Measuring γ at LHCb with Dalitz Methods and Global Sensitivity

- Measuring γ with $B^- \to D^0(K_S\pi\pi)K^-$
  - Yield and background expectations
  - Amplitude model fits
  - Model independent fits
- Other Dalitz Opportunities
- Global Sensitivity to γ with Tree-Level Processes at LHCb

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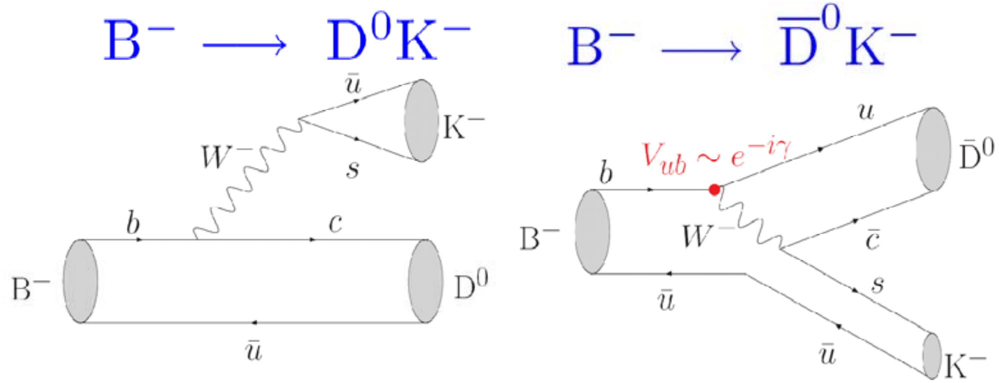
On behalf of the LHCb collaboration

Dalitz fits to extract γ

Measuring γ in $B^- \to D^0(K_S\pi\pi)K^-$

Can measure γ through the interference in $B^- \to (D^0/\overline{D}^0)K^-$ decays…



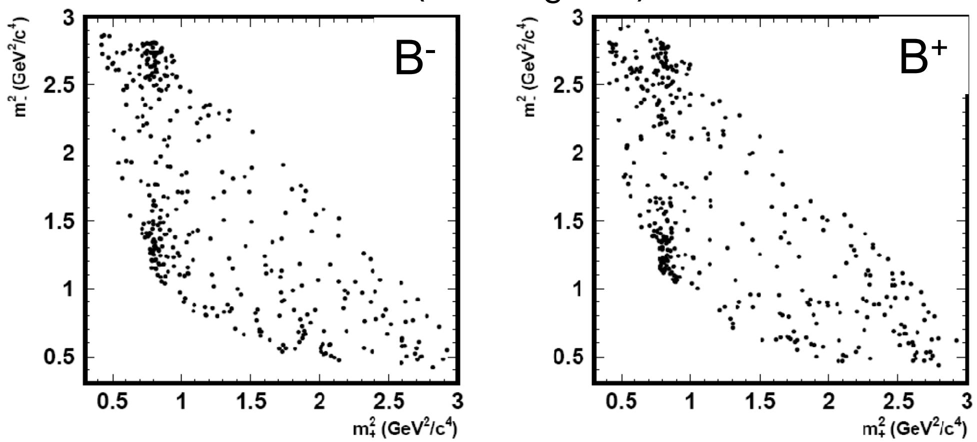
$$\frac{< B^- \longrightarrow \overline{D}^0 K^- >}{< B^- \longrightarrow D^0 K^- >} = r_B e^{i(\delta_B - \gamma)}$$

…provided D^0 and $\overline{D}^0$ decay into a common final state.

B-factories have pioneered Dalitz analysis of $K_S\pi\pi$.

How well will this method work at LHCb?

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



BELLE: arXiv:0803.3375

$B^- \to D^0(K_S\pi\pi)K^-$ Selection [LHCb-48-2007]

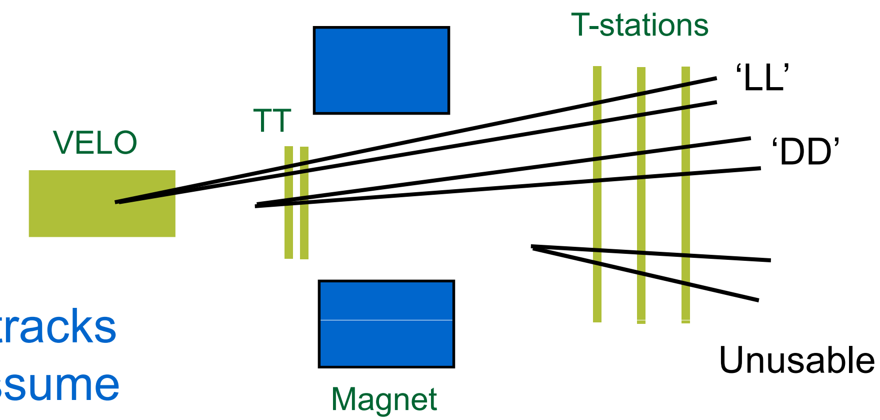
Hadronic state such as $B^- \to D^0(K_S\pi\pi)K^-$ is well suited to capabilities of LHCb

At earliest ('L0') trigger level hadron high-p_T trigger most important discriminator

Offline, signal separated from background through usual cuts, eg. :

p_T requirements; impact parameter significance w.r.t. primary-vertex; vertex chi2; RICH PID requirements; consistency of reconstructed B flight direction and direction of primary-vertex→B-vertex; mass cuts…

Only specific challenge w.r.t. other hadronic decays comes from K_S Reconstruction. After all offline cuts 'DD' make up ~2/3 of sample.



