Summary of WG4
"Lifetime, mixing and weak mixing phase in charm and beauty, including direct determination of V_{tx}"

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6–10 September 2010

CKM worshop, Warwick, UK

Outlines

Introduction

- Summarize 3 sessions and 13 talks (7 theory, 6 experiment)
- lifetime and mixing, weak mixing phases in B^0 and B_s^0 systems, V_{tx}.

Contributing talks

- **NIERSTE, Ulrich** Lifetimes and mixing parameters of neutral B hadrons
- **GARRON, Nicolas** Lattice determination of f_{B_d}, f_{B_s} and ξ
- **KREPS, Michal** Measurement of ϕ_s at CDF
- **BORISSOV, Guennadi** Measurement of ϕ_s at DØ
- **HANSMANN-MENZEMER, Stephanie** Measurement of ϕ_s at LHCb
- **PETROV, Alexey** CP violation in charm mixing, theory
- **MALDE, Sneha** Lifetimes and mixing parameters of neutral D mesons and neutral B hadrons, experiment
- **MEADOWS, Brian** CP violation in charm mixing (B-factories and Tevatron)
- **GERSABECK, Marco** CP violation in charm mixing (LHCb)
- **CIUCHINI, Marco** Measurements of sin(2β) and cos(2β), theory
- **LI, Jin** Measurement of CPV with $B^0 \to (c\bar{c})K^0$ and $B_s^0 \to J/\psi h^0$ decays
- **ROHRWILD, Juergen** Theoretical situation for V_{td}, $V_{ts}$and V_{tb}
- **WAGNER, Wolfgang** Prospects for direct measurements of $|V_{ts}|$ and $|V_{tb}|$

B mixing and lifetime I

The neutral B_q $(q = d, s)$ system is described by the following equation

$$i \frac{d}{dt} \begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(\hat{M}^q - \frac{i}{2} \hat{\Gamma}^q \right) \begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$$

The famous box diagrams give rise to off-diagonal elements M_{12}^q and Γ_{12}^q in the mass matrix $\hat{M}^q$ and the decay rate matrix $\hat{\Gamma}^q$

Diagonalization of $\hat{M}^q$ and $\hat{\Gamma}^q$ gives the mass eigenstates

$$\text{CP-odd:} \quad B_H := p\, B + q\, \bar{B} \quad , \quad \text{CP-even:} \quad B_L := p\, B - q\, \bar{B}$$
$$\text{with} \qquad |p|^2 + |q|^2 = 1$$

with the corresponding masses M_H^q, M_L^q and decay rates Γ_H^q, Γ_L^q

B mixing and lifetime II

$|M_{12}^q|$, $|\Gamma_{12}^q|$ and $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ are related to three observables:

- **Mass difference:** $\Delta M_q := M_H^q - M_L^q = 2|M_{12}^q| \left(1 + \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right)$
  $|M_{12}^q|$: heavy virtual particles: t, SUSY, ...

- **Decay rate difference:**
  $\Delta\Gamma_q := \Gamma_L^q - \Gamma_H^q = 2|\Gamma_{12}^q|\cos\phi_q \left(1 - \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right)$
  $|\Gamma_{12}^q|$: light real particles: u, c, ... no NP – below hadronic uncertainties

- **Flavor specific / semi leptonic CP asymmetries:**
  * $\bar{B}_q \to f$ and $B_q \to \bar{f}$ forbidden
  * no direct CP violation: $|\langle f|B_q\rangle| = |\langle \bar{f}|\bar{B}_q\rangle|$
  e.g. $B_s \to D_s^- \pi^+$ or $B_q \to Xl\nu$ (*semi leptonic*)

$$a_{sl}^q = \mathrm{Im}\frac{\Gamma_{12}^q}{M_{12}^q} + \mathcal{O}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)^2 = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q + \mathcal{O}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)^2$$

