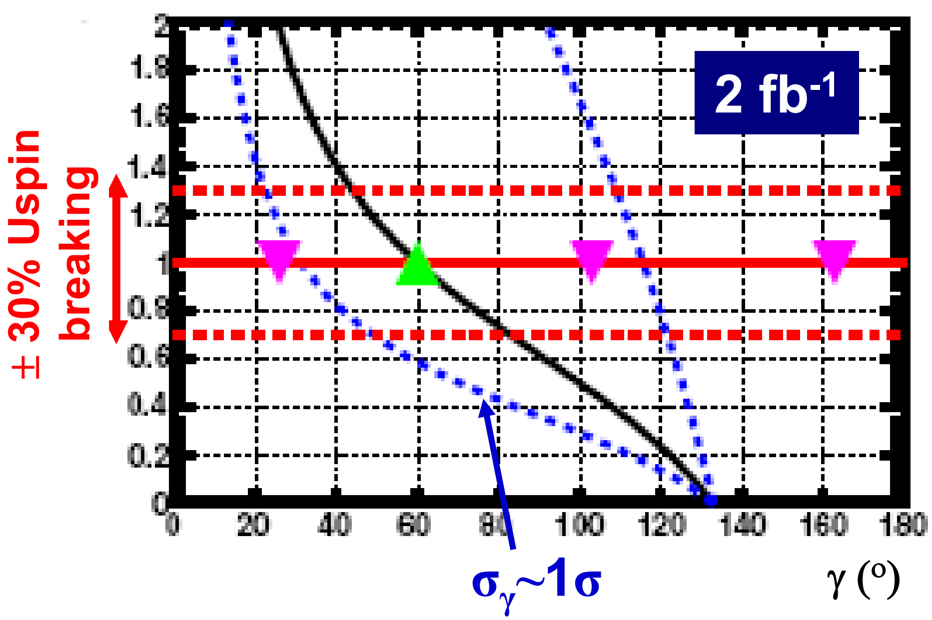


Time dependent $B^0 \to D\pi$

LHCb-2008-035

- Analogous to $B_s \to D_s K$
  - measure $\gamma + \varphi_d$ ($B^0 \to J/\psi K_s$) from decay amplitude ratio and mixing
- But…
  - 8 fold ambiguity ($\Delta\Gamma$ small)
  - Small interference

$$r_{D\pi} \sim -\lambda^2 r_{DK} \approx -0.02$$



- Can …
  - Compare with other channels (e.g. $B^0 \to D^*\pi$)
  - **Uspin approach**: $B^0 \to D\pi$ and $B_s \to D_s K$ Uspin symmetry

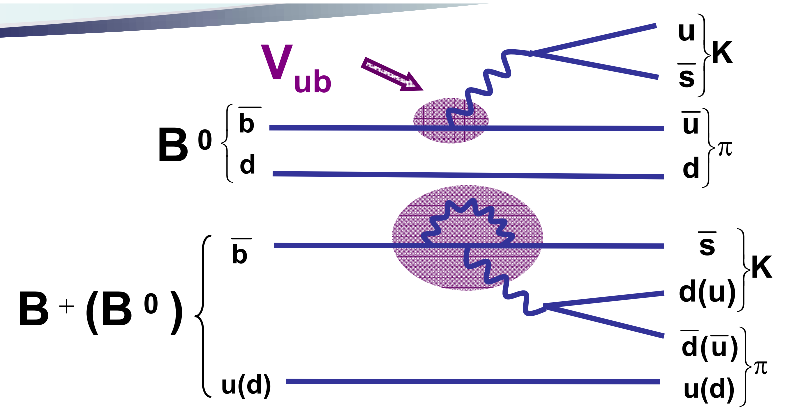
Mode	Sig. yield	B/S
$B_s \to D_s K$	6.2K	0.7
$B \to D\pi$	1340K	0.22