Ongoing work focused at finding 'DD' tracks with necessary speed in HLT. Here assume HLT selection is fully efficient.

Event Yields and Background

Mature analysis - numbers assumed for sensitivity studies

Indications from most recent simulation study

Expected yield in 2 fb^{-1}: 5000 events

This number looks rather stable

Background studied with inclusive $b\bar{b}$ events, & with specific $B^- \rightarrow D^0 \pi^-$ sample

Study with similar samples and with large bb MC sample enriched in 'dangerous' events.

- Combinatorics from $b\bar{b}$

  B/S < 0.7 at 90% CL

No indication to revise significantly this estimate ; also have learnt dangerous 'DK' component (see later) is not dominant

- Contamination from $B^- \rightarrow D^0 \pi^-$

  B/S ≈ 0.25

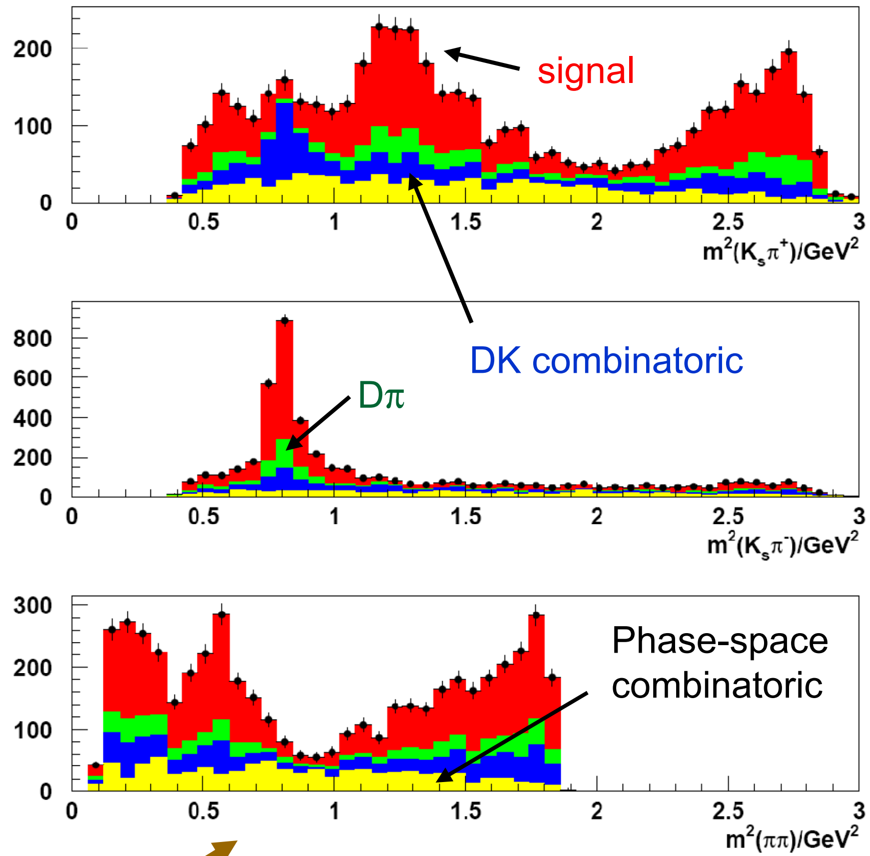
$B^- \rightarrow D^0 \pi^-$ background suppressed to < 10% through introducing max. momentum cut (good for RICH)

Acceptance and background classification

Dalitz acceptance rather flat and can be measured in data from $B^- \rightarrow D^0\pi^-$ events. Here model with polynomial for subsequent amplitude fit.

Make-up of background found in $b\bar{b}$ events largely unknown.
2 main possibilities:

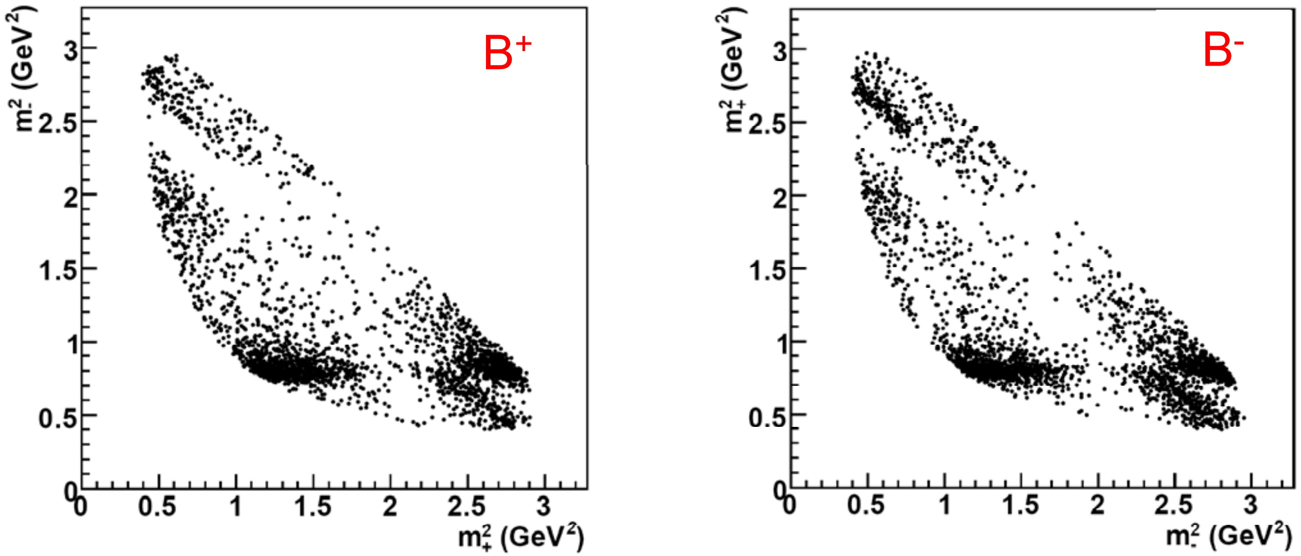
- True D with random/fake K ('DK combinatorial')
- Fake D ('Phase-space combinatorial')