B mixing and lifetime III

In the SM one obtains

$$M_{12,q} = \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_0(x_t) B_{B_q} f_{B_q}^2 M_{B_q} \hat{\eta}_B$$

$$\Delta\Gamma_s = \left(\frac{f_{B_s}}{240\,\text{MeV}}\right)^2 \left[0.105 B + 0.024 \tilde{B}_S' - 0.027 B_R\right]$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = 10^{-4} \cdot \left[46.2 + 10.6 \frac{\tilde{B}_S'}{B} - 11.9 \frac{B_R}{B}\right]$$

1. Lattice parameters f_{B_s}, B_s,... - **N. Garron**
2. Numerical results/ updates - **U. Nierste**
3. CKM elements V_{td}, V_{ts}, V_{tb} - **J. Rohrwild, W. Wagner**
4. Test via lifetimes - **U. Nierste, S. Malde**

Note:

$$\frac{\Gamma_{12}}{M_{12}}(B_s) \approx 5 \cdot 10^{-3} \qquad \frac{\Gamma_{12}}{M_{12}}(D^0) \approx \mathcal{O}(1)$$

Lattice Predictions

Non-perturbative matrix elements that appear in mixing (lifetimes)

$$
\begin{aligned}
\langle \bar{B}_q | (\bar{b}q)_{V-A} (\bar{b}q)_{V-A} | B_q \rangle &= \frac{8}{3} B_{B_q} f_{B_q}^2 M_{B_q} \\
\xi &= \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}}
\end{aligned}
$$

Advanced stage of lattice calculations

- statistical error $\equiv$ computer power: “easy” to estimate
- systematic error
  - “under control”: finite lattice spacing, finite volume,...
  - “ very hard to control”: e.g. is there a systematic error due to the use of staggered fermions?,....

Unquenched lattice results (a selection)

Group	f_{B_d} (MeV)	f_{B_s} (MeV)	ξ	n_f	Heavy	Light
FNAL/MILC @ lat 08-09	$195(11)$	$243(11)$	$1.205(52)$	$2+1$	Fermilab	Asqtad
HPQCD PRD 09	$190(13)$	$231(15)$	$1.258(33)$	$2+1$	NRQCD	Asqtad
RBC-UKQCD PRD 10			$1.13(12)$	$2+1$	Static	Domain Wall
ETMC @lat 09	$191(14)$	$243(13)$		2	Stat. +Int.	Twisted Mass
ETMC JHEP 10	$194(16)$	$235(12)$		2	Stat +Int. new method	Twisted Mass

SM expectations for mixing observables and V_{tx}

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.147 \pm 0.060 \rightarrow 0.13 \pm 0.04$$

$$a_{fs}^s = (2.06 \pm 0.57) \cdot 10^{-5}$$

$$\phi_s = 0.24^\circ \pm 0.08^\circ$$

$$\frac{\Delta\Gamma_d}{\Gamma_d} = 4.1^{+0.9}_{-1.0} \cdot 10^{-3}$$

$$a_{fs}^d = -(4.8 \pm 1.1) \cdot 10^{-4}$$

$$\phi_d = -5.2^{\circ}{}^{+1.5^\circ}_{-2.1^\circ}$$

$$A_{sl}^b = 0.494 a_{sl}^s + 0.506 a_{sl}^d = (-2.3^{+0.5}_{-0.6}) \cdot 10^{-4}$$

$$V_{td} = 0.00865^{+0.00024}_{-0.00039}$$

$$V_{ts} = 0.04072^{+0.00038}_{-0.00146}$$

$$V_{tb} = 0.999133^{+0.000060}_{-0.000016}$$

Lenz, Nierste 2006; Nierste; Rohrwild from CKMfitter

Test via lifetimes I

Strategy

- HQE describes mixing Γ_{12} and lifetimes
- Γ_{12}/M_{12} sensitive to new physics
- lifetimes insensitive to new physics
- Test HQE via lifetimes