Input $\gamma = 60^o$ (±Stat. ±30% Uspin breaking)

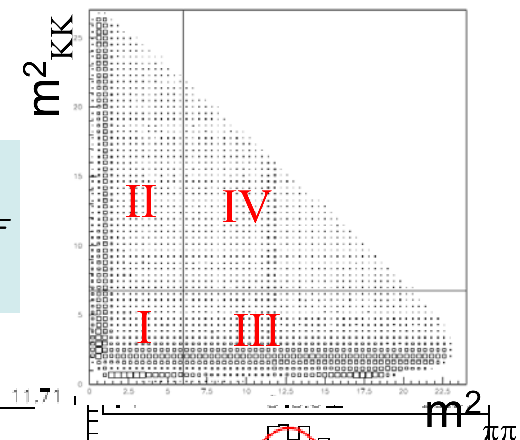
Sensitivity	2 fb^{-1}	10 fb^{-1}
σ_γ (°) for $\delta = 60^o$	$\pm 9^{+3}_{-4}$	$\pm 5 \pm 3$
σ_γ (°) for $\delta = 10^o$	$^{+30}_{-20}$ $^{+22}_{-10}$	$^{+12}_{-8}$ $^{+4}_{-15}$

$B^+ \rightarrow K^+\pi^+\pi^-$ and $B^0 \rightarrow K_s\pi^+\pi^-$

- Dalitz analysis to extract γ
  - Dominant K* resonance
- 2 step process
  - $B^+ \rightarrow K^+\pi^+\pi^-$ - penguin contribution
    - Dalitz anisotropy - CP asymmetry including phase differences
  - $B^0 \rightarrow K_s\pi^+\pi^-$ - Dalitz analysis
    - Input $B^\pm$ penguin contribution
    - Extract untagged B^0 tree contribution $\alpha\ e^{i\gamma}$

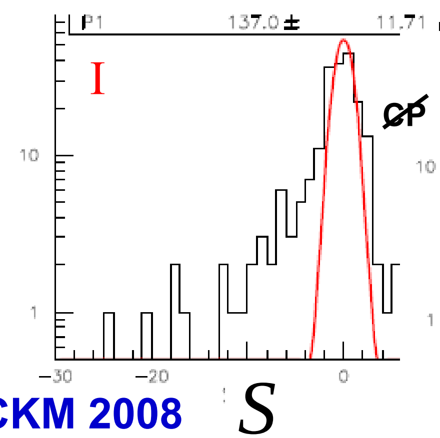


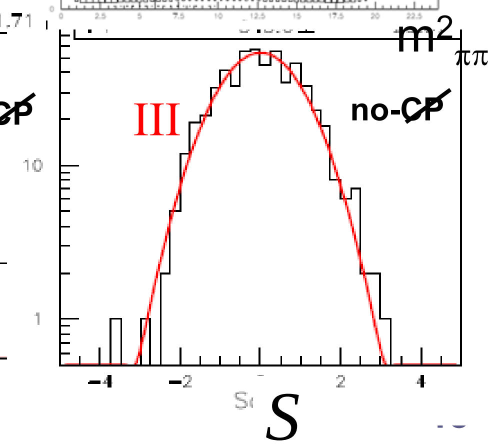
$$S_i = \frac{N_i^+ - N_i^-}{\sqrt{N_i^+ + N_i^-}}$$



Mode	Sig. Yield	B/S
$B^+ \rightarrow K\pi\pi$	494k	0.3
$B^0 \rightarrow K_s\pi\pi$	90k	t.b.d

$\sigma_\gamma \sim 5^o$ with $2fb^{-1}$





(Dalitz) Isobar model

- Both isobar models with:

# of resonances → N

amplitude+phase extracted from $D^{*+}, D^0\pi^+$ sample → $a_j e^{i\alpha_j}$

$$f(m_+^2, m_-^2) = \sum_{j=1}^{N} a_j e^{i\alpha_j} A_j(m_+^2, m_-^2) + b e^{i\beta}$$

