Charm inputs to γ/ϕ_3 for the next decade

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6th International Workshop on the CKM Unitarity Triangle
6-10 September 2010
University of Warwick

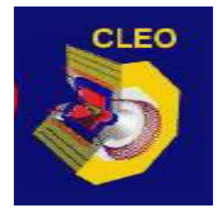
Experimental horizon

Beauty Experiments

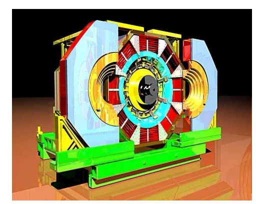
LHCb Taking data now!
1 fb^{-1} at sqrt(s) = 7 TeV in 2011 : 7-10° uncertainty comb ined
10 fb^{-1} at sqrt(s) = 14 TeV by 2016 : 1.9-2.7° combined
LHCb upgrade after 2016, 10x larger sample : < 1.4° combined

Belle II Commissioning in 2014
50 ab^{-1} at $\Upsilon(4S)$ by 2021 : 1.5° uncertainty combined

Charm at ψ(3770) Super B could come online in the next decade



CLEO-c to finish analysis on 818 pb^{-1} ≈ 5.4 million DDbar pairs

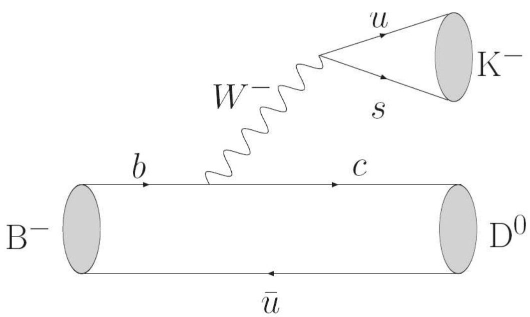


BESIII has collected 950 pb^{-1}
Expected to collect a total 10 fb^{-1} of open charm by 2016
Plenary Talk by Yangheng Zheng

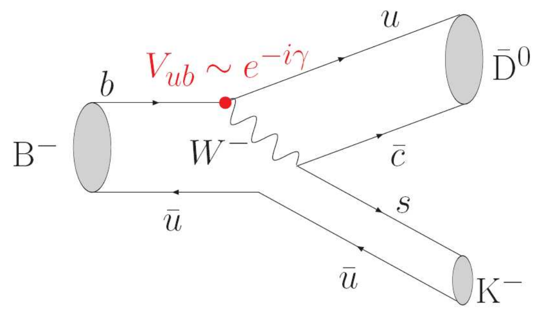
ψ(3770) run at a super B factory and a t-charm factory at Novosibirsk possible

γ/ϕ_3 from $B^\pm \longrightarrow DK^\pm$

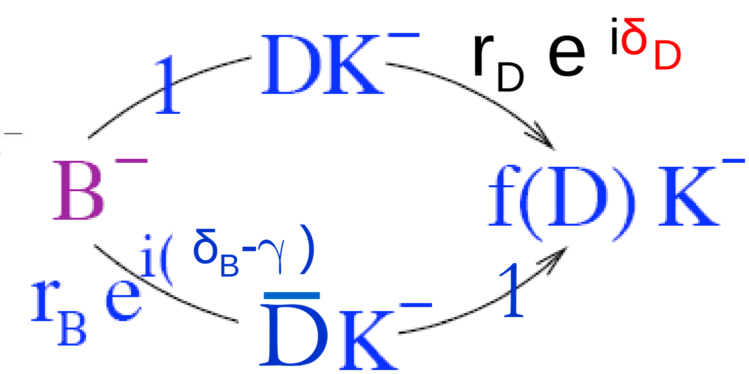
$B^- \longrightarrow D^0 K^-$



$B^- \longrightarrow \overline{D}^0 K^-$



$$\frac{< B^- \longrightarrow \overline{D}^0 K^- >}{< B^- \longrightarrow D^0 K^- >} = r_B e^{i(\delta_B - \gamma)}$$



- Extraction through interference between b→u and b→c transitions

- Require D^0 and $\overline{D}^0$ decay to a common final state, f(D). Some examples:

