CKM 2010, University of Warwick, UK

CKM 2010

WGV Summary
γ from B to charm decays

Robert Fleischer

and Stefania Ricciardi

on behalf of the speakers of WGV

12 Talks

Mainly experimental discussions: time-dependent and time-integrated measurements of γ

Introduction and conclusions by theorists

Jure Zupan, **The case for measuring gamma precisely**

RUBIN, Ada, **BaBar time-dependent gamma measurements**

ONUKI, Yoshiyuki, **Belle time-dependent gamma measurements**

GLIGOROV, Vladimir, **LHCb time-dependent gamma measurements**

RICCIARDI, Stefania, **Charm inputs to gamma measurements from CLEO**

HORII, Yasuyuki, **Belle time-integrated gamma measurements**

MARCHIORI, Giovanni, **BaBar time-integrated gamma measurements**

SQUILLACIOTI, Paola **Tevatron time-integrated gamma measurements and prospects**

WILLIAMS, J Michael, **LHCb time-integrated gamma measurements and prospects**

SPRADLIN, Patrick, **Charm inputs for the next decade**

POLUEKTOV, Anton, **Ultimate sensitivity on gamma/phi3 from B to DK**

FLEISCHER, Robert, **Extracting gamma from Bs to J/psi Ks**

WGV - γ from B to charm decays: what have we learnt?

1. The case for a very precise measurement of γ
2. New results from well-established methods
3. New methods (since CKM2008)
4. Future prospects (LHCb and beyond)

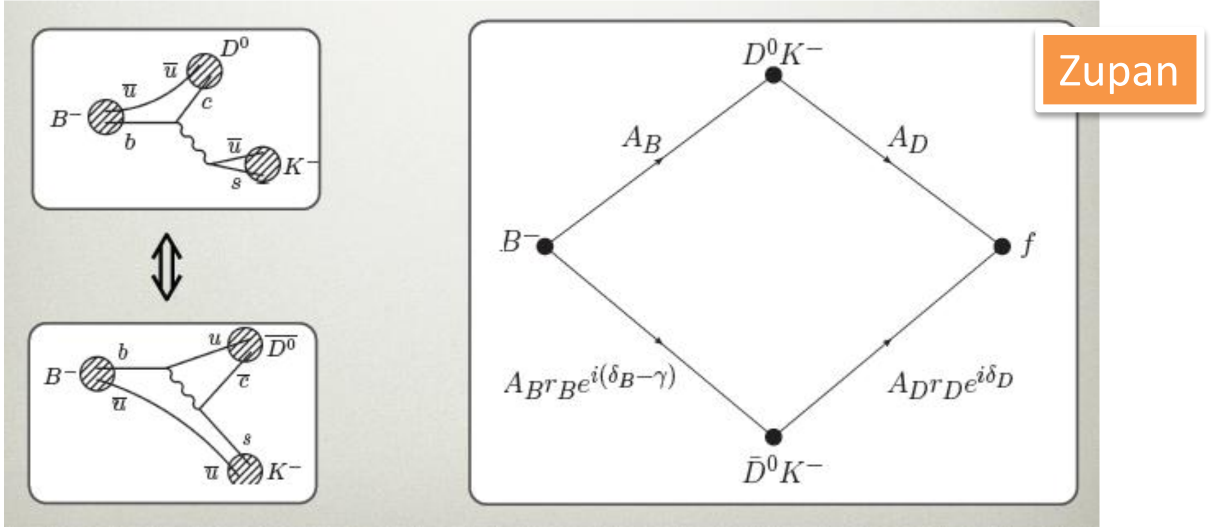
Measuring γ with B to charm decays: definitions

- γ is extracted from the interference between b → c and b → u transitions in decays of the B->DK family
  - tree-level amplitudes only
  - no penguin pollution, only one weak phase
  - Other B and D hadronic parameters in game, including B and D strong phases

r_B = relative magnitude of suppressed B-decay amplitude over favoured one

δ_B = *B*-decay strong phase difference

r_D and δ_D similarly defined



Several clean methods to extract all unknowns from data
(use combinations of several D modes or input from charm studies)

Jure Zupan

How clean is γ from B to charm decays?

Beyond the usual mantra:

Only tree-level amplitudes,

No theoretical uncertainties,

No NP contributions,

SM standard candle

Jure Zupan

Theory errors: D-mixing

[Grossman, Soffer, JZ, 2005]
[Bondar, Poluektov, Vorobiev, arXiv 1004.2350]

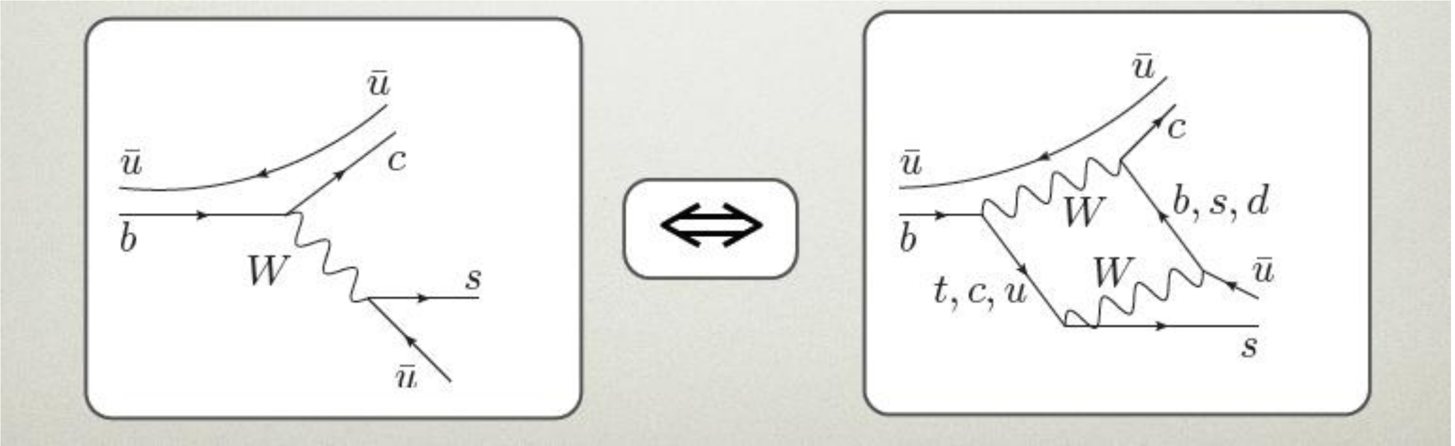
- Assuming SM:
  - D-mixing is CP conserving in SM, hence error on γ is small
    - if D-mixing neglected -> error $<1^o$
  - Most importantly: D-mixing effects can be included exactly if x_D and y_D precisely measured

NO irreducible uncertainty

Jure Zupan

Theory errors: electroweak corrections

- Only contribution which can change CKM structure is from box diagrams



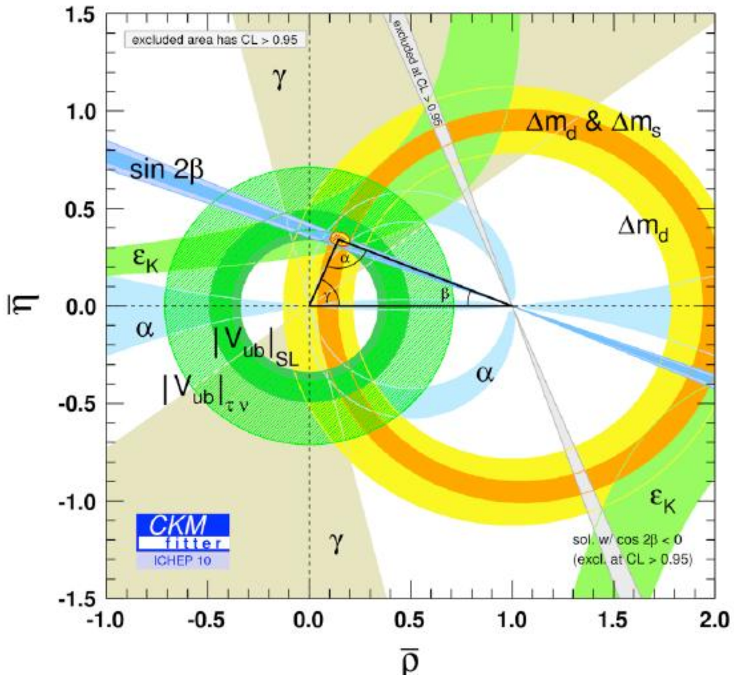
Shift in γ if different weak phase than leading order.

