CKM angle measurements at LHCb

Sergey Barsuk

Laboratoire de l'Accélérateur Linéaire, Orsay

on behalf of the LHCb collaboration

13th Lomonosov Conference on Elementary
Particle Physics

Moscow, August 23-29, 2007

Moscow State University

Faculty of Physics

THIRTEENTH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

Mikhail Lomonosov
1711-1765

Moscow, August 23-29, 2007

Electroweak Theory
Tests of Standard Model & Beyond
Developments in QCD (Perturbative
and Non-Perturbative Effects)
Heavy Quark Physics
Neutrino Physics
Astroparticle Physics
Gravitation and Cosmology
Physics at the Future Accelerators

**SEVENTH
INTERNATIONAL
MEETING
ON
PROBLEMS
OF INTELLIGENTSIA**
August 29, 2007
Rights and Responsibility
of the Intelligentsia
V.Sadovnichy (Rector of MSU) - Chairman

International Advisory Committee Organizing Committee

E.Akhmedov (KTH, Stockholm & Kurchatov Inst.)	V.Bagrov (Tbilisi Univ.)
S.Belyaev (Kurchatov Inst., Moscow)	V.Braginsky (MSU)
V.Belokurov (MSU)	A.Egorov (ICAS)
V.Berezinsky (JINR, Dubna)	D.Galtsov (MSU)
S.Bilenky (JINR, Dubna)	A.Grigoriev (MSU)
J.Bleimaier (PNNL)	S.Kapitzka (EAPS)
M.Danilov (ITEP, Moscow)	P.Kashkarov (MSU)
G.Diambrini-Palazzi (Univ. of Rome)	A.Kataev (JINR, Moscow)
A.Dolgov (INFN, Ferrara & ITEP, Moscow)	O.Khrustalev (MSU)
V.Kadyshevsky (JINR, Dubna)	V.Mikhailin (MSU & ICAS)
A.Logunov (JHEP, Protvino)	A.Mourao (STICENTRA, Lisbon)
V.Matveev (JINR, Moscow)	N.Nerozhny (JHEP, Moscow)
L.Okun (ITEP, Moscow)	N.Nikitova (MSU)
M.Panasuk (MSU)	A.Nikishov (Lomonosov Phys. Inst., Moscow)
V.Rubakov (JINR, Moscow)	V.Ritus (Lomonosov Phys. Inst., Moscow)
D.Shirkov (JINR, Dubna)	Yu.Popov (JINR)
J.Silk (Univ. of Oxford)	V.Savrin (MSU)
A.Sissakian (JINR, Dubna)	A.Studenikin (MSU & ICAS)
A.Skrinsky (JHEP, Moscow)	
A.Slavov (MSU & Bulgarian Acad. Sci.)	
A.Smirnov (JINR, Dubna)	
P.Spillantini (INFN, Florence)	
A.Starobinsky (Lomonosov Inst., Moscow)	
V.Trukhin (MSU)	

Organizers and sponsors

Faculty of Physics, Moscow State University
Skobeltsyn Institute of Nuclear Physics, Moscow State University
Interregional Centre for Advanced Studies
Joint Institute for Nuclear Research (Dubna)
Institute for Theoretical and Experimental Physics (Moscow)
Institute for Nuclear Research (Moscow)
Institute for High Energy Physics (Protvino)
Budker Institute of Nuclear Physics (Novosibirsk)
Russian Foundation for Basic Research
Ministry for Education and Science of Russia
Russian Academy of Sciences
Russian Agency for Atomic Energy

For contact: Alexander Studenikin, Chairman, studenik@srds.inp.msu.ru; Alexander Grigoriev, Scientific Secretary, aneg@srds.inp.msu.ru

Department of Theoretical Physics,
Moscow State University, 119992 Moscow, Russia
Phone (007-495) 939-50-33 Fax (007-495) 932-88-20

<http://www.icas.ru>

matrix in

parametrization...

$$V_{CKM} = \begin{pmatrix} 1 - \lambda^2/2 - \lambda^4/8 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + A^2\lambda^5(1/2 - \rho - i\eta) & 1 - \lambda^2/2 - \lambda^4(1 + 4A^2)/8 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) + A\lambda^5(\rho + i\eta)/2 & -A\lambda^2 + A\lambda^4(1/2 - \rho - i\eta) & 1 - A^2\lambda^4/2 \end{pmatrix} + O(\lambda^6)$$