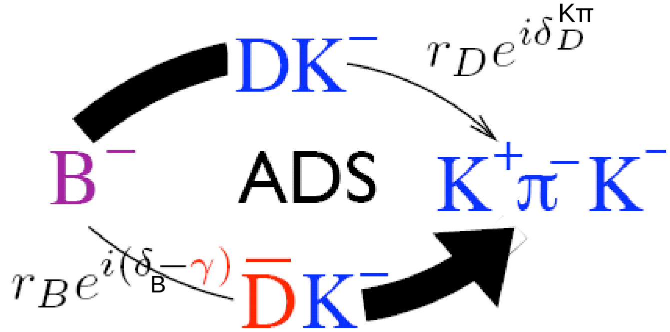
  $K^0_S hh$; $K\pi$; $K\pi\pi\pi$; $K\pi\pi^0$

- Comparison of B^- and B^+ rates allow γ to be extracted. But other parameters in game. In particular invaluable to have constraint on δ_D – the very quantity we can access in quantum-correlated D-decays !

r_D & δ_D analogous to B-decay quantities. For 3, 4-… body decays, these parameters vary over Dalitz space

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

Atwood-Dunietz-Soni (ADS) method uses Doubly Cabibbo suppressed decays to enhance γ/ϕ_3-sensitive interference terms



$r_D^{K\pi} \approx 0.06$ similar magnitude to $r_B \approx 0.1$

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

Coefficients of interference terms similar order to rest of expression

Method can be extended to multibody decays, e.g., Kπππ:

$\delta_D^{K3\pi}$ is the average strong phase difference over Dalitz space

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

Coherence factor $R_{K3\pi}$ value between 0 (incoherent) and 1 (2 body single amplitude limit)

Two body strong phase, $\delta_D^{K\pi}$

CLEO-c recently released preliminary update

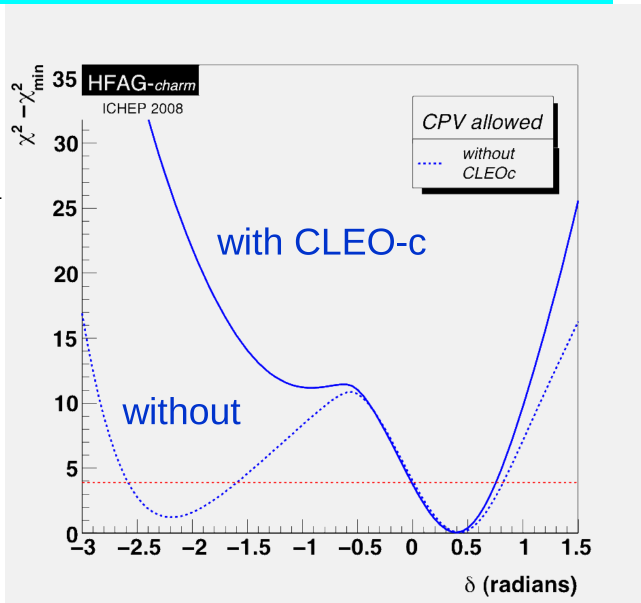
Previous: $\delta_D^{K\pi} = \left(22^{+11+9}_{-12-11}\right)^\circ$ **PRL 100 (2008) 221801**, 281 pb^{-1}

New: $\delta_D^{K\pi} = \left(15^{+11}_{-17} \pm 7\right)^\circ$ **Talk by Stefania Ricciardi**, 818 pb^{-1}

Preliminary

Parameter	Previous: PDG, HFAG, or CLEO	Fit: no ext. meas.	Fit: with ext. y, x, y'
y (10^{-2})	0.79 ± 0.13	$3.0 \pm 2.0 \pm 1.2$	0.635 ± 0.118
x^2 (10^{-3})	0.037 ± 0.024	$1.5 \pm 2.0 \pm 0.9$	0.022 ± 0.017
r^2 (10^{-3})	3.32 ± 0.08	$4.12 \pm 0.92 \pm 0.23$	3.32 ± 0.08
$\cos\delta$	1.10 ± 0.36	$0.98\ ^{+0.27}_{-0.20} \pm 0.08$	$1.15 \pm 0.16 \pm 0.12$
$\sin\delta$	---	$-0.04 \pm 0.49 \pm 0.08$	$0.55\ ^{+0.36}_{-0.40} \pm 0.08$
δ (°) [derived]	$22\ ^{+11}_{-12}\ ^{+9}_{-11}$	$0 \pm 22 \pm 6$	$15\ ^{+11}_{-17} \pm 7$