Theory predictions

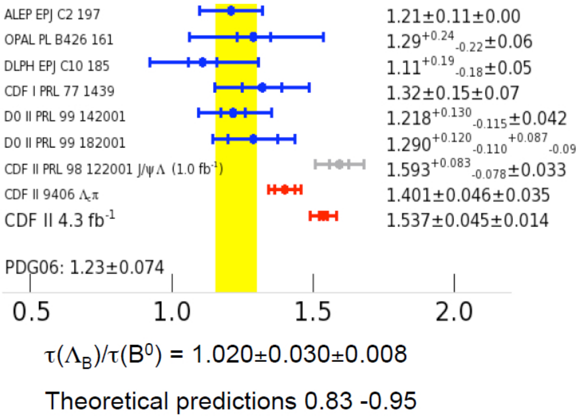
$$\frac{\tau(B_s)}{\tau(B_d)} - 1 \in [-5 \cdot 10^{-3}; +1 \cdot 10^{-3}]$$

$$\frac{\tau(B^+)}{\tau(B_d)} - 1 = 1.063 \pm 0.027$$

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} - 1 = 0.86 \pm 0.05$$

!BEWARE: Theory for Λ_b not complete: NLO-QCD+ lattice are missing!

Nierste; Lenz 2008; Gabbiani et al.



$\tau_{B^+} = 1.638 \pm 0.011\,\mathrm{ps}$ (PDG 2010), $\tau_{B^0} = 1.525 \pm 0.009\,\mathrm{ps}$ (PDG 2010),
$\tau_{B_s^0} = 1.53 \pm 0.025(\mathrm{stat}) \pm 0.012(\mathrm{syst})\,\mathrm{ps}$ (CDF 5.2 fb^{-1}),
$\tau_{B_s^0} = 1.45 \pm 0.04(\mathrm{stat}) \pm 0.01(\mathrm{syst})\,\mathrm{ps}$ (DØ 6.1 fb^{-1}),
$\Delta\Gamma_s = 0.075 \pm 0.035(\mathrm{stat}) \pm 0.01(\mathrm{syst})\,\mathrm{ps}^{-1}$ (CDF FPCP 2010)
$\Delta\Gamma_s = 0.15 \pm 0.06(\mathrm{stat}) \pm 0.01(\mathrm{syst})\,\mathrm{ps}^{-1}$ (DØ ICHEP 2010)

New physics effects

General parametrization of new physics effects in mixing

$$\Gamma_{12,s} = \Gamma_{12,s}^{\mathrm{SM}}\,, \qquad M_{12,s} = M_{12,s}^{\mathrm{SM}} \cdot \Delta_s\,; \qquad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta}$$

leads to the following relations for observables

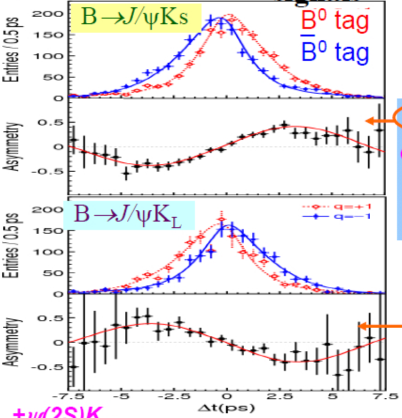
$$\begin{aligned}
\Delta M_s &= 2|M_{12,s}^{\mathrm{SM}}| \cdot |\Delta_s| \\
\Delta \Gamma_s &= 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right) \\
a_{fs}^s &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\mathrm{SM}}|} \cdot \frac{\sin\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right)}{|\Delta_s|} \\
\phi_s^{J/\Psi\phi} &= -2\beta_s + \phi_s^\Delta + \delta_{\mathrm{Peng.}}^{\mathrm{SM}} + \delta_{\mathrm{Peng.}}^{\mathrm{NP}}
\end{aligned}$$

Discussion of penguin contribution by Marco Ciuchini
Remember: $\phi_s^{\mathrm{SM}} = \arg(-M_{12}^s/\Gamma_{12}^s)$ and $\beta_s = \arg\left(-V_{\mathrm{ts}} V_{\mathrm{tb}}^* / V_{\mathrm{cs}} V_{\mathrm{cb}}^*\right)$