β (pointing to ρ) χ (pointing to η) γ (pointing to λ^3)

$B_d \bar{B}_d$ mixing phase $\varphi_d^{SM} = 2\beta$

$B_s \bar{B}_s$ mixing phase $\varphi_s^{SM} = -2\chi = -2\lambda^2\eta \approx -0.037$

... and Unitarity triangles

□ Two of the 6 triangles useful for B physics. Divided by $|V_{cb}^* V_{cd}|$.

$\rho \sim 0.2$
 $\eta \sim 0.4$
 $\lambda \sim 0.23$
 $A \sim 0.8$

CKM angle measurements $\arg(V_{ub}) = -\gamma, \quad \arg(V_{td}) = -\beta, \quad \arg(V_{ts}) = \chi + \pi$

Current status of CKM parameters

- Impressive improvement due to results from B-factories and Tevatron
- The so far measurements are entirely consistent with the SM predictions

Accuracy of angles is limited by experiment:

$$\alpha \sim \pm 6^\circ$$

$$\beta \sim \pm 1^\circ$$

$$\gamma \sim \pm 20^\circ$$

χ not yet measured

Current status of CKM parameters

- Impressive improvement due to results from B-factories and Tevatron
- The so far measurements are entirely consistent with the SM predictions

Accuracy of angles is limited by experiment:

$$\alpha \sim \pm 6^\circ$$

$$\beta \sim \pm 1^\circ$$

$$\gamma \sim \pm 20^\circ$$

χ not yet measured

Accuracy of sides is limited by theory:

Extraction of $|V_{ub}|$ for Rb side

Lattice calculation of $\xi^2 = \frac{\hat{B}_{B_s} f_{B_s}^2}{\hat{B}_{B_d} f_{B_d}^2}$ for Rt side

In coming 2 years errors CKM constraints should halve.

Christine Davies Lattice review at LP07

- Improve precision of angles to further improve CKM consistency check
- Search for New Physics by comparing tree-mediated processes (γ , Rb) to those involving loop diagrams (γ , β , Rt)

$\rightarrow$ complementary to direct searches !

LHCb - experiment to study $\mathcal{CP}$ and rare phenomena in B meson decays

→ General LHCb talk

→ Bernhard Spaan

Main LHCb features

- Large rates, $\sim 10^{12}$ b-hadrons / year with all b-species produced:
 B_u ($\sim 40\%$), B_d ($\sim 40\%$), B_s ($\sim 10\%$), B_c ($\sim 0.1\%$), Λ_b ($\sim 10\%$), ... , Excited states, ...
- Well separated B decay vertices $\Rightarrow$ "easy" B_s oscillations
- Excellent vertexing and particle identification capabilities
- Dedicated B-physics trigger

Important LHCb contributions:

- precision CKM measurements, in particular angle γ and B_s mixing phase ϕ_s
- search for NP with rare decays

→ Rare decays at LHCb

→ Victor Egorychev

Data collection plan

- 2008 : $\int \mathcal{L} dt = 0.5 \text{ fb}^{-1}$
- ~ 2013 : $\int \mathcal{L} dt \sim 10 \text{ fb}^{-1}$ (~ 5 nominal years)

LHCb detector - single-arm forward spectrometer 10 - 250/300 mrad

Vertex reconstruction:
VELO

Kinematics:
Magnet
Tracker
Calorimeters

PID:
RICHs
Calorimeters
Muon Chambers

Trigger:
Muon Chambers
Calorimeters
Tracker

φ_s from $B_s \rightarrow J/\psi \Phi$

$J/\psi \rightarrow \ell\ell$

$\Phi \rightarrow KK$

- Mixture of $CP=+1$ for $L=0,2$
and $CP=-1$ for $L=1 \Rightarrow$ partial waves
- Measures $\varphi_s^{SM} = -2\chi = -0.037$ is small
- Simultaneous measurement of $\Delta\Gamma_s$

$$\frac{d\Gamma(t)}{d(\cos(\theta_{tr}))} \propto \left[|A_0(t)|^2 + |A_{\parallel}(t)|^2 \right] \frac{3}{8} (1 + \cos^2 \theta_{tr}) + |A_{\perp}(t)|^2 \frac{3}{4} \sin^2 \theta_{tr}$$