See talk by Stefania Ricciardi



Effect of PRL 100 (2008) 221801;PRD 78 (2008) 012001 (previous measurement) on world average

Precision relies on constraints from external measurements of mixing parameters

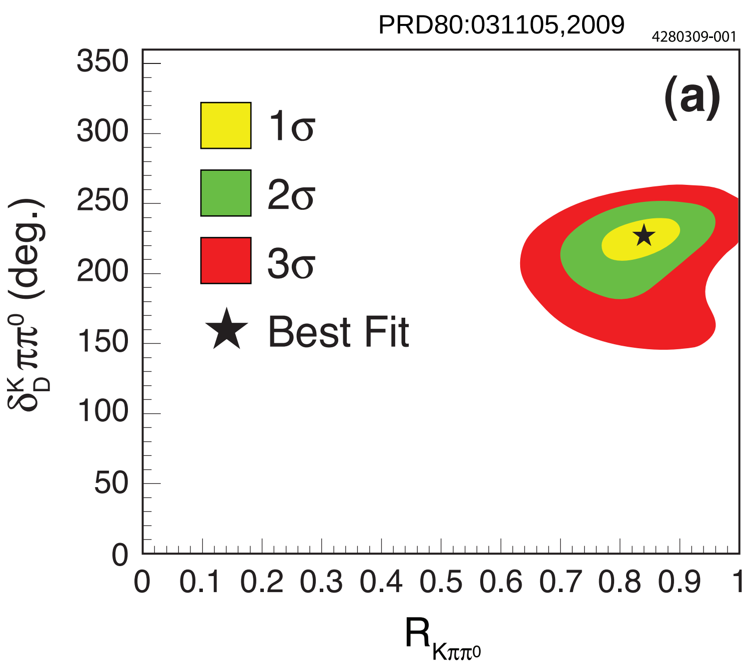
New result without the constraints: $\delta_D^{K\pi} = \left(0 \pm 22 \pm 6\right)^\circ$

Desirable to have higher precision independent measurement → BESIII

Multibody coherence and strong phase

ADS method extensible to multibody D^0 decay if coherence factor R_f and mean strong phase δ_D^f are independently measured.

CLEO-c measurements with **$K^-\pi^+\pi^0$** and $K^-\pi^+\pi^+\pi^-$
Other modes, e.g. $K_S K\pi$, can be treated similarly



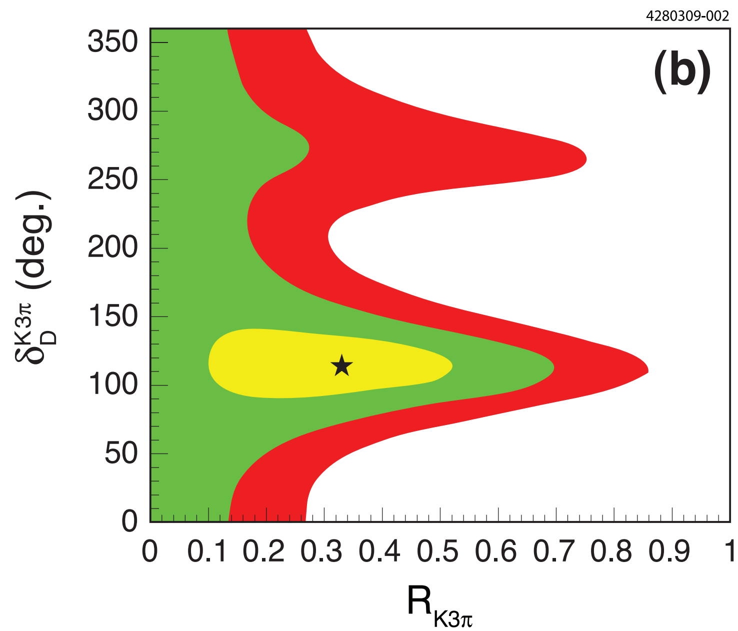
- $K^-\pi^+\pi^0$ highly coherent: $R_{K\pi\pi^0} = 0.84 \pm 0.07$
- Excellent for pseudo-2body ADS measurement
- Precision of parameters enhanced by external mixing constraints
- Sensitivity to γ in $K\pi\pi^0$ still under investigation
- Current precision of strong phase not likely to be limiting at LHCb: $\delta_D^{K\pi\pi^0} = \left(227\,^{+14}_{-17}\right)^\circ$
- Belle II and LHCb Upgrade will benefit from improved precision

Multibody coherence and strong phase

ADS method extensible to multibody D^0 decay if coherence factor R_f and mean strong phase δ_D^f are independently measured.