Status of mixing-induced CPV in B^0(1)

535M $B\bar{B}$

14000 signals



CP-odd

$J/\Psi K_S$

$\Psi(2S) K_S$

$\chi_{c1} K_S$

$\eta_c K_S$

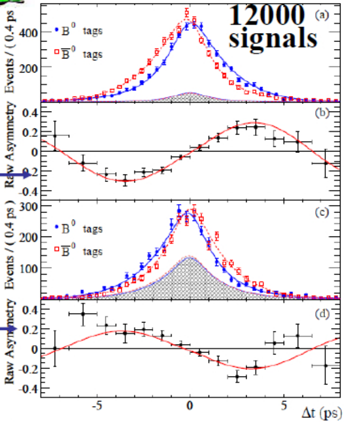
CP-even

$J/\Psi K_L$

465M $B\bar{B}$

$(c\bar{c})K^{(*)0}$

12000 signals



$+\psi(2S)K_S$

$\sin 2\phi_1 = 0.650 \pm 0.029 \pm 0.018$

[PRL 98,031802(07)+PRD77 091103(08)]

$0.687 \pm 0.028 \pm 0.012$

[PRD 79,072009(2009)]

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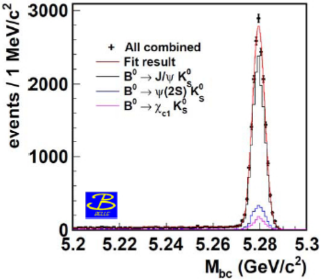
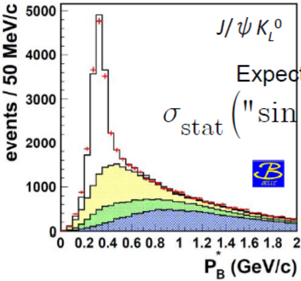
Status of mixing-induced CPV in B^0(2)

Coming soon : Final Belle sample

$b \to c\bar{c}s$ from 772×10^6 *BB* pairs = final Belle data sample





Expected sensitivity:

$$\sigma_{\rm stat}\left(\text{"}\sin 2\phi_1\text{"}\right) \approx 0.024$$

	$J/\psi K_S^0$	$J/\psi K_L^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	N_{BB} (x 10^6)
Signal yield ('10)	**12727±115**	**10087±154**	**1981±46**	**943±33**	**772**
Purity ('10) [%]	**97**	**63**	**93**	**89**	
Signal yield ('06)	7484±87	6512±123	–	–	535
Purity ('06) [%]	97	59	–	–	

New tracking software helps to increase signal yield.

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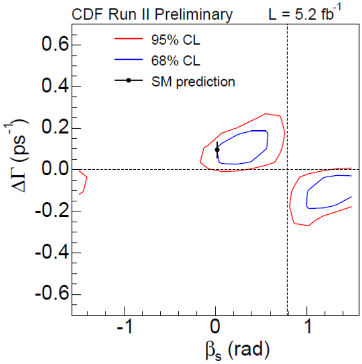
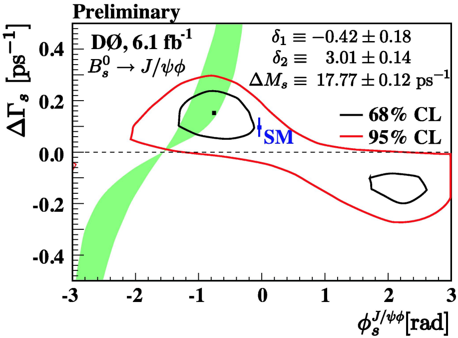
CDF FPCP $B_s^0 \to J/\psi\phi$ results