Largest shift:

$$\sim \frac{g^2}{16\pi^2} V_{cb} V_{cs}^* V_{cs}^* V_{us} \frac{m_c^2}{m_W^2} [A_B/(V_{cb} V_{us}^*)] \sim \frac{g^2}{16\pi^2} \frac{m_c^2}{m_W^2} A_B$$

irreducible theory error on γ is $\delta\gamma/\gamma \sim O(10^{-6})$

Current experimental precision



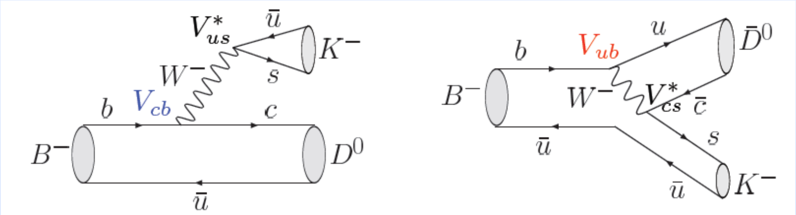
$\gamma_{CKMFITTER} = (71^{+21}_{-25})^o$

$\gamma_{UTFIT} \sim 11\text{–}12\,^o$ [see A. Stocchi, Joint Session]

- Error still very large
- Individual measurements more precise than CKM Fitter average
  - An issue here?
  - Not discussed at this workshop
  - Consensus: larger data sample will reduce disagreement between different statistical treatments
- Achieved precision much beyond B-factory design, thanks (mainly) to
  - B-factories excellent performance
  - GGSZ method (new on the scene at CKM2003)

Smallest theoretical uncertainty but largest experimental error among all UT constraints!

Results from well-established methods



1. Time-integrated methods

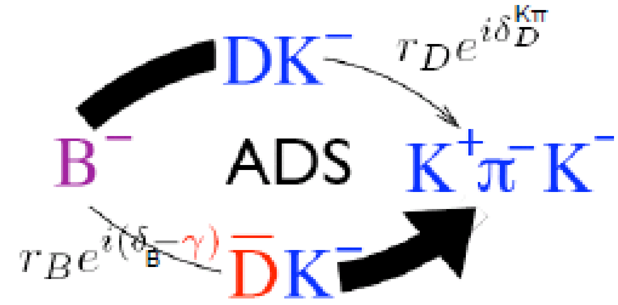
GLW : D to CP eigenstates
Gronau & London, PLB 253, 483 (1991);
Gronau & Wyler, PLB 265, 172 (1991)
ADS: D to pseudo-flavour specific states
Atwood, Dunietz, & Soni, PRL 78, 3257 (1997),
Atwood, Dunietz, & Soni, PRD 63, 036005 (2001)
GGSZ: D to 3-body decays
Giri, Grossman, Soffer, & Zupan, PRD 68, 054018 (2003)
Bondar, PRD 70, 072003 (2004)

2. Time-dependent methods

Several new results from B-factories and Tevatron
.... NO signs of "dusk"yet! On the contrary...

$B^{\pm} \to D^0(K\pi)K^{\pm}$ 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 $r_B \approx 0.1$

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

Coefficients of interference terms similar order to rest of expression

Method can be extended to multibody decays, e.g., $K\pi\pi\pi$:

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

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

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

09 Sep 2010 | Charm inputs to γ/ϕ^3 for the next decade
Spradlin, CKM 2010 WG V, Warwick | 4/13

NEW

FIRST evidence of suppressed ADS modes $B^- \rightarrow D(K^+\pi^-)K^-$ and $B^+ \rightarrow D(K^-\pi^+)K^+$ from Belle

HORII

PRELIMINARY

Simultaneous Fit for $B^- \rightarrow [K^+\pi^-]_D h^-$

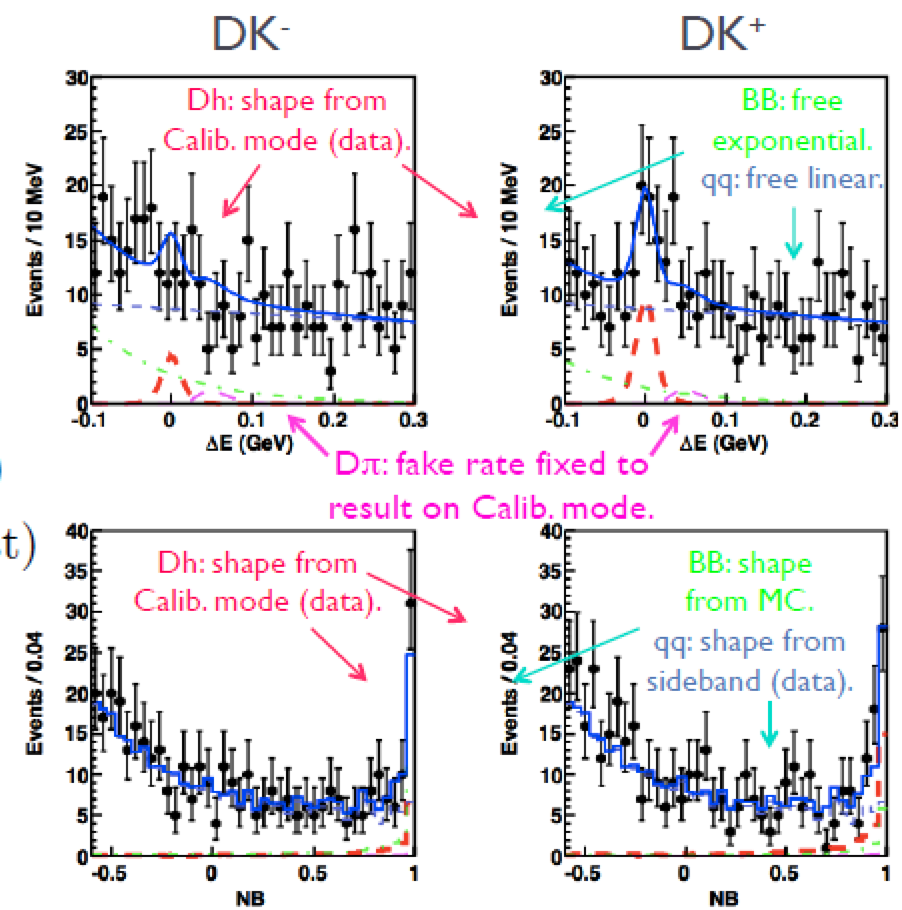
772 M BB

- Projections for h=K in signal regions are shown.
  - NB > 0.5
  - $|\Delta E| < 0.04$ GeV
- The results (R_{DK} in 10^{-2}) are

$$\mathcal{R}_{DK} = 1.62 \pm 0.42(\text{stat})^{+0.16}_{-0.19}(\text{syst})$$

$$\mathcal{A}_{DK} = -0.39 \pm 0.26(\text{stat})^{+0.06}_{-0.04}(\text{syst})$$

- First evidence is obtained with a significance 3.8σ (including syst).