Consider 3 scenarios with a 0.7 B/S coming from: 1) all 'DK combinatoric'; 2) half DK combinatoric, half phase-space ;3) all phase-space

Extracting γ

LHCb simulated sample for 2 fb^{-1} (with no background), CPV included:



The $K_S\pi\pi$ Dalitz plots contain a CP-violating contribution from the B^+ and B^- interference which is sensitive to γ. Consider two analysis methods:

- Unbinned fit based on amplitude model;
- Model independent binned fit using results from ψ(3770) on D decays

Amplitude Model Fit [LHCb-48-2007]

LHCb has followed example of B-factories and investigated potential of amplitude fit to extract γ from analysis of $K_S\pi\pi$ Dalitz plots from B^+ and B^-

Generate, and then fit, events assuming isobar model. Have considered both BaBar [PRL 95 (2005) 121802] and Belle [hep-ex/0411049] models. (Sensitivity results consistent, so here only report those from latter.)

Sensitivities for 2 fb^{-1} (ie. 5000 events)

Fit Scenario	σ_γ	σ_{r_B}	σ_{δ_B}
No background; flat acceptance	5.8°	0.010	6.0°
Dπ (B/S=0.24) + phase-space (B/S=0.7); real acceptance	9.1°	0.017	9.0°
Dπ + phase-space (B/S=0.35) + DK (B/S=0.35); real acceptance	9.8°	0.018	9.3°
Dπ + DK (B/S=0.7); realistic acceptance	10.7°	0.017	9.1°

Input values:

$\gamma = 60^o$; $\delta_B=130^o$; $r_B=0.10$

Fits work well, with any bias small compared with statistical uncertainty

Results scale with sample sizes & r_B in expected manner

So statistical error on γ of 9-11°. Total error will also include a model uncertainty – latest BaBar analysis [PRD 78 (2008) 034023] estimates this at 7°.

Binned Model-Independent Fit

Binned fit proposed by Giri *et al.* [PRD 68 (2003) 054018] and developed by Bondar & Poluektov [arXiv:0801.0840; hep-ph/0703267; 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

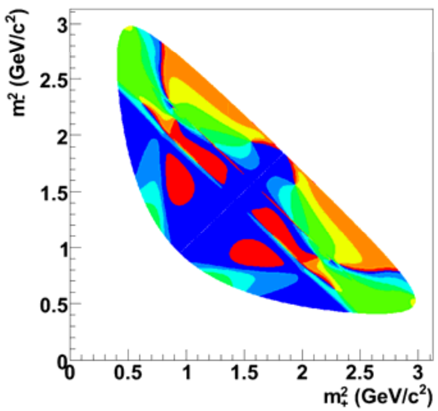
$x_\pm = r_B \cos(\delta_B \pm \gamma)$

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

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

c_i, s_i : average in bin of cosine, sine of strong phase between D^0 and $\overline{D}^0$

Can be measured *directly* in quantum correlated decays at ψ(3770)! Expect final CLEO-c results soon…



Choosing bins of similar strong phase difference maximises statistical precision

No model error! Instead: i) slight degradation in statistical precision; ii) residual error on γ from finite CLEO-c statistics:

- B & P [arXiv:0801.0840] estimate 5^o (used in our global fit)
- Latest CLEO-c estimate is $1\text{-}2^o$ [Asner, ICHEP 08]

Binned Fit: LHCb study [LHCb-2007-141]

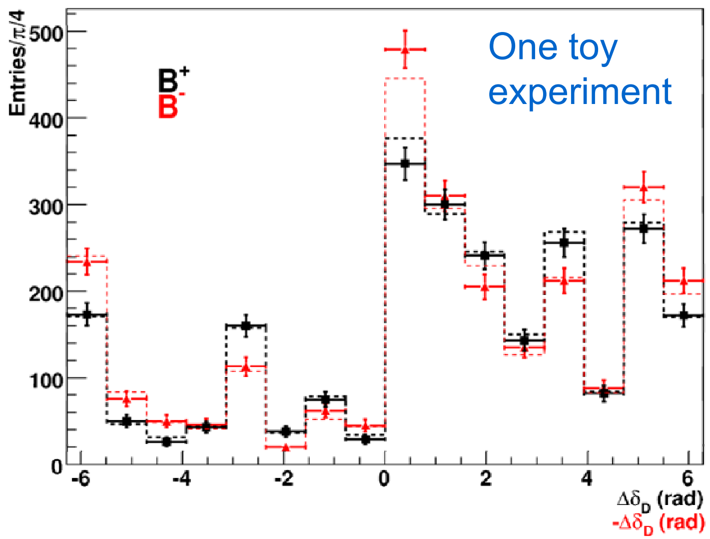
Study performed using BaBar isobar model [PRL 95 (2005) 121802], both for generation and to define 8 equally separated bins in strong phase difference.