CDF Public Note 10206 (18 July 2010), no new results since ICHEP



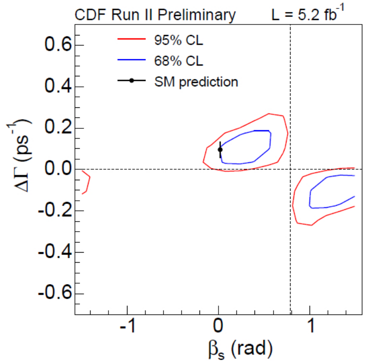
- 5.2 fb^{-1}, $\beta_s \in [0.02, 0.52] \cup [1.08, 1.55]$ rad at 68%CL
  $\Rightarrow \quad \phi_s^{J/\psi\phi} = -0.54 \pm 0.50\,\mathrm{rad}$ (our estimate)
- S-wave taken into account in the fit
- Selection: optimized directly stat uncertainty on β_s (before was $\sqrt{S/(S+B)}$)
- 6500 $B_s^0 \to J/\psi\phi$ candidates
- SSK calibration checked on data with $B_s^0 \to D_s^- \pi^+$

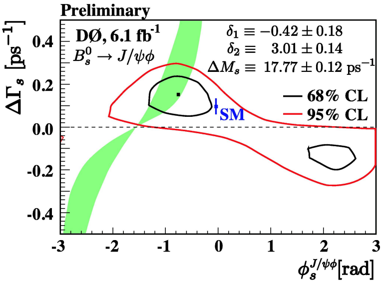
DØ ICHEP $B_s^0 \to J/\psi\phi$ results



- 6.1 fb^{-1}: $\phi_s^{J/\psi\phi} = -0.76^{+0.38}_{-0.36}(\mathrm{stat}) \pm 0.02(\mathrm{syst})\,\mathrm{rad}$.
- About 3400 signal events ($\sim$ 2 times less than CDF with similar lumi)
- Checks F-B asymmetry of cos(ψ) distribution versus K^+K^- mass that there is no significant s-wave contribution, but do not account for possible contribution in the fit
- Constraints strong phases to the values from $B^0 \to J/\psi K^{*0}$

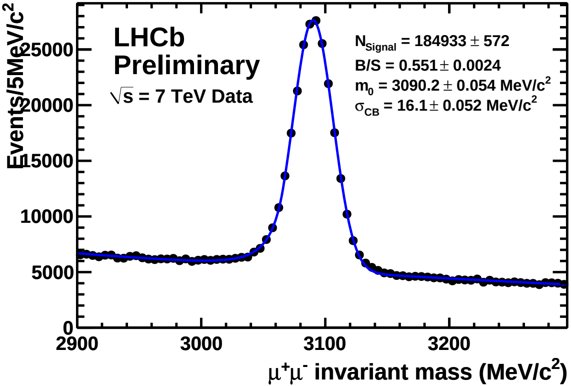
Tevatron ICHEP $B_s^0 \to J/\psi\phi$ results





LHCb $B \to J/\psi X$ peaks

$\mathcal{L}^{\text{int}} \sim 600\,\text{nb}^{-1}$, $J/\psi \to \mu^+\mu^-$

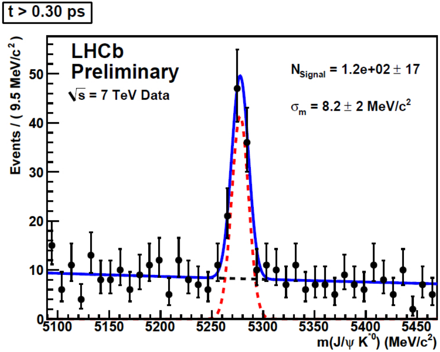


Mass resolution currently $\sim 1.35\times$ MC.