NEW

ADS results from CDF (5 fb^{-1})

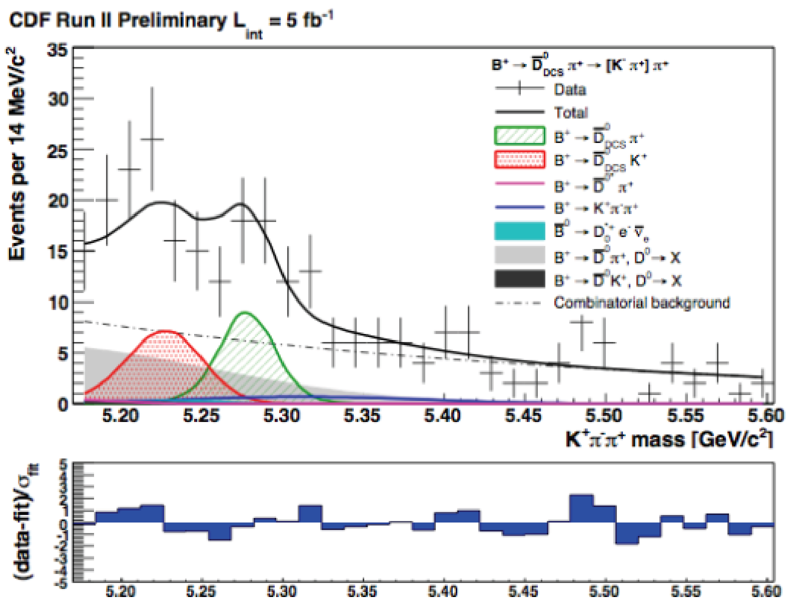
SQUILLACIOTI

- This supplements recently published first GLW analysis in hadron collisions within a CDF global program to measure angle gamma from trees.

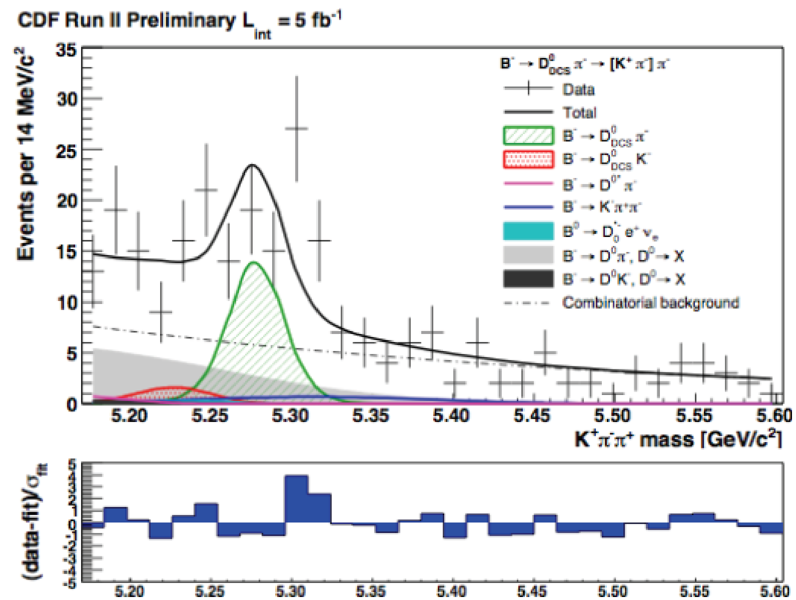
Yield ($B \rightarrow D_{DCS}K$) = 34 ± 14 (5 fb^{-1})
Yield ($B \rightarrow D_{DCS}\pi$) = 73 ± 16 (5 fb^{-1})

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

$B^+ \rightarrow \bar{D}^0_{DCS}\,\pi^+ \rightarrow [K^-\,\pi^+]\,\pi^+$



$B^- \rightarrow D^0_{DCS}\,\pi^- \rightarrow [K^+\,\pi^-]\,\pi^-$



SQUILLACIOTI

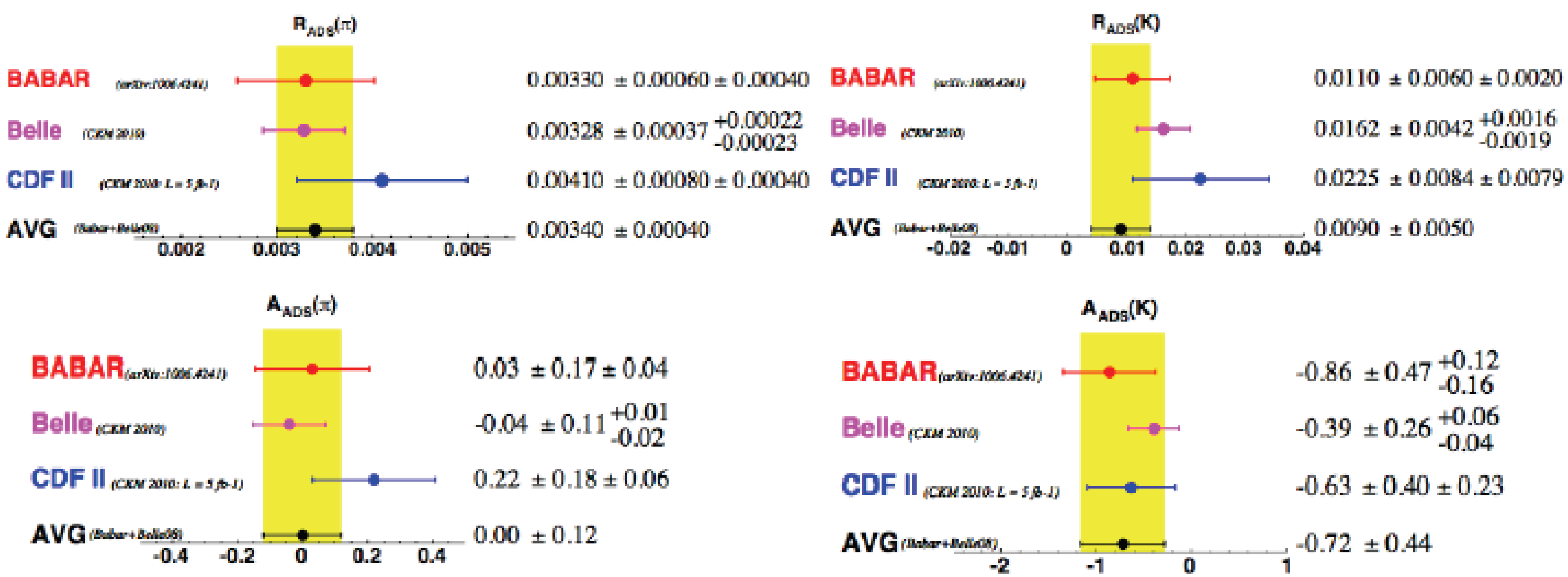
Results

$$R_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{CF}K^-) + N(B^+ \to D^0_{CF}K^+)}$$

$$A_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) - N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}$$

$$R_{ADS}(\pi) = 0.0041 \pm 0.0008(stat) \pm 0.0004(syst)$$
$$A_{ADS}(\pi) = 0.22 \pm 0.18(stat) \pm 0.06(syst)$$
$$R_{ADS}(K) = 0.0225 \pm 0.0084(stat) \pm 0.0079(syst)$$
$$A_{ADS}(K) = -0.63 \pm 0.40(stat) \pm 0.23(syst)$$

- First measurement of A_{ADS} and R_{ADS} at a hadron collider.
- Agrees with previous measurements from other experiments.