Simultaneous fit to **Time** and **Angular** Distributions

$$A_{CP}(t) = \frac{\Gamma[\bar{B}_s(t) \rightarrow f] - \Gamma[B_s(t) \rightarrow f]}{\Gamma[\bar{B}_s(t) \rightarrow f] + \Gamma[B_s(t) \rightarrow f]}$$

$$A_{CP}(t) = \frac{\eta_f \sin \phi_s \sin(\Delta m_s t)}{\cosh(\Delta \Gamma_s t/2) - \eta_f \cos \phi_s \sinh(\Delta \Gamma_s t/2)}$$

1 LHCb year (2 fb^{-1}), $BR=3 \cdot 10^{-5}$:

131k events, $\sigma(\varphi_s) = 0.023$

ϕ_S : adding pure CP eigenstates

Channels used	Yield (2 fb ⁻¹)	B/S	$\langle \delta_\tau \rangle$ (fs)	σ_{mass} (MeV/c ²)
$B_s \rightarrow J/\psi(\mu^- \mu^+) \phi(K^+ K^-)$	131k	0.12	36	14
$B_s \rightarrow \eta_c(h^- h^+ h^- h^+) \phi(K^+ K^-)$	3k	0.6	30	12
$B_s \rightarrow J/\psi(\mu^- \mu^+) \eta(\gamma\gamma)$	8.5k	2.0	37	34
$B_s \rightarrow J/\psi(\mu^- \mu^+) \eta(\pi^+ \pi^- \pi^0(\gamma\gamma))$	3.0k	3.0	34	20
$B_s \rightarrow J/\psi(\mu^- \mu^+) \eta'(\pi^+ \pi^- \eta(\gamma\gamma))$	2.2k	2.0	32	19
$B_s \rightarrow D_s(K^+ K^- \pi^-) D_s(K^+ K^- \pi^+)$	4.0k	0.3	56	6

Channels	$\sigma(\phi_S)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s \rightarrow J/\psi \eta(\pi^+ \pi^- \pi^0)$	0.142	2.3
$B_s \rightarrow D_s D_s$	0.133	2.6
$B_s \rightarrow J/\psi \eta(\gamma \gamma)$	0.109	3.9
$B_s \rightarrow \eta_c \phi$	0.108	3.9
Combined (pure CP eigenstates)	0.060	12.7
$B_s \rightarrow J/\psi \phi$	0.023	87.3
Combined (all CP eigenstates)	0.022	100.0

Example: impact of φ_s from $B_s \rightarrow J/\psi \Phi$

Example: New Physics through Tree-Penguin comparison

B_d

Tree

B_s

Penguin

Beginning 2007:

$$\beta(\text{tree}) - \beta(\text{penguin}) = \delta\beta(\text{NP})$$

Currently: $\delta\beta(\text{NP}) \sim 8^\circ$ (2.6σ)

$$\chi(\text{tree}) - \chi(\text{penguin}) = \delta\chi(\text{NP})$$

In SM: $\delta\chi(\text{NP}) = \delta\beta(\text{NP})$

LHCb sensitivity on $\delta\chi(\text{NP}) \sim 3^\circ$ (1 nominal year, 2fb^{-1})

Example: constraining NP with φ_s and Δm_s measurement

- The measurement can be interpreted via a parameterization of NP effects:

$$M_{12} = (1 + h_s e^{2i\sigma_s}) M_{12}^{SM}$$

M_{12}^{SM} = dispersive part of the B_s mixing amplitude in the SM

- Then Δm_s and φ_s can be used to constrain NP in the oscillation:

$$\Delta m_s = \Delta m_s^{SM} |1 + h_s \exp(2i)\sigma_s|$$

$$\Phi_s = \Phi_s^{SM} + \arg(1 + h_s \exp(2i\sigma_s))$$

From Z. Ligeti et al hep-ph/0604112
Allowed regions CL > 0.90, 0.32, 0.05

γ measurement: $B_s \rightarrow D_s K$ $D_s \rightarrow KK\pi$

TREE

- ☐ $B_s \rightarrow D_s K^+$ and $B_s \rightarrow D_s K^-$ ($b \rightarrow u$), both $\sim \lambda^3$ tree diagrams, interference via mixing
- ☐ Phase $D_s K^-$: $\Delta - (\gamma + \phi_s)$
- ☐ Phase $D_s K^+$: $\Delta + (\gamma + \phi_s)$
- ☐ Fit 4 tagged time-dependent rates
- ☐ Measure simultaneously Δ and $\gamma + \phi_s$