Include acceptance variation & background.

Fit parameters $x^{\pm}$ & $y^{\pm}$, then transform to physics parameters

Sensitivities for 2 fb^{-1} (ie. 5000 events)

Fit Scenario	σ_{γ}	σ_{r_B}	σ_{δ_B}
No background; flat acceptance	7.9°	0.013	8.0°
Dπ (B/S=0.24) + phase-space (B/S=0.7); real acceptance	12.8°	0.020	12.9°
Dπ + phase-space (B/S=0.35) + DK (B/S=0.35); real acceptance	12.8°	0.020	12.6°
Dπ + DK (B/S=0.7); realistic acceptance	12.7°	0.020	12.7°

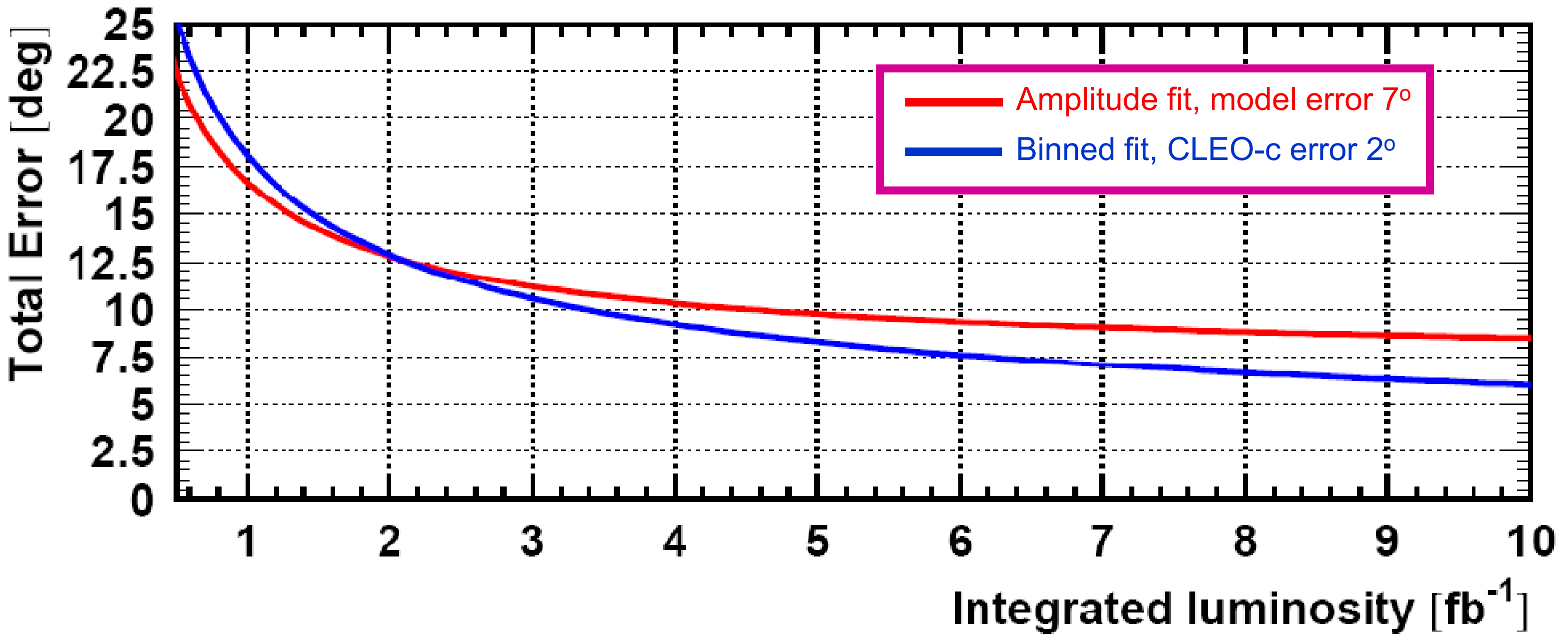


Compare with amplitude fit:

- Dπ+DK bckgd scenario 20% worse
- Results more robust against bckgd

Sensitivity to γ with $\int Ldt$

Calculate how total error evolves with time for amplitude fit & binned approach.