CLEO-c measurements with $K^-\pi^+\pi^0$ and **$K^-\pi^+\pi^+\pi^-$**

PRD80:031105,2009



Kπππ incoherent: $R_{K3\pi} = 0.33^{+0.26}_{-0.23}$

Thus insensitive to γ/ϕ_3 in an ADS analysis

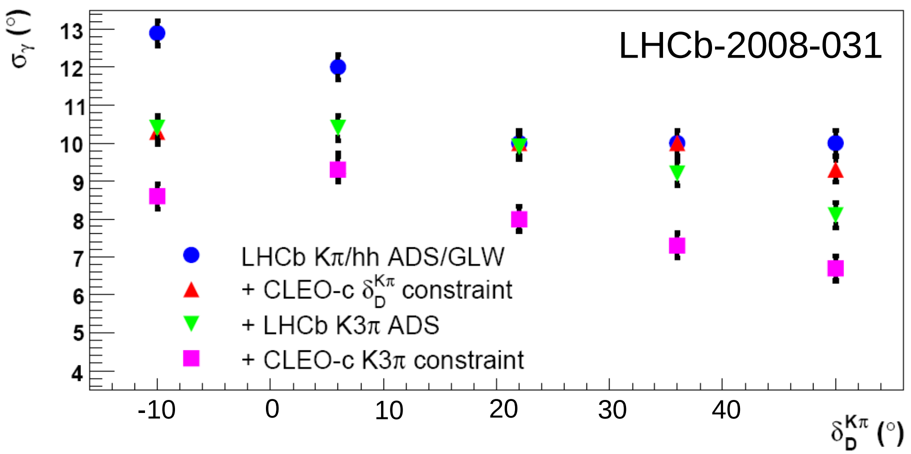
$$\Gamma \propto r_B^2 + (r_D^{K3\pi})^2 + 2 r_B r_D^{K3\pi} R_{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

Found to be useful due to enhanced sensitivity to r_B

For low coherence modes, power to extract γ requires model-independent binned method

Model-independent strong phase structure of K3π requires larger sample at BESIII

LHCb combined sensitivity



LHCb study of γ sensitivity with toy samples equivalent to 2 fb^{-1} in selected ADS/GLW* modes shows the striking benefit of independent measurements of strong phases δ_D

*GLW: Phys.Lett.B253:483, Phys.Lett.B265:172

An extension of the combined sensitivity study included Dalitz method with $K_S\pi\pi$

Trend suggests that sensitivity is dominated by B statistics with current charm constraints

LHCb-2008-03

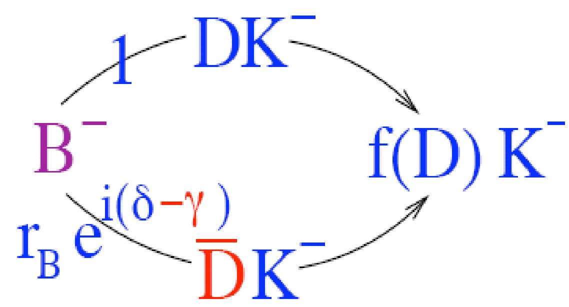
δ_{B^0} (°)	0	45	90	135	180
0.5 fb^{-1}					
σ_γ without CLEO-c constraints (°)	11.5	12.9	13.1	12.5	9.7
σ_γ with CLEO-c constraints (°)	9.0	12.0	10.7	11.1	8.6
2 fb^{-1}					
σ_γ without CLEO-c constraints (°)	5.8	8.3	7.8	8.4	5.0
σ_γ with CLEO-c constraints (°)	4.6	6.1	5.7	6.0	4.3
10 fb^{-1}					
σ_γ without CLEO-c constraints (°)	2.6	5.4	3.5	4.8	2.4
σ_γ with CLEO-c constraints (°)	2.3	3.5	2.9	3.2	2.2

Current strong phase precision for these modes satisfactory until Belle II/LHCb upgrade

(Does not include the potential benefit of a binned analysis with K3π)

Amplitude analyses

In multibody D decays, the amplitude modulus and strong phase vary across the Dalitz plot