- ☐ Annual yield: 6.2k events, $S/B > 1.4$ @90% CL
- ☐ $\sigma(\gamma + \phi_s) \sim 10^\circ$ with 2fb^{-1} (1 LHCb year)

$B_s \rightarrow D_s \pi$ residual contamination $\sim 10\%$

γ from $B^\pm \rightarrow DK^\pm$

Interference between the two diagrams if same final state

Weak phase diff.: γ

Magnitude ratio: $r_B \sim 0.08$

Strong phase diff.: δ_B

$$A(B^- \rightarrow \bar{D}^0 K^-) / A(B^- \rightarrow D^0 K^-) = r_B e^{i(\delta_B - \gamma)}$$

Parameters: $\gamma, (r_B, \delta_B)$ per B mode

1) Use a CP mode for the D^0

Parameters: $r_B, \gamma, \delta_B, (r_D = 1, \delta_D = 0)$

GLW (Gronau, London, Wyler)

CP+ and CP- modes

$(K^+ K^-, \pi^+ \pi^-)$

$(K_S \pi^0, \phi K_S, \eta K_S, \rho K_S, \omega K_S)$

2) Use CAD ($K^- \pi^+$) for the V_{ub} decay and DCSD

($K^- \pi^+$) for the V_{cb} decay

Parameters: $r_B, \gamma, \delta_B, r_D \sim 0.06, \delta_D$

ADS

(Atwood, Dunietz, Soni)

$$\left\{ \begin{array}{l} D^0 \rightarrow K^- \pi^+ \\ D^0 \rightarrow K^- \pi^+ \pi^0 \\ D^0 \rightarrow K^- \pi^+ \pi^- \pi^+ \end{array} \right.$$

3) Use Dalitz plot analysis of 3-body D^0 decay, e.g. $D^0 \rightarrow K_S \pi \pi$

GGSZ (Giri, Grossman, Soffer, Zupan)

γ from $B^\pm \rightarrow DK^\pm$

□ ADS: 4 time-integrated decay rates, 5 unknowns

$$\begin{aligned}\Gamma(B^- \rightarrow (K^- \pi^+)_D K^-) &\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B - \delta_D^{K\pi} - \gamma) \\ \Gamma(B^- \rightarrow (K^+ \pi^-)_D K^-) &\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B + \delta_D^{K\pi} - \gamma), \\ \Gamma(B^+ \rightarrow (K^+ \pi^-)_D K^+) &\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B - \delta_D^{K\pi} + \gamma) \\ \Gamma(B^+ \rightarrow (K^- \pi^+)_D K^+) &\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B + \delta_D^{K\pi} + \gamma)\end{aligned}$$

favoured ~60k evts
suppressed ~0.5k evts

Parameters: γ $r_B, \delta_B, \delta_D^{K\pi}, \delta_D^{K3\pi}, \dots$ $\rightarrow$ may come from CLEO-C and (later) BESIII

mode dependent

□ GLW: 2 time-integrated decay rates, +1 unknown

$$\begin{aligned}\Gamma(B^- \rightarrow D_{CP} K^-) &\propto 1 + r_B^2 + 2 r_B \cos(\delta_B + \gamma) \\ \Gamma(B^+ \rightarrow D_{CP} K^+) &\propto 1 + r_B^2 + 2 r_B \cos(\delta_B - \gamma)\end{aligned}$$

$\Rightarrow$ common ADS +GLW fit solves for all unknowns, including γ

Precision: $\sigma(\gamma) \sim 5^\circ - 13^\circ$ in 1 nominal year, 2 fb^{-1}

depending on $\delta_D^{K\pi}$ ($-25^\circ < \delta_D^{K\pi} < 25^\circ$) and on $\delta_D^{K3\pi}$ ($-180^\circ < \delta_D^{K3\pi} < 180^\circ$)