Breit-Wigner + non-resonant

- Decay amplitudes:

$$A^- = f(m_-^2, m_+^2) + r_B e^{i(-\gamma+\delta)} f(m_+^2, m_-^2)$$

$$A^+ = f(m_+^2, m_-^2) + r_B e^{i(\gamma+\delta)} f(m_-^2, m_+^2)$$

  - $m_\pm = K_s\pi^\pm$ invariant mass
  - $f(m_\pm^2, m_m^2)$ Dalitz amplitudes

$$|A^-|^2 = |f(m_-^2, m_+^2)|^2 + r_B^2 |f(m_+^2, m_-^2)|^2 + 2 r_B \Re(f(m_+^2, m_-^2) f^*(m_-^2, m_+^2) e^{i(-\gamma+\delta)})$$

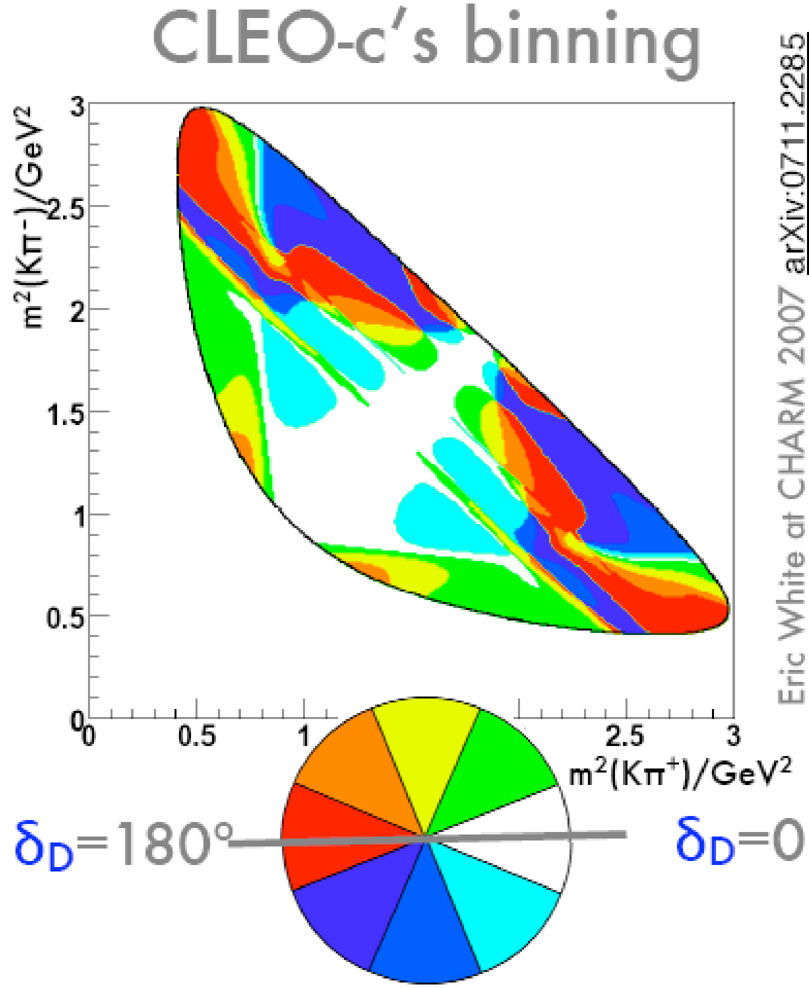
(Dalitz) Isobar model

doubly-Cabbibo suppressed

Resonance	BABAR			BELLE		
	a_r	ϕ_r (°)	F_r	a_r	ϕ_r (°)	F_r
$K^*(892)^-$	1.781	131.0	0.586	1.621	131.7	0.612
$K_0^*(1430)^-$	2.45	-8.3	0.083	2.15	-11.3	0.074
$K_2^*(1430)^-$	1.05	-54.3	0.027	1.11	-39.5	0.022
$K^*(1410)^-$	0.52	154	0.004	0.22	120	0.001
$K^*(1680)^-$	0.89	-139	0.003	2.34	110	0.004
$K^*(892)^+$	0.180	-44.1	0.006	0.154	-42.3	0.006
$K_0^*(1430)^+$	0.37	18	0.002	0.52	89	0.004
$K_2^*(1430)^+$	0.075	-104	0.000	0.23	-97	0.001
$K_2^*(1410)^+$	–	–	–	0.35	-107	0.001
$K_2^*(1680)^+$	–	–	–	1.3	87	0.001
$\rho(770)$	1 (fixed)	0 (fixed)	0.224	1 (fixed)	0 (fixed)	0.216
$\omega(782)$	0.0391	115.3	0.006	0.0310	113.4	0.004
$f_0(980)$	0.482	-141.8	0.061	0.394	-153	0.049
$f_0(1370)$	2.25	113.2	0.032	1.25	69	0.011
$f_2(1270)$	0.922	-21.3	0.030	1.32	-12	0.015
$\rho(1450)$	0.52	38	0.002	0.89	1	0.004
σ	1.36	-177.9	0.093	1.57	-146	0.098
σ'	0.340	153.0	0.013	0.23	-150	0.006
Non-res.	3.53	128.0	0.073	3.8	157	0.097