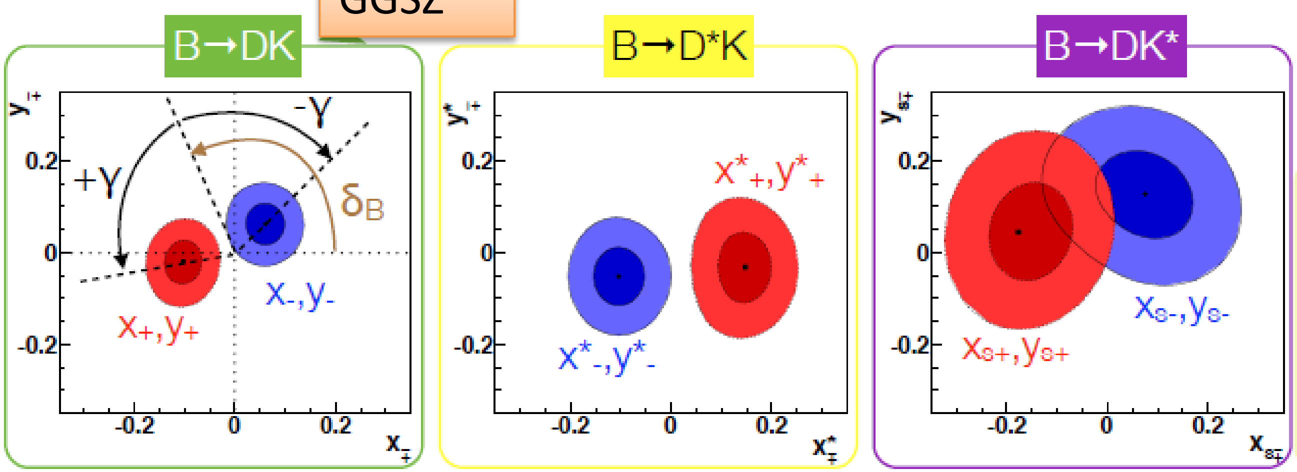
MARCHIORI

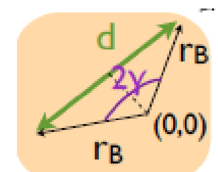
Time-integrated γ at BaBar

GLW, ADS, and GGSZ measurements updated recently using full Υ(4S) data set (468M BB pairs)

Measurement	CKM 2008 N(BB̄)	CKM 2008 pub. status	CKM 2010 N(BB̄)	CKM 2010 pub. status	changes
GGSZ $D^{(*)0}K^{(*)}$	383M	PRD 78, 034023 (2008)	468M	arXiv:1005.1096 accepted by PRL	updated Dalitz model, added DK* (D→KsKK)
GLW D^0K	382M	PRD 77, 111102 (2008)	467M	arXiv:1007.0504 accepted by PRD	improved fit technique, added CL scan of γ
ADS $D^{(*)0}K$	232M	PRD 72, 032004 (2005)	467M	arXiv:1006.4241 submitted to PRD	improved fit technique, better statistical analysis, CL scan of γ

GGSZ





$d=2r_B|\sin\gamma|\neq 0$
⇒direct CPV

Significance:
B→DK: 2.7σ
B→D*K: 2.8σ
B→DK*: 1.9σ
combined: 3.5σ

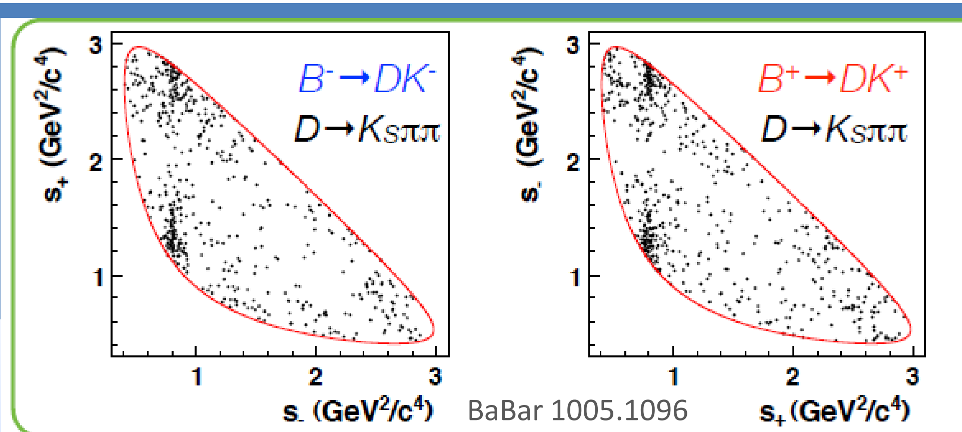
39.3% and 86.5% 2D CL contours

12

Reminder: GGSZ or "Dalitz" method

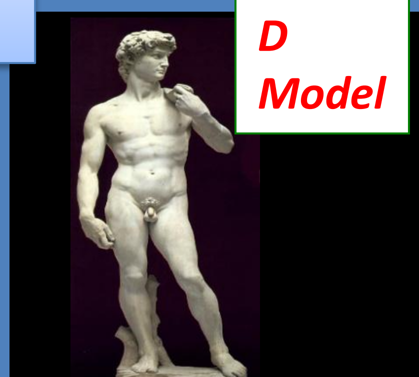
- Exploits different interference pattern in the two D to $K_S\pi\pi$ Dalitz plot (from B^+ and B^-)
- *CLASSIC APPROACH : amplitude fit to the B event densities in the D Dalitz plots*

Analysis main ingredients



$D\to K_S\pi\pi$ DP for B+ and B-

D Model



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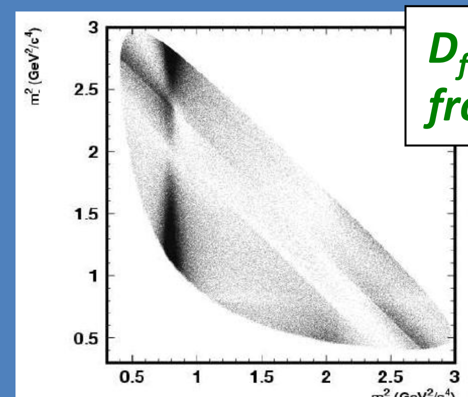


$D_{flav}\to K_S\pi\pi$ from $D^* \to D\pi$

$$A(B^\pm \to D(K_S\pi\pi)K^\pm) \propto f(m_\mp, m_\pm) + r_B e^{i(\delta_B \pm \gamma)} f(m_\mp, m_\pm)$$

- D-decay amplitude determined from a flavour-tagged sample from $D^{*+} \to D^0\pi^+$ using model assumptions

HORII
MARCHIORI

GGSZ results from Belle and BaBar on full data set

$$\phi_3 = 78.4^\circ \,{}^{+10.8^\circ}_{-11.6^\circ} \pm 3.6^\circ(\text{syst}) \pm 8.9^\circ(\text{model})$$