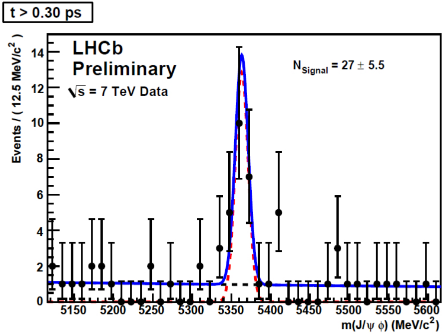
LHCb $B \to J/\psi X$ peaks

$\mathcal{L}^{int} \sim 600\,\mathrm{nb}^{-1}$

$B^0 \to J/\psi K^{*0}$

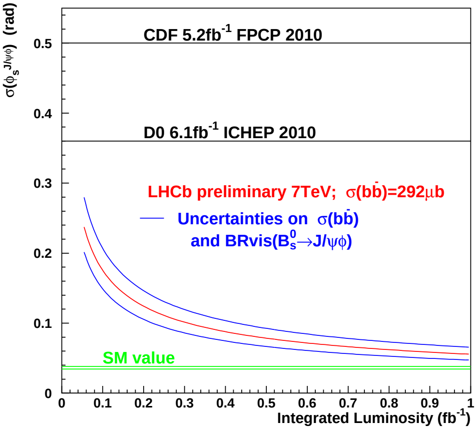


$B_s^0 \to J/\psi \phi$



Proper time resolution currently $\sim 2\times$MC ($\sim 0.08\,\mathrm{ps}$). However, good enough to resolve Δm_s (with more stat) and will improve with better alignment

$B_s^0 \to J/\psi\phi$ sensitivity projection (LHCb)



BEWARE:

$\Delta\Gamma_s = 0.075 \pm 0.035(\text{stat}) \pm 0.01(\text{syst})\,\text{ps}^{-1}$ (CDF FPCP 2010)

$\Delta\Gamma_s = 0.15 \pm 0.06(\text{stat}) \pm 0.01(\text{syst})\,\text{ps}^{-1}$ (DØ ICHEP 2010)

and $\phi_s^{J/\psi\phi}$ uncertainty decreases when $\Delta\Gamma_s$ grows!

$B_s^0 \to J/\psi f_0$

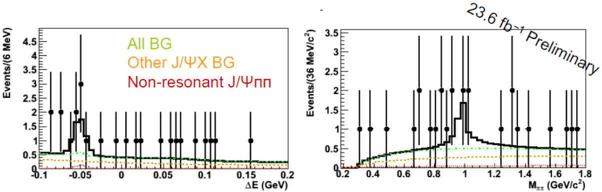
$$\frac{\mathcal{B}(B_s^0 \to J/\psi f_0)\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi \phi)\mathcal{B}(\phi \to K^+K^-)} \simeq 0.2 - 0.3 \text{ [Stone et al, PRD79, 07024 (2009)]}$$

Since $\mathcal{B}(B_s^0 \to J/\psi \phi(K^+K^-)) = (6.4 \pm 2.0) \times 10^{-4}$

$\Rightarrow \quad \mathcal{B}(B_s^0 \to J/\psi f_0(\pi^+\pi^-)) = (1.3 - 2.7) \times 10^{-4}$

Belle result:

2D fit to ΔE and m(π⁺π⁻)



6.0±4.4 events

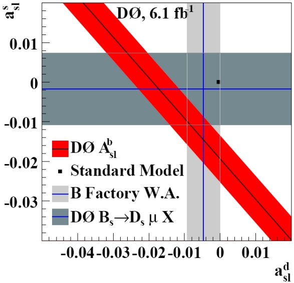
1.6σ

$$\mathcal{B}(B_s^0 \to J/\psi f_0)\mathcal{B}(f_0 \to \pi^+\pi^-) < 1.63 \times 10^{-4} \text{ (90\% CL)}$$

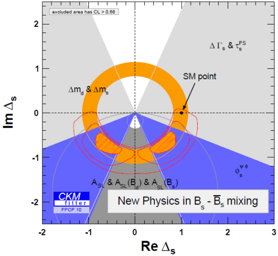
update with 5 times more data (121 fb^{-1}) on going

Belle also observes $B_s^0 \to J/\psi\eta$ and $B_s^0 \to J/\psi\eta'$

Semileptonic asymmetry