(Dalitz) Model independent

- Plot shows 8 bins of Belle
- δ_D phase values measured from CLEO-c



J. Rademacker CKM 2008

Global γ sensitivity from trees

LHCb-2008-031

Decay modes considered:

- $B^{\pm} \to D^0 K^{\pm}$
  - $D^0 \to K\pi, KK, \pi\pi$
  - $D^0 \to K\pi\pi\pi$
  - $D^0 \to K_s\pi\pi$
- $B^0 \to D^0 K^{*0}$
  - $D^0 \to K\pi$, KK, $\pi\pi$
- t-dependent modes
  - $B^0 \to D\pi$
  - $B_s \to D_s K$

Input fit parameters:

γ - (60°)

r_B – magnitude ratio of $D^0 / \overline{D}^0$ diagrams (0.1)

δ_B – strong CP conserving phase (130°)

Analogues: r_{B^0} – (0.4)

δ_{B^0} – (Scan)

Standard approach: use σ_γ=20° with 2fb^{-1} in $B^0 \to D\pi$ to avoid large correlations between the two modes

Parameters for $D^0 \to K\pi, K\pi\pi\pi$:

$r_{K\pi}$, $r_{K3\pi}$ – Established (PDG)

$\delta_{K\pi}$(-158°), $\delta_{K3\pi}$(144°)

$R_{K3\pi}$ – coherence factor

→ CLEO-C

δ_{B^0} (°)	0	45	90	135	180
σ_γ for 0.5 fb^{-1} (°)	8.1	10.1	9.3	9.5	7.8
σ_γ for 2 fb^{-1} (°)	**4.1**	5.1	4.8	**5.1**	3.9
σ_γ for 10 fb^{-1} (°)	2.0	**2.7**	2.4	2.6	**1.9**

Global fit decay contributions

Contribution to γ in % from each mode with varying δ_{B^0}

Analysis	$\delta_{B^0} = 0^o$	$\delta_{B^0} = 45^o$
$B^{\pm} \to D^0(hh)K^{\pm}$, $B^{\pm} \to D^0(K3\pi)K^{\pm}$	25%	38%
$B^{\pm} \to D^0(K_s\pi\pi)K^{\pm}$	12%	25%
$B^0 \to D^0(hh)K^{*0}$	44%	8%
$B_s \to D_s K^{\pm}$	16%	24%
$B^0 \to D\pi$	3%	5%