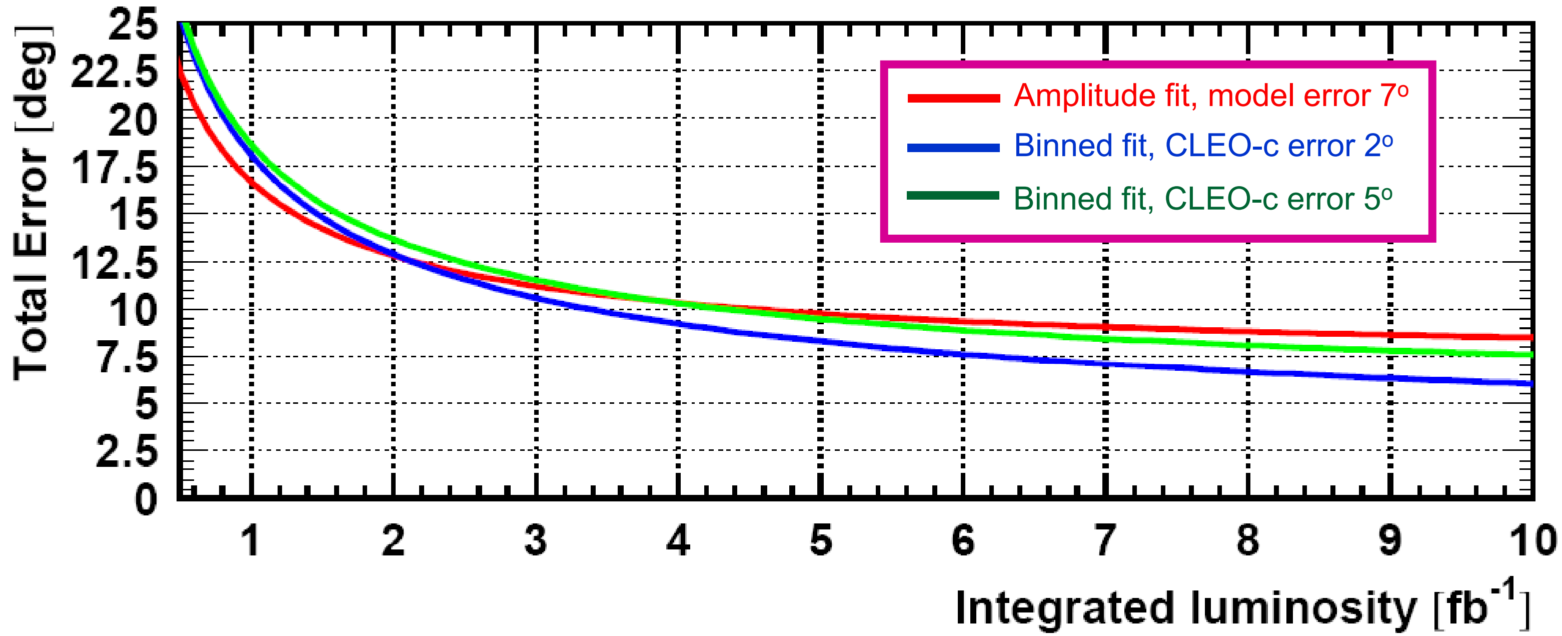


Error at end of baseline LHCb (10 fb^{-1}): 8.5° (amplitude model); 6.0° (binned).

These numbers neglect experimental systematics. For unbinned fit, resolution and acceptance effects have been considered and are expected to be small.

Sensitivity to γ with $\int Ldt$

In global fit studies (see later) a binned analysis is assumed with 5° CLEO error



This is historical, and – if we believe 'Asner ICHEP 08' – conservative.

This assumption gives a 10 fb^{-1} error on γ of 7.6° (new CLEO-c value → 6.0°).

Other Opportunities in Dalitz Studies

$B^- \to D^0(K_S\pi\pi)K^-$ approach can be extended to other multi-body modes.

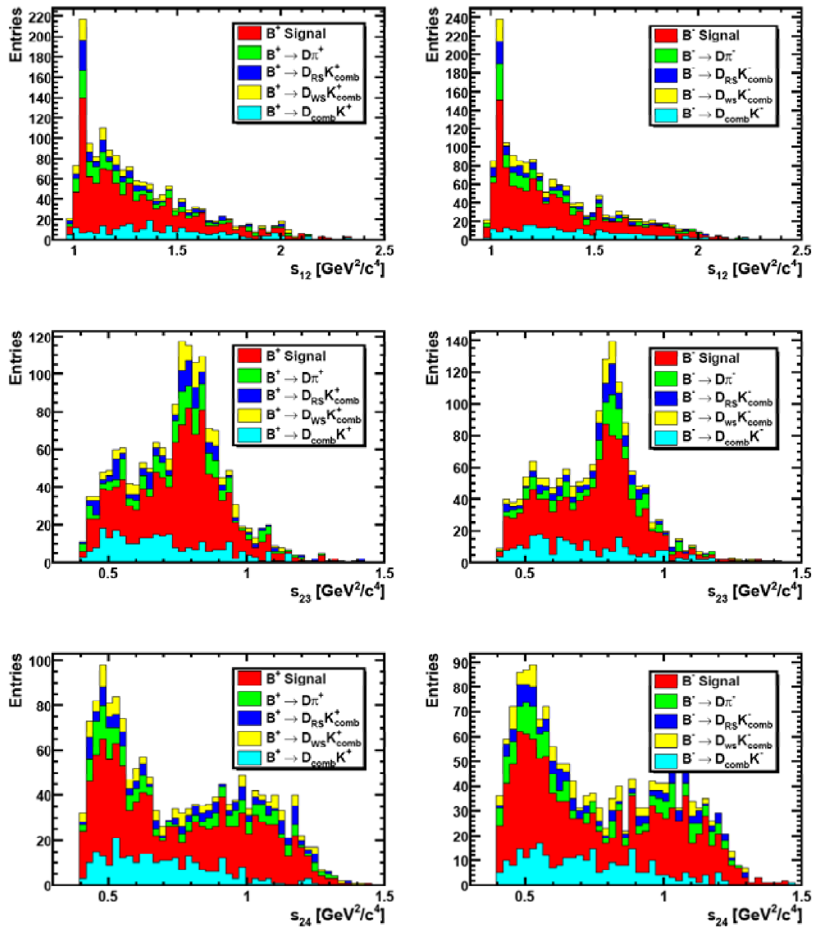
Some possibilities:

- $D^0 \to K_S KK$ (already exploited at BaBar [PRD 78 (2008) 034023]) or $D^0 \to K_S K\pi$
- $D^0 \to KK\pi\pi$: proposed in PLB 647 (2007) 400 and explored in LHCb in LHCb-2007-098. Same principle, but Dalitz space now requires 5-variables.

  Amplitude model now exists, [FOCUS, PRD B610 (2005) 225] but requires further development.