A. Poluektov et al., PRD 81, 112002 (2010)

Belle

657M BB

D($K_s\pi\pi$)K

$$\gamma(\text{mod}180^\circ) = (68 \pm 14 \pm 4 \pm 3)^\circ$$

stat syst model

Babar

468M BB

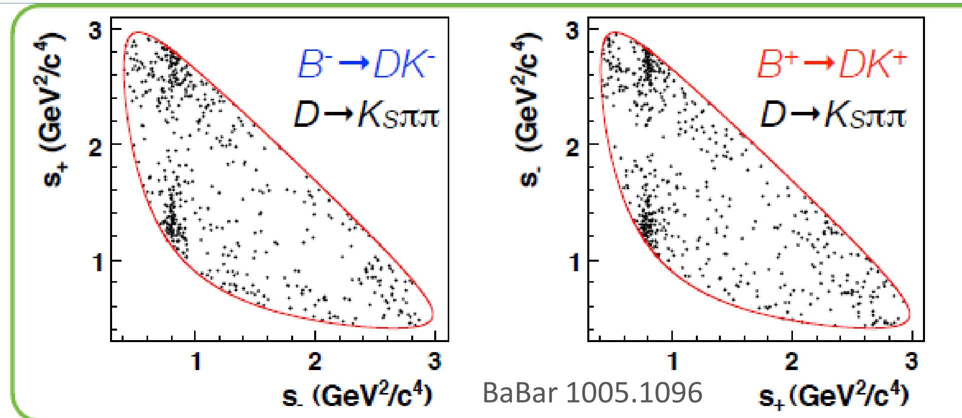
D($K_s\pi\pi$)K

D(K_sKK)K

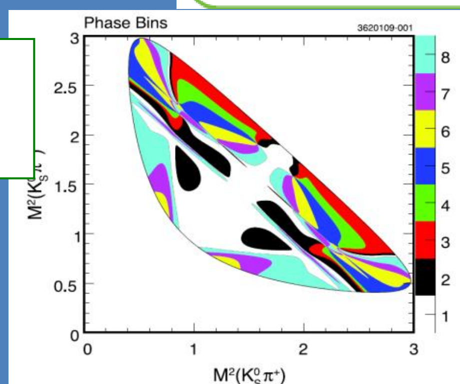
Still dominated by statistical error.
Improved model and much reduced model error from BaBar: 3 degrees.
Still model error hard to quantify .Will limit the precision of future high-statistics measurements using this method

From “classic” to “modern” art: model independent methods

[GGSZ, PRD 68(2003)054018, Bondar&Poluektov, EPJ C 47(2006) 347, EPJ C55 (2008) 51]



CLEO-c
Binned δ_D



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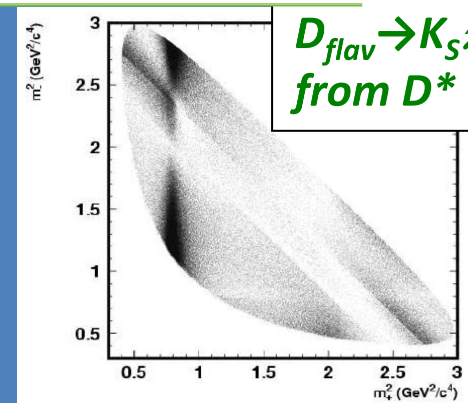


$D_{flav} \to K_S\pi\pi$ from $D^* \to D\pi$

Binned fit, no model assumptions: uses instead external binned information on δ_D from CLEO-c

SPRADLIN
RICCIARDI

CLEO-c results on δ_D

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)

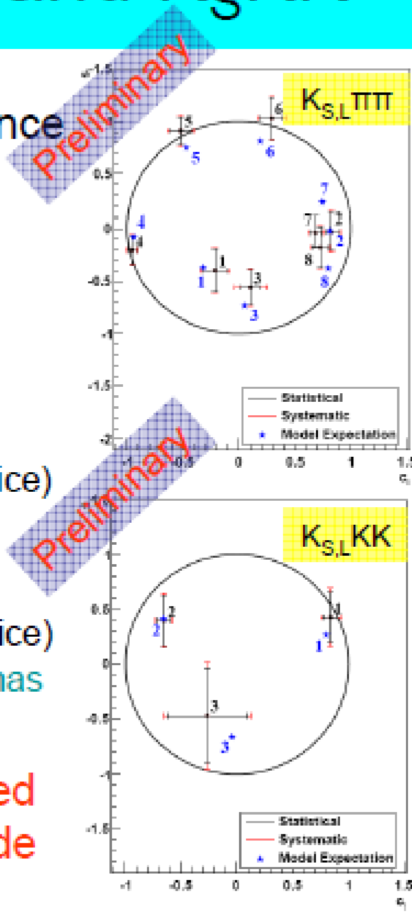
Estimated LHCb statistical uncertainties:
~15.0° with 2 fb^{-1}, ~7° with 10 fb^{-1}

$K_{S,L}KK$: 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

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Results from well-established methods – Part II

I. Time-integrated methods

II. Time-dependent methods

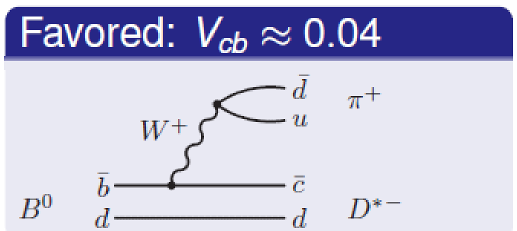
Sensitive to $\sin(2\beta_{(s)} + \gamma)$ via interference in decay w and w/o mixing.

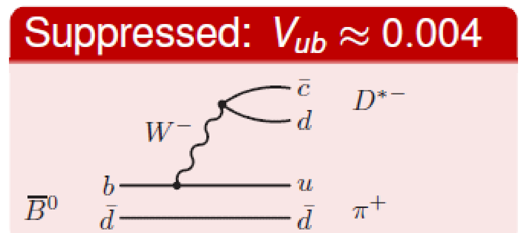
More results from B-factories...

Rubin

Time-dependent at BaBar

- Comprehensive review
- One on-going analysis $B^0 \rightarrow D^{0(*)}K_s$
- Several published measurements (to be updated to full data sample)
    1) Partial Reconstruction of B to $D^{*+}\pi^-$ (BaBar, PRD, 2005)
    2) Full Reconstruction of B to $D^{(*)+}\pi^-$ and $D^+\rho$- (BaBar, PRD, 2006)
    3) Dalitz plot analysis of B^0->$D^+K^0\pi$- (BaBar, PRD, 2008)





Extraction of sin(2β+γ) from 2) and 3) requires external constraint on r = ratio of suppressed over favoured amplitude (very small)

$$r = \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}} \frac{f_{D^*}}{f_{D_s^*}} \tan(\theta_C) \Rightarrow 0.015^{+0.004}_{-0.006} + 30\%$$

- 30% systematic to account from SU(3) breaking and factorization

ONUKI

Time-dependent: Belle

- Two recent results for $R_{D^*\pi}$
  1. Using isospin relations (Belle, PRL 2008)

$$R_{D^*\pi} = \sqrt{\frac{\tau_{B^0}}{\tau_{B^+}} \frac{2\mathcal{B}(B^+ \to D^{*+}\pi^0)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

$$R_{D^*\pi} < 0.051 (90\% \text{ C.L})$$

Dominated by statistical error on BF(B →D*π^0) (UL)