γ from Dalitz plot analysis of 3-body decay $D^0 \rightarrow K_S \pi \pi$

Interference due to the overlap of large resonances from V_{cb} and V_{ub} transitions

Dalitz distribution density: $d\sigma(m_{K_S\pi^+}^2, m_{K_S\pi^-}^2) \propto |\mathbf{A}|^2 dm_{K_S\pi^+}^2 dm_{K_S\pi^-}^2$

$$|\mathbf{A}(m_{K_S\pi^+}^2, m_{K_S\pi^-}^2)|^2 = \left| \text{[Plot 1]} + r e^{i\delta \pm i\phi_3} \text{[Plot 2]} \right|^2$$

- ☐ Assume no significant CP violation in D decays
- ☐ Measure magnitudes (r_D) from D $\rightarrow$ flavour tags
- ☐ Measure phases (δ_D) from D $\rightarrow$ CP tags
- ☐ D decay model: 'exclusive' point-by-point in PS or 'inclusive' (integrating)

$f(m_{\pm}^2, m_{\mp}^2)$ is determined from $D^{*-} \rightarrow D^0 \pi^-$, $D^0 \rightarrow K_S \pi^+ \pi^-$ decay
 $\Rightarrow$ model uncertainty of the result

Or measure phase difference directly (model-independent) using the CP-tagged D^0 sample e.g. from $\psi'' \rightarrow D^0 \bar{D}^0$, where tag-side D^0 decays into CP-eigenstate

$\Rightarrow$ CLEO-c, BESIII

Amplitude:
$$f(m_-^2, m_+^2) = \sum a_r e^{i\phi_r} \mathcal{A}_s(K_S^0 \pi^- \pi^+ | r) + a_{NR} e^{i\phi_{NR}}$$

BELLE '07

Resonance	Amplitude	Phase ($^\circ$)	Fit fraction
$K^*(892)^-$	1.629 ± 0.006	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.8	0.0724
$K_2^*(1430)^-$	0.87 ± 0.02	-47.3 ± 1.2	0.0133
$K^*(1410)^-$	0.65 ± 0.03	111 ± 4	0.0048
$K^*(1680)^-$	0.60 ± 0.25	147 ± 29	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 1.3	0.0054
$K_0^*(1430)^+$	0.541 ± 0.019	91.8 ± 2.1	0.0047
$K_2^*(1430)^+$	0.276 ± 0.013	-106 ± 3	0.0013
$K^*(1410)^+$	0.33 ± 0.02	-102 ± 4	0.0013
$K^*(1680)^+$	0.73 ± 0.16	103 ± 11	0.0004
$\rho(770)$	1 (fixed)	0 (fixed)	0.2111
$\omega(782)$	0.0380 ± 0.0007	115.1 ± 1.1	0.0063
$f_0(980)$	0.380 ± 0.004	-147.1 ± 1.1	0.0452
$f_0(1370)$	1.46 ± 0.05	98.6 ± 1.8	0.0162
$f_2(1270)$	1.43 ± 0.02	-13.6 ± 1.2	0.0180
$\rho(1450)$	0.72 ± 0.04	41 ± 7	0.0024
σ_1	1.39 ± 0.02	-146.6 ± 0.9	0.0914
σ_2	0.267 ± 0.013	-157 ± 3	0.0088
NR	2.36 ± 0.07	155 ± 2	0.0615

Fit fraction:

$$F_r = \frac{\int \int |a_r e^{i\phi_r} \mathcal{A}_s(K_S^0 \pi^- \pi^+ | r)|^2 dm_+^2 dm_-^2}{\int \int |\sum_j a_j e^{i\phi_j} \mathcal{A}_s(K_S^0 \pi^- \pi^+ | j)|^2 dm_+^2 dm_-^2}$$