  LHCb error on γ : 18° in 2 fb^{-1}
- Perhaps Dalitz fits of suppressed ADS modes for $K\pi\pi\pi$ or $K\pi\pi^0$?

LHCb $KK\pi\pi$ study [LHCb-2007-098]



Combined Fit to γ

LHCb Global Sensitivity to γ

With $B \to DK$ methods perform global fit of common parameters. In addition consider results from B^0 and B_s time dependent analyses. (LHCb-2008-031)

Input measurements considered:

$B^- \to D^0 K^-$:

- $D^0 \to K\pi$, KK, $\pi\pi$ (LHCb-2008-011)
- $D^0 \to K\pi\pi\pi$ (LHCb-2007-004)
- $D^0 \to K_S\pi\pi$ (LHCb-2007-048)

$B^0 \to D^0 K^{*0}$

- $D^0 \to K\pi$, KK, $\pi\pi$ (LHCb-2007-050)

Time dependent measurements:

- $B^0 \to D\pi$ (LHCb-2007-044)
- $B_s \to D_s K$ (LHCb-2007-041)

Summary of event yields in 2 fb^{-1}

Channel	Signal	Background
$B^\pm \to D(K^\pm\pi^\mp)K^\pm$	56k	35k
$B^+ \to D(K^-\pi^+)K^+$	680	780
$B^- \to D(K^+\pi^-)K^-$	400	780
$B^+ \to D(K^+K^- + \pi^+\pi^-)K^+$	3.3k	7.2k
$B^- \to D(K^+K^- + \pi^+\pi^-)K^-$	4.4k	7.2k
$B^\pm \to D(K^\pm\pi^\mp\pi^+\pi^-)K^\pm$	61k	40k
$B^+ \to D(K^-\pi^+\pi^+\pi^-)K^+$	470	1.2k
$B^- \to D(K^+\pi^-\pi^+\pi^-)K^-$	350	1.2k
$B^0 \to D(K^+\pi^-)K^{*0}$, $\bar{B}^0 \to D(K^-\pi^+)\bar{K}^{*0}$	3.4k	1.7k
$B^0 \to D(K^-\pi^+)K^{*0}$	350	850
$\bar{B}^0 \to D(K^+\pi^-)\bar{K}^{*0}$	230	850
$B^0 \to D(K^+K^- + \pi^+\pi^-)K^{*0}$	150	500
$\bar{B}^0 \to D(K^+K^- + \pi^+\pi^-)\bar{K}^{*0}$	550	500
$B^\pm \to D(K^0_S\pi^+\pi^-)K^\pm$	5k	4.7k
$B_s, \bar{B}_s \to D_s^\mp K^\pm$	6.2k	4.3k
$B^0, \bar{B}^0 \to D^\mp\pi^\pm$	1,300k	290k

B→DK free parameters and constraints

Free parameters
(and values used toy MC studies)

Parameters common to $B^- \to DK^-$:

r_B - ratio of magnitude of diagrams (0.1)

δ_B - strong phase difference (130°)

$B^0 \to DK^{0*}$ analogues: r_{B^o} (0.40), δ_{B^o} (scan)

D decay parameters for Kπ, Kπππ:

$\delta_D^{K\pi}$ (-158°), $\delta_D^{K3\pi}$ (144°) - strong phase differences ($r_D^{K\pi}$, $r_D^{K3\pi}$ well known)

$R_{K3\pi}$ - coherence factor

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

And of course γ (60°)

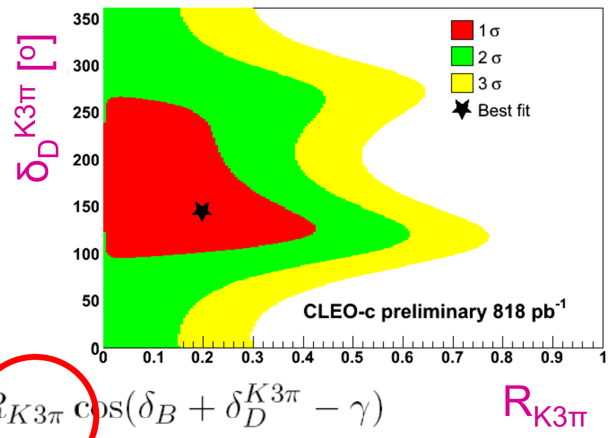
Constraints (from CLEO-c)

- PRL 100 (2008) 221801:

$$\delta_D^{K\pi} = (-158 \, ^{+22}_{-16})^o$$

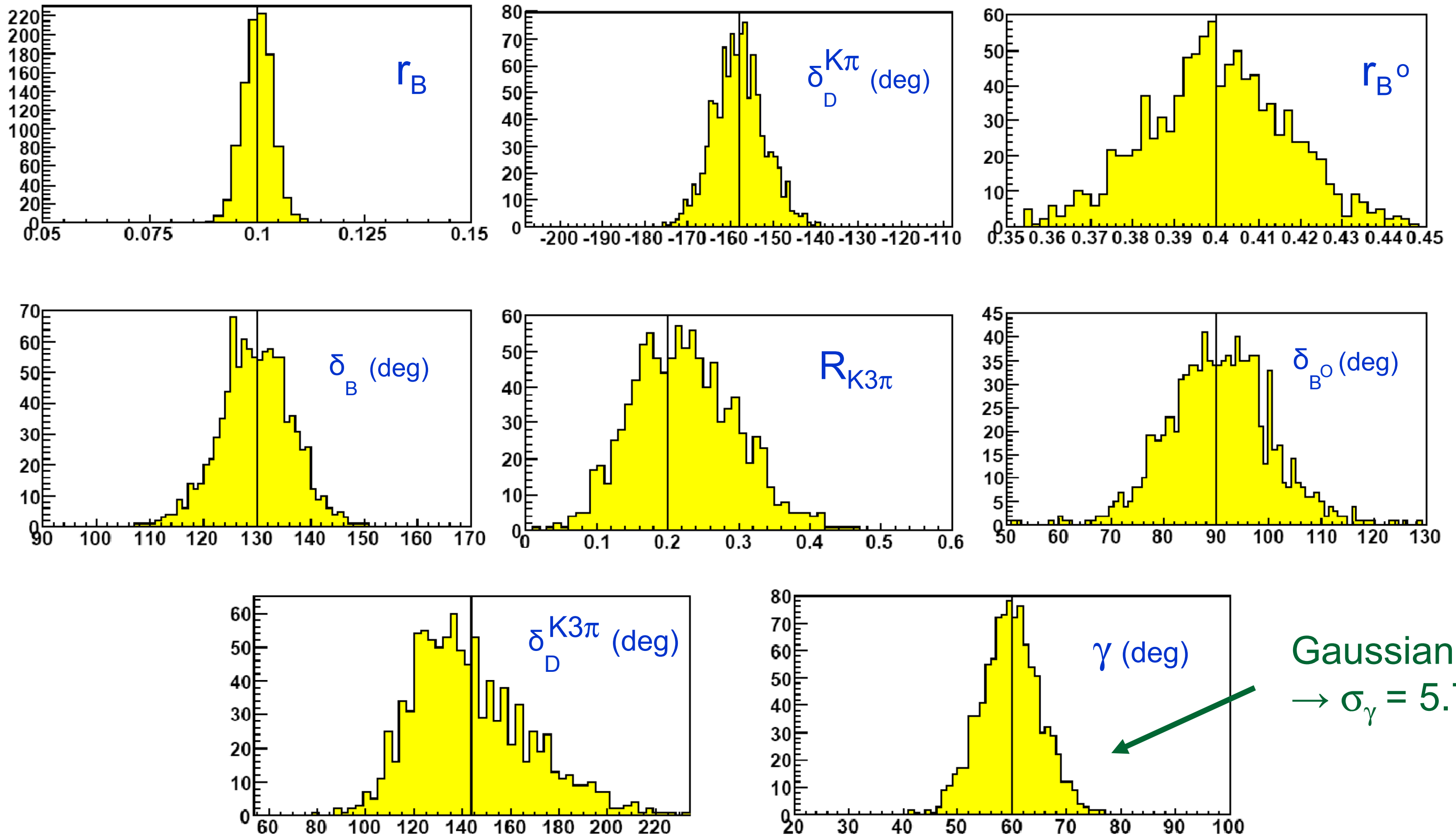
(ADS formalism requires -180° phase shift w.r.t. published result)

- Preliminary: arXiv:0805.1722



Fitted B→DK parameters for many 2fb^{-1} experiments

In general Gaussian – tails less pronounced than in fits to individual modes.

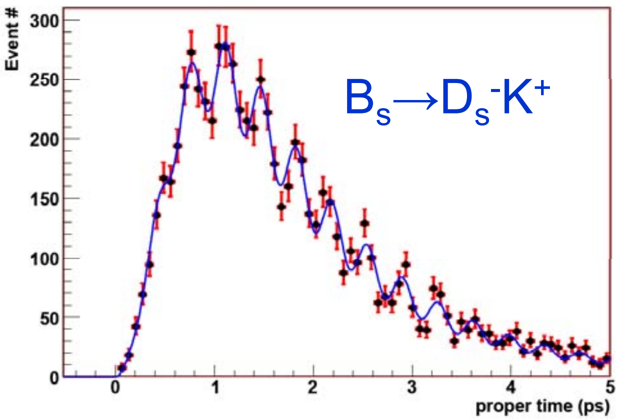


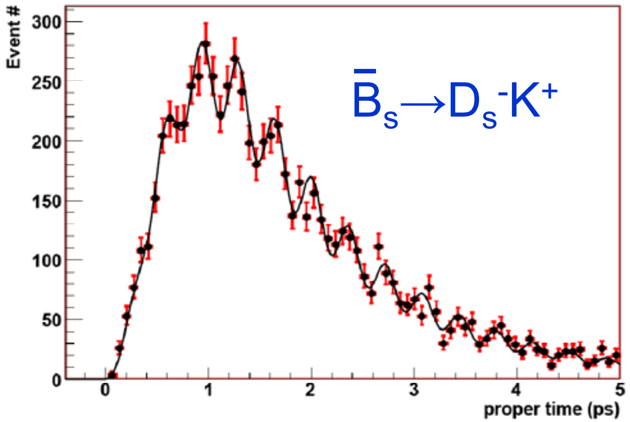
Gaussian fit
→ $\sigma_\gamma = 5.7^o$

Include Time Dependent CP Measurements

Add results from time dependent CP-measurements (see Carbone talk):

$B_s \to D_s K$ very powerful [LHCb-2007-041] :





2 fb^{-1} error on γ:

10.3°

As explained in Carbone talk, $B^0 \to D\pi$ is very promising, but in conventional analysis requires complementary measurement, eg. $B^0 \to D^*\pi$, or alternatively U-spin combination with $B_s \to D_s K$ to yield competitive results [LHCb-2008-035] .