  2. Using SU(3) flavour symmetry assumptions

$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right) \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

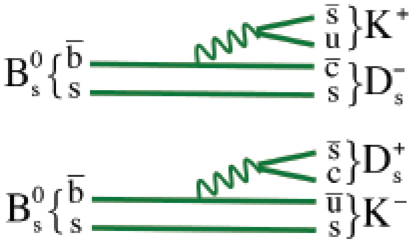
$R_{D^*\pi} = 1.58 \pm 0.15 \pm 0.10 \pm 0.03\%$ (stat. syst. th. error) PRD81(2010)031101

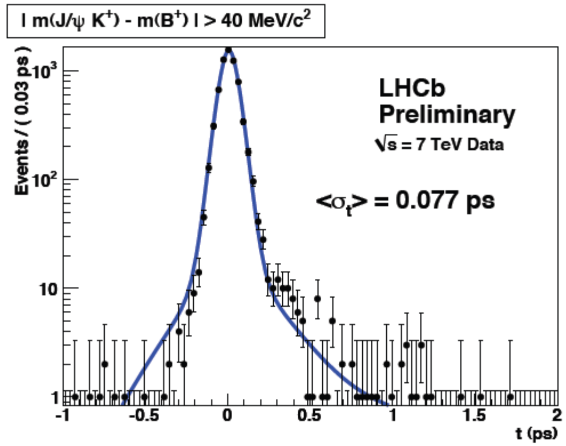
$R_{D\pi} = 1.71 \pm 0.11 \pm 0.09 \pm 0.02\%$ (stat. syst. th. error) arXiv:1007.34619 NEW

Most precise determinations but possible non-factorizable SU(3) breaking effects not completely accounted for in theory errors

Time-dependent: $B_s \to D_sK$ at LHCb

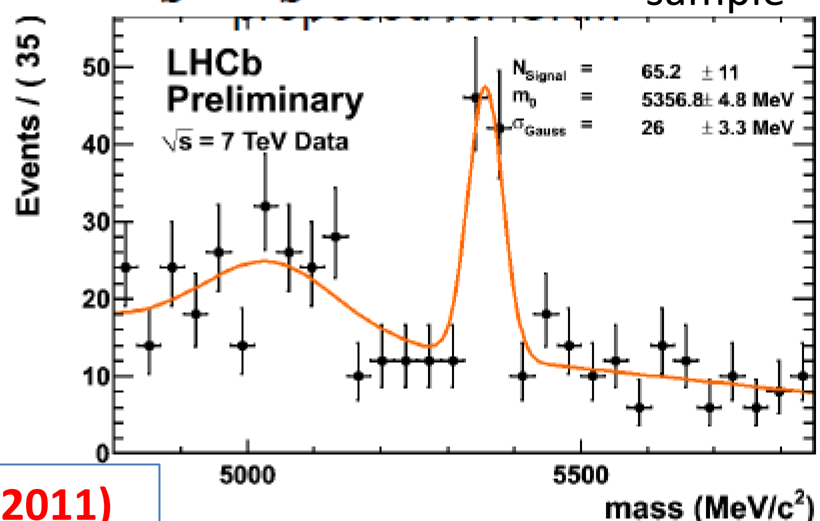
The golden mode is $B_s \to D_sK$ because of the much larger interference than in the B_d modes





Time-dependent
Fast Bs oscillations
Important:
- proper time resolution
-Tagging
Simultaneous fit to $B_s \to D_s\pi$ control sample

$B_s \to D_s\pi$



$B_s \to D_s\pi$ @LHCb^{2011} ~= 67 k

$B_s \to D_sK$ @LHCb^{2011} ~= 5.6 k

From MC sensitivity to γ is 10° with 6k $B_s \to D_sK$: we should not be far off this!

Expect $\sigma_{stat}(\gamma) \sim 10^{\circ}$ with 1/fb at LHCb(2011)

New methods for the measurement of γ

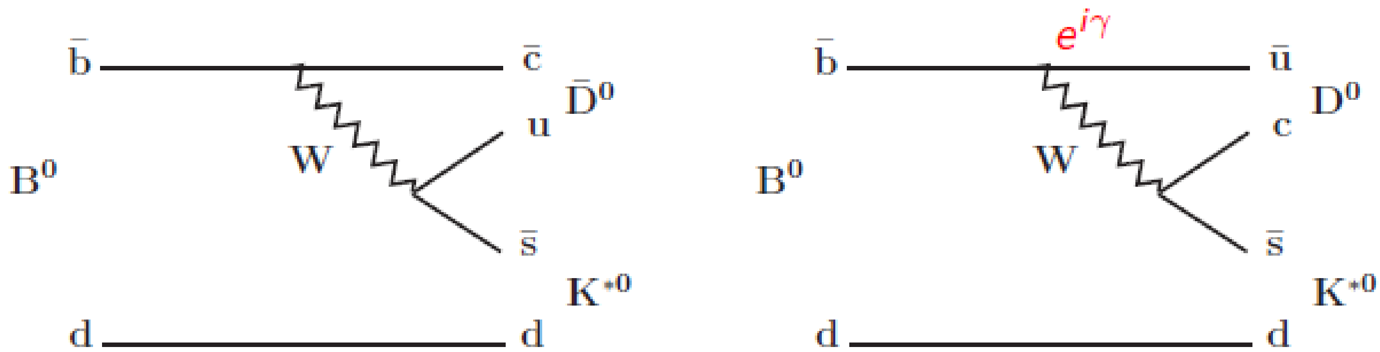
1. $B^0 \rightarrow DK^+\pi^-$
2. $B_s \rightarrow D\phi$
3. $B_s \rightarrow J/\psi\phi$

Reminder: γ from $B^0 \rightarrow D^0K^{*0}$

WILLIAMS

Neutral GLW/ADS

The neutral analog of $B^{\pm} \to D(hh)K^{\pm}$, the decays $B^0 \to D(hh)K^{*0}$, can also be used to determine γ due to the interference b/t amplitudes where the $D/\bar{D}$ decay to the same final state.



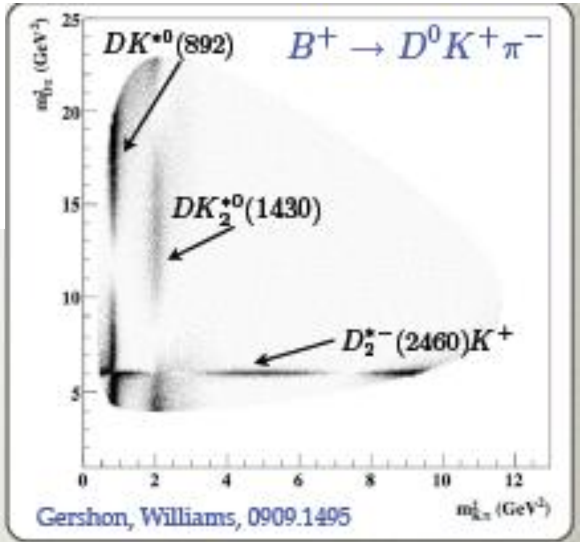
- Good: both diagrams are color suppressed ($r_{B^0} \approx 3 \times r_{B^{\pm}}$); increased interference increases the sensitivity on γ.
- Bad: the K^* interferes w/ the $B \to DK\pi$ *background*; effective hadronic parameters must be introduced (reduces sensitivity).