*CP Tags give information
on phase between
 D and $\bar{D}$ amplitudes*

$K_S \rho^0$ resonance enhanced
in CP-odd Dalitz plot

CP-odd $K_S \rho^0$ resonance absent
in CP-even Dalitz plot

CLEO-C '07

γ from Dalitz plot analysis of 3-body decay $D^0 \rightarrow K_S \pi \pi$

With known

$$f(m_{\pm}^2, m_{\mp}^2)$$

fit simultaneously
for r_B , δ_B , γ

$K^{*+}(892)(K_S \pi^+) \pi^-$ ADS
method

Event yield: 5k per 1 LHCb year
 $S/B > 1.0$ @ 90% CL

Sensitivity with 2 fb^{-1} : $\sigma(\gamma) \sim 7^\circ\text{--}12^\circ$
for $r_B=1$, depending on background conditions

γ from $B^0 \rightarrow DK^{*0}$

□ Self-tagging mode

□ ADS: 4 time-integrated decay rates, 5 unknowns

$$\Gamma(B^0 \rightarrow (K^+ \pi^-)_D K^{*0}) \propto 1 + (r_B r_D)^2 + 2r_B r_D \cos(\delta_B + \delta_D + \gamma),$$

$$\Gamma(B^0 \rightarrow (K^- \pi^+)_D K^{*0}) \propto r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B - \delta_D + \gamma),$$

$$\Gamma(\bar{B}^0 \rightarrow (K^- \pi^+)_D \bar{K}^{*0}) \propto 1 + (r_B r_D)^2 + 2r_B r_D \cos(\delta_B + \delta_D - \gamma),$$

$$\Gamma(\bar{B}^0 \rightarrow (K^+ \pi^-)_D \bar{K}^{*0}) \propto r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B - \delta_D - \gamma),$$

□ GLW: 2 time-integrated decay rates, +1 unknown

$$\Gamma(B^0 \rightarrow D_{CP} K^{*0}) \propto 1 + r_B^2 + 2r_B \cos(\delta_B + \gamma)$$

$$\Gamma(\bar{B}^0 \rightarrow D_{CP} \bar{K}^{*0}) \propto 1 + r_B^2 + 2r_B \cos(\delta_B - \gamma)$$

□ Magnitude ratios

$$r_B \equiv \frac{A_2}{A_1} = \frac{|A(B^0 \rightarrow D^0 K^{*0})|}{|A(B^0 \rightarrow \bar{D}^0 K^{*0})|} \sim 0.4 (?)$$

$$r_D \equiv \frac{|A(D^0 \rightarrow K^+ \pi^-)|}{|A(\bar{D}^0 \rightarrow K^+ \pi^-)|} \sim 0.06$$

Decay mode (+cc)	2 fb ⁻¹ yield	S/B _{bb}
$B^0 \rightarrow (K^+ \pi^-)_D K^{*0}$	3.4 k	>3.3
$B^0 \rightarrow (K^- \pi^+)_D K^{*0}$	0.5 k	>0.6
$B^0 \rightarrow (K^+ K^-, \pi^+ \pi^-)_D K^{*0}$	0.6 k	>0.7

Sensitivity to γ from $B \rightarrow DK$ decays

B mode	D mode	Method	$\sigma(\gamma)$, 2 fb ⁻¹
$B^+ \rightarrow DK^+$	$K\pi + KK/\pi\pi + K3\pi$	ADS+GLW	4°-13°
$B^+ \rightarrow D^*K^+$	$K\pi$	ADS+GLW	Under study
$B^+ \rightarrow DK^+$	$K_S\pi\pi$	GGSZ	7°-12°
$B^+ \rightarrow DK^+$	$KK\pi\pi$	4-body "Dalitz"	18°
$B^+ \rightarrow DK^+$	$K\pi\pi\pi$	4-body "Dalitz"	Under study
$B^0 \rightarrow DK^{*0}$	$K\pi + KK + \pi\pi$	ADS+GLW	7°-10°
$B^0 \rightarrow DK^{*0}$	$K_S\pi\pi$	GGSZ	Under study
$B_s \rightarrow D_s K$	$KK\pi$	tagged+untagged, $A(t)$	10°

All channels combined (educated guess): $\sigma(\gamma) \sim 4^\circ$ with 2 fb⁻¹
 $\sigma(\gamma) \sim 2^\circ$ with 10 fb⁻¹