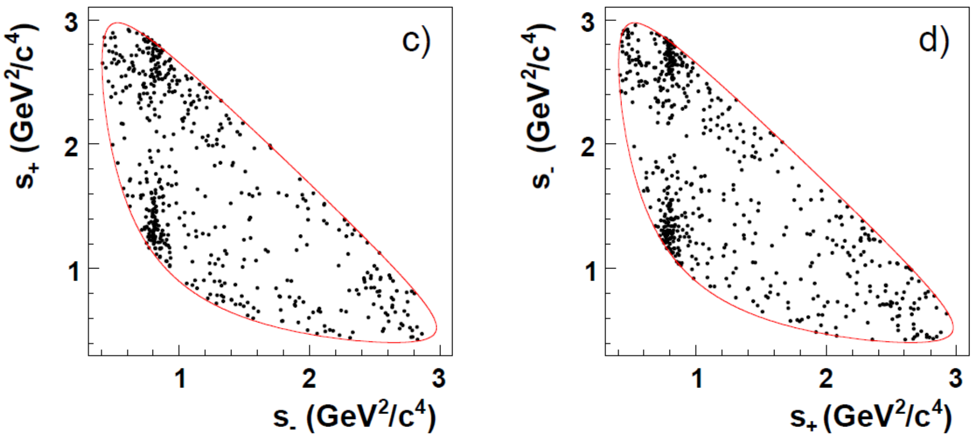


Extraction of γ/ϕ_3 by comparing Dalitz Plots of $B^- \to DK^-$ and $B^+ \to DK^+$

Requires independent understanding of Dalitz plot:

1. Precise amplitude model, or
2. Binned model-independent measurement of parameters

$B^\pm \to (D \to K^0_S \pi^+\pi^-)K^\pm$



BaBar,: arXiv:1005.1096 submitted to PRL

Use of a model incurs irreducible systematic uncertainty, e.g.,

- 3° BaBar $K_S\pi\pi$ and K_SKK
  arxiv:1005.1096 [hep-ex]
- 9° Belle $K_S\pi\pi$
  PRD81:112002,2010

Potential for improved models, but model-independent method shows great promise

Reminder: Model-independent method

Binned fit proposed by Giri *et al.* [PRD 68 (2003) 054018] and developed by Bondar & Poluektov [EPJ C 55 (2008) 51; EPJ C47 (2006) 347] removes model dependence by relating events in bin i of Dalitz plot to *experimental observables*.

$B^\pm$ events in bin i of Dalitz plot

Number of events for flavour-tagged D sample

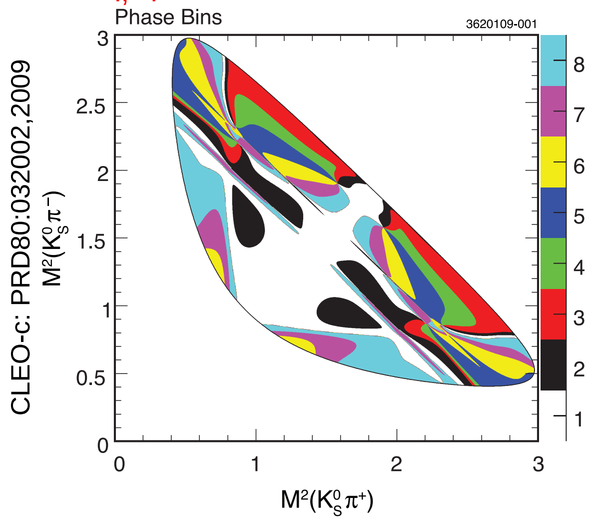
$x_\pm = r_B \cos(\delta_B \pm \gamma)$

$y_\pm = r_B \sin(\delta_B \pm \gamma)$

$$N_i^\pm = h\left(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}\left(c_i x_\pm \pm s_i y_\pm\right)\right)$$

c_i, s_i : average in bin of cosine, sine of strong phase difference

Can be measured *directly* in quantum correlated decays at ψ(3770)!