Another powerful Dalitz plot analysis $B^0 \to DK^+\pi^-$ and prospects at LHCb

ZUPAN WILLIAMS

Gershon,2008
Gershon and Williams, 2009
Gershon and Poluektov,2009

Exploits resonance structure in the Dalitz plot from the self-tagged B^0 multibody decay



- contains flavor specific $D_2^{*-}(2460) \to \bar{D}^0\pi^-$
- interf. with other resonances (e.g. $B^0 \to DK^{*0}$) gives γ
- many choices for $D \to f$ still
- equivalent of GLW does not need CP-odd $D \to K_S\pi^0$ decays (that is difficult for LHCb)

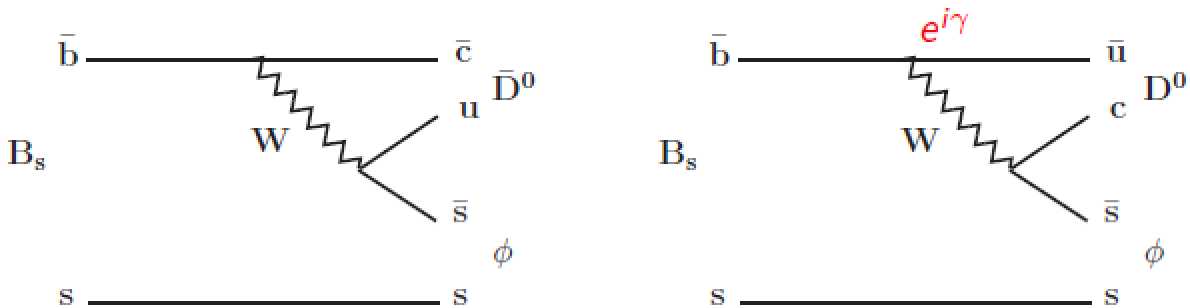
J. Zupan The case for measuring gamma... 5

Expect $\sigma_{stat}(\gamma)\sim 11^o$ with 1/fb at LHCb(2011)
Estimated with assumptions on the DP model to be assessed on early LHCb data [measure branching ratios of main resonance components]

Exploiting B_s production at LHCb: γ from $B_s \rightarrow D\phi$ (untagged)

WILLIAMS

The strange analog of $B^0 \to DK^{*0}$, the decays $B_s \to D\phi$, can also be used to determine γ using the GLW/ADS method.



Large CP asymmetry, very small background

Expected yields in 1 fb^{-1} @ 7 TeV (2011 running)

$B_s + \bar{B}_s \to D_{\mathrm{fav}}\phi$	$B_s + \bar{B}_s \to D(K3\pi)\phi$	$B_s + \bar{B}_s \to D_{CP+}\phi$
~ 200	~ 200	~ 25

Expect $\sigma_\gamma \sim 17°$ (see CERN-LHCB-PUB-2010-005)

Including $\Delta\Gamma_s$ corrections (from Zupan)

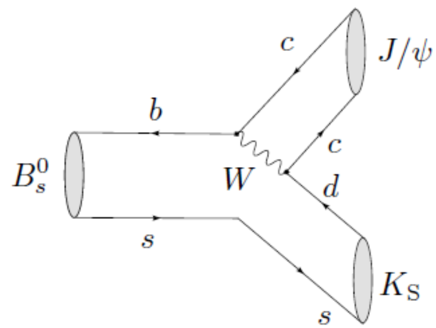
FLEISCHER

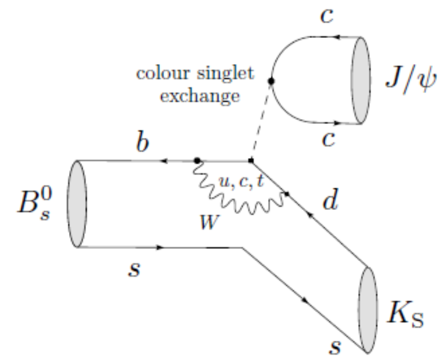
Another decay with a promising physics potential:

$B_s \rightarrow J/\psi\, K_S$ (time-dependent)

[R.F., Eur. Phys. J. C **10** (1999) 299 [arXiv:hep-ph/9903455]]

U-spin partner of the "golden" $B_d \rightarrow J/\psi\, K_s$





Sensitivity to γ from interference between tree and penguin (suppressed for B_d but not for B_s)

$$A(B_s^0 \to J/\psi\, K_S) = -\lambda\, \mathcal{A}\left[1 - a e^{i\theta} e^{i\gamma}\right]$$

With assumption on U-spin flavour symmetry γ and penguin decay parameters (a,θ) can be extracted

$$\mathcal{A} \equiv \lambda^2 A \left[A_T^{(c)} + A_P^{(c)} - A_P^{(t)}\right], \quad a e^{i\theta} \equiv R_b \left[\frac{A_P^{(u)} - A_P^{(t)}}{A_T^{(c)} + A_P^{(c)} - A_P^{(t)}}\right]$$

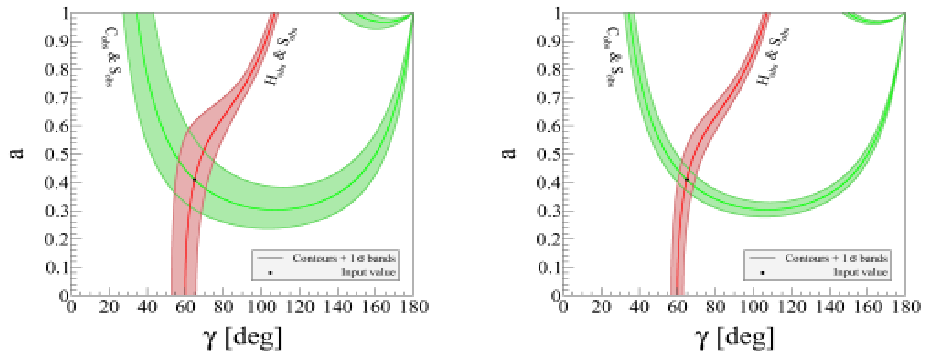
$$A \equiv |V_{cb}|/\lambda^2, \quad R_b \equiv \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right|$$

FLEISCHER

$B_s \to J/\psi\ K_S$: feasibility studies at LHCb

Contours in the γ–a plane: [6 fb^{-1} and 50 fb^{-1}]

R.Fleischer in collaboration with P.Koppenburg and K. De Bruyn



Numerical results: [only statistical sensitivity]

$$6\,\text{fb}^{-1}:\quad \gamma = (65.0 \pm 7.4)^\circ,\quad a = 0.410 \pm 0.060,\quad \theta = (194 \pm 13)^\circ,$$

$$50\,\text{fb}^{-1}:\quad \gamma = (65.0 \pm 3.3)^\circ,\quad a = 0.410 \pm 0.024,\quad \theta = (194.0 \pm 4.3)^\circ.$$

Our LHCb feasibility study shows:

– The $B_{s,d} \to J/\psi K_S$ strategy offers another extraction of γ.