γ measurement: $B_d \rightarrow \pi\pi$, $B_s \rightarrow KK$

PENGUIN
LOOP

- Measures γ
- Time-dependent asymmetries
for $B_d \rightarrow \pi\pi$ and $B_s \rightarrow KK$:

$$A_{CP}(t) = A_{dir} \cos(\Delta m t) + A_{mix} \sin(\Delta m t)$$

- Parameters: γ , $\varphi_d(\varphi_s)$, $P/T = d e^{i\theta}$
- Take $\varphi_d(\varphi_s)$ from other measurements
- U-spin symmetry assumption [Fleischer]:

$$d_{\pi\pi} = d_{KK} \text{ and } \theta_{\pi\pi} = \theta_{KK}$$

$\Rightarrow$ 4 measurements, 3 unknown

$\Rightarrow$ Solve for γ

- Uncertainty from U-spin assumption
- Sensitive to new physics in penguins

$B_d \rightarrow \pi\pi$ 25k events/year, $S/B \sim 2$

$B_s \rightarrow KK$ 37k events/year, $S/B > 7$

If perfect U-spin symmetry

in 1 LHCb year (2 fb^{-1}): $\sigma_{stat}(\gamma) \sim 4^\circ$

Particle ID: $B_d \rightarrow \pi\pi$, $B_s \rightarrow KK$

K/π !!!

Summary: LHCb is fit to precisely measure the CKM angles

B_d mixing phase $\varphi_d = 2\beta$

Validation channel for LHCb, but also search for direct CPV term $\sim \cos \Delta m_d t$
 $\sigma_{\text{stat}}(\sin 2\beta) \sim 0.02$, $\sigma_{\text{stat}}(\beta) \sim 0.6^\circ$ in one LHCb year (2 fb^{-1})

► B_s mixing phase $\varphi_s = -2\chi$

LHCb will be the first experiment to reach sensitivity of φ_s (SM) ~ -0.04
 $\sigma_{\text{stat}}(\varphi_s) \sim 0.02$ in one LHCb year (2 fb^{-1})

► LHCb will precisely measure angle γ via

- > Pure tree processes : $\sim 10^\circ$
- > Potential NP in D^0 loops: $\sigma_{\text{stat}}(\gamma) \sim 4^\circ$ in one LHCb year (2 fb^{-1})
- > Awaited NP in penguin loops: $\sim 4^\circ$ *perfect U-spin symmetry limit*

LHCb will measure angle α via $B \rightarrow \rho\pi$ Dalitz plot analysis and measuring asymmetry in $B \rightarrow \rho^0 \rho^0$
 $\sigma_{\text{stat}}(\alpha) \sim 6^\circ$ in one LHCb year (2 fb^{-1})

Summary: UT evolution

now

LHCb after 5 years/10fb⁻¹

$\sigma(\beta) \sim 0.3^\circ$; $\sigma(\gamma) \sim 2^\circ$; $\sigma(\alpha) \sim 3^\circ$
(incl. Lattice QCD improvements, $\sigma(\xi)/\xi=1.5\%$)

Summary: LHCb is fit to probe NP in loops

Will γ measured with tree processes be compatible with loop measurements ?

At present large uncertainties on γ from tree processes only (no NP contribution)

LHCb will provide tighter constraint on γ from $B \rightarrow DK$ (tree process only, no NP contribution) after 5 years/10fb⁻¹

Either:

Trees agree with loops
→ No evidence for NP

Or.....!!!

Other tools:

χ : if $\gg 1^\circ$

$\delta\alpha, \delta\beta, \delta\chi$: if non-zero

⇒ NP in box diagram

⇒ NP in penguin loops

Copyrighted Material

PAUL DAVIES

*Author of Other Worlds and
The Edge of Infinity*

New Physics == Beyond SM
is already heavily exploited,
before being discovered ...

GOD & THE NEW PHYSICS

*"The concepts are breathtaking...the general thrust of
modern physics is amazingly well described."
-The New York Times Book Review*

Copyrighted Material

Copyrighted Material

QUANTUM REALITY

BEYOND THE NEW PHYSICS

AN EXCURSION INTO
METAPHYSICS...

... and New New Physics ==
Beyond New Physics is also
becoming fashionable.

...AND THE
MEANING OF REALITY

NICK HERBERT

Copyrighted Material