Choosing bins of *expected* similar strong phase difference maximises statistical precision

Small loss in statistical sensitivity of γ/ϕ_3 due to binning

No irreducible model uncertainty
Uncertainty due to statistical precision of bin parameters scales with size of ψ(3770) sample

First successes: $K_S\pi\pi$ and K_SKK

CLEO-c has measured the strong phase difference of D0 decays to $K_{S,L}\pi\pi$ and $K_{S,L}KK$ in bins of expected strong phase

Toy studies estimate uncertainty on potential measurement of γ/ϕ_3 at LHCb from CLEO-c precision:

$K_{S,L}\pi\pi$: 1.7-3.9° systematic (varies with bin choice)

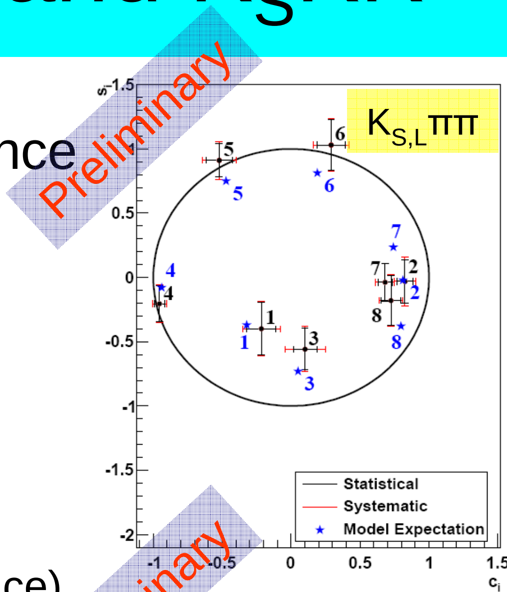
Estimated LHCb statistical uncertainties:
~15.0° with 2 fb $^{-1}$, ~7° with 10 fb $^{-1}$

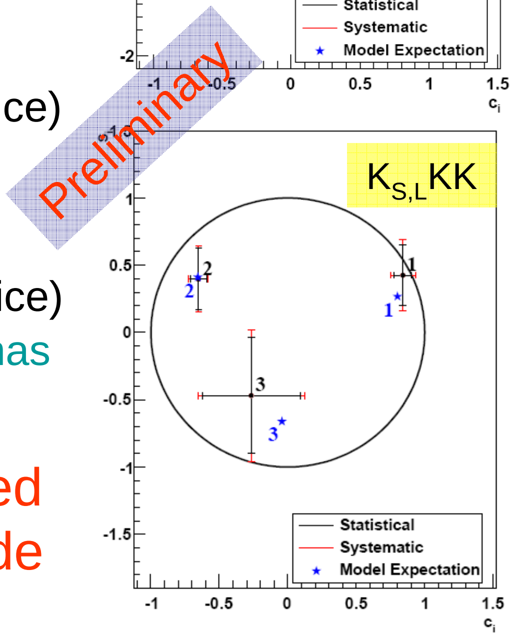
$K_{S,L}KK$: 3.1-4.5° systematic (varies with bin choice)

BaBar arXiv:1005.1096 [hep-ex] indicates that K_SKK has the same per-event sensitivity as $K_S\pi\pi$

Current precision sufficient for LHCb, but improved BESIII precision needed for Belle II/LHCb Upgrade

Belle II predicts 2° with 50 ab $^{-1}$ of $K_S\pi\pi$





CLEO-c: See talk by Stefania Ricciardi

Toward exploitation of more D decays

Measurements of γ/ϕ_3 with an amplitude analysis can be extended to many D decay modes to enhance sensitivity

- Provided that precise models or model-independent determinations of parameters are available!

- High BR modes analogous to $D^0 \rightarrow K_S\pi^+\pi^-$: $\pi^+\pi^-\pi^0$ and $K_S\pi^+\pi^-\pi^0$
  - Under investigation. Like $K_S\pi^+\pi^-$, current data samples likely sufficient for LHCb, but more precision required for Belle II/LHCb Upgrade.
- Suppressed modes: D0 $\rightarrow K_SK\pi$ and $K^+K^-\pi^+\pi^-$
  - Models under investigation. Model-independent measurements will probably require BES-III sample
- Low coherence ADS modes: $K\pi\pi\pi$
  - Certainly improved with large BES-III sample.

Conclusions

- More precise charm measurements are necessary to obtain long-term target precision of γ/ϕ_3.
  - Current precision of several inputs are sufficient for LHCb 10 fb^{-1}
- Model-independent parameter measurements for multibody Dalitz measurements of γ/ϕ_3 can and should be carried out for additional modes to maximize future sensitivity