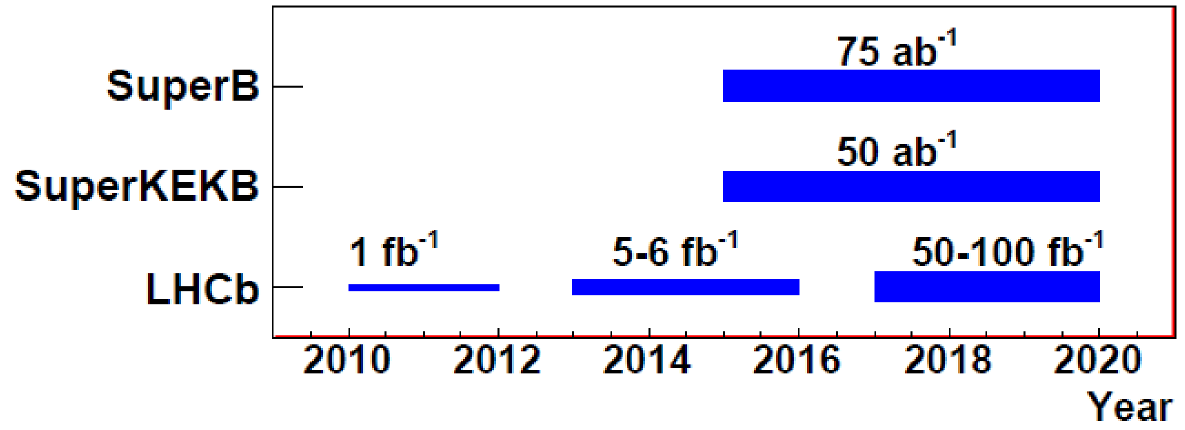
– The major application will be the control of the penguin effects in $(\sin 2\beta)_{J/\psi K_S}$, which will allow us to match the experimental precision:

$\to$ may eventually allow us to resolve NP in B^0_d–$\bar{B}^0_d$ mixing.

!!!

Visions for the next decade and beyond

Comparison on experimental reach



LHCb: 20×10^{12} produced $B\overline{B}$ pairs
detection efficiency $< 1\%$.
B/S typically $O(1)$

SuperB: 50×10^{9} produced $B\overline{B}$ pairs
detection efficiency $O(100\%)$
clean signals

‘Super-γ’ (~2020 AD)

POLUEKTOV

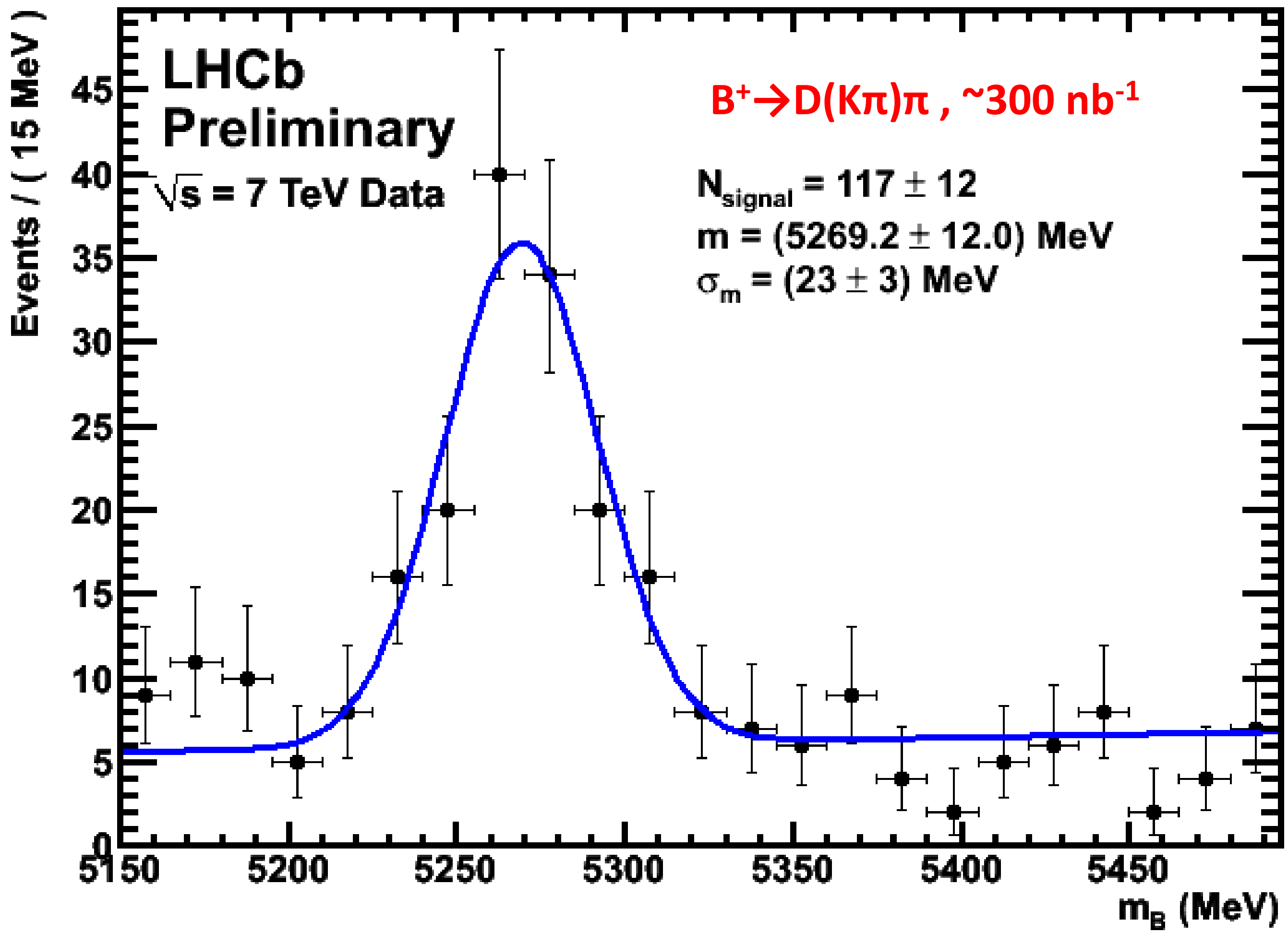
- Various independent methods should allow for $\sim 1 - 3^{\circ}$ measurement with SuperB and upgraded LHCb:
  - ADS + GLW modes
  - $B \to D(K_S\pi\pi)K$ Dalitz analysis
  - Self-tagging $B^0 \to DK\pi$ modes
  - $B_s \to D_sK$ (LHCb only)
- Overall, LHCb sensitivity with 50 fb^{-1} potentially looks better than that of SuperB, but higher backgrounds can reduce it. SuperB is more stable against "unlucky" parameter combinations when the sensitivity can be significantly reduced.
- Having a large ($\sim$ 10-20 fb^{-1}) sample at charm threshold is desirable for an efficient use of B data:
  - Significant fraction of BES-III sample.
  - Dedicated charm-tau factory.
  - SuperB operated at low energy.

Back to near future: 2010-2012

By 2012 (next CKM?) expect to hear new exciting results on γ from B to charm decays from experiments at *hadron colliders*:

- CDF has demonstrated capability of hadron colliders with B to charm decays
- New ADS/GLW results (5/fb) results competitive with B-factories
- Exploration continues, double data-set by 2011 (Expect 10-12/fb)

- LHCb expects $\sigma(\gamma)<10^{o}$ degrees by end 2011, several promising measurements (~1/fb at 7TeV)
- Excellent tracking, PID and trigger performance for these multi-hadron decay modes demonstrated with <1/pb of data collected and analysed this summer



Similar significance expected for the "suppressed" ADS mode (B→DK) at LHCb with 3 order of magnitude larger data sample by the end of 2011

Acknowledgements

Many other new results presented in these sessions. Apologies, could not show them all!

BIG THANKS to all the WGV SPEAKERS
for the excellent talks and discussions!!

AND BIG THANKS to Warwick for the impeccable organisation!!!