Here take $B^0 \to D\pi$ uncertainty of 20° in 2 fb^{-1} (rather conservative)

Sensitivity to γ including all measurement

Results shown as function of δ_{B^o}, least well known parameter. Sensitivity of $B^0 \rightarrow D^0 K^{*0}$ improves by factor of two in going from $\delta_{B^o} = 45 \rightarrow 180^o$. Residual dependence remains in global fit, but diluted due to other measurements.

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

Weight (in %) of each contributing analysis with 2 fb^{-1} for two values of δ_{B^o}:

Analysis	$\delta_{B^0} = 0°$	$\delta_{B^0} = 45°$
$B^- \rightarrow D^0(hh)K^-$, $B^- \rightarrow D^0(K^\pm\pi^\mp\pi^+\pi^-)K^-$	25	38
$B^- \rightarrow D^0(K^0_S\pi^+\pi^-)K^-$	12	25
$B^0 \rightarrow D^0(hh)K^{*0}$	44	8
$B_s \rightarrow D_s^\mp K^\pm$	16	24
$B^0 \rightarrow D^\mp\pi^\pm$	3	5

Conclusions

- Measurement of γ with $B^- \to D^0(K_S\pi\pi)K^-$ as pioneered by B-factories appears a very promising strategy at LHCb. Model independent approach gives uncertainty of 6° over lifetime of baseline experiment.
- Dalitz strategy can be extended to other modes, eg: K_SKK, $KK\pi\pi$
- Combined fit of all tree-level γ measurements helps obtain Gaussian fit results for parameters, and yields best-possible overall precision.

  → γ uncertainty around 2° with 10 fb^{-1}
- Although real data may inevitably hold nasty surprises, and final stage of HLT is still under development, there are also promising other modes not yet included in average/study:

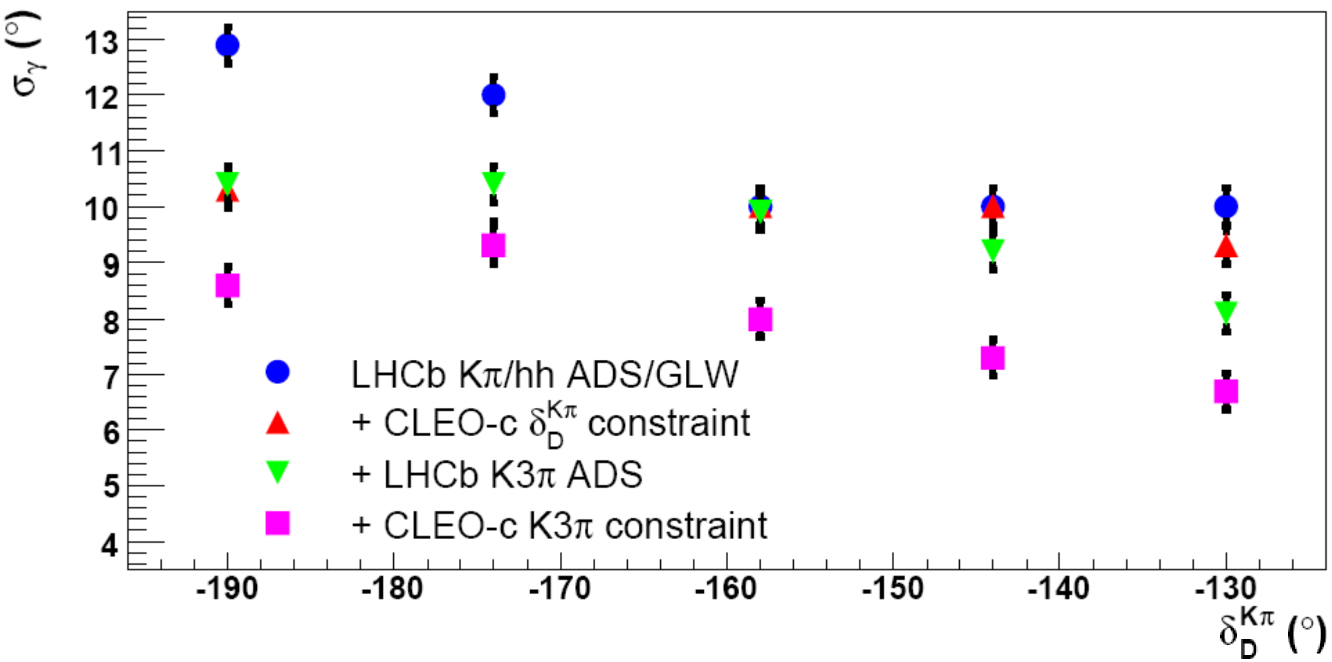
  → $D \to K\pi\pi^0$, K_SKK, $KK\pi\pi$ …, $B \to D^{(*)}K^{(*)}$ + other time dependent measurements, eg. $B^0 \to D^*\pi$, $B_s \to D_s(*)K_1$ + improved Information from other experiments (eg. c_i, s_i precision from CLEO-c)

The work will begin very soon – first experience in reconstructing real hadronic final states in the next couple of months !

Backup

ADS/GLW $B^{\pm}$ measurements alone: the role of the external constraints

2 fb^{-1} of data: $D^0(K\pi, KK, \pi\pi)K$ + $D^0(K\pi\pi\pi)K$ + CLEO-c constraints; scan in $\delta_D^{K\pi}$



External constraints important: equivalent to doubling of B dataset at $\delta_D^{K\pi} = -158^{\circ}$

(And external input *essential* for $D^0 \to K_S\pi\pi$ to avoid model dependent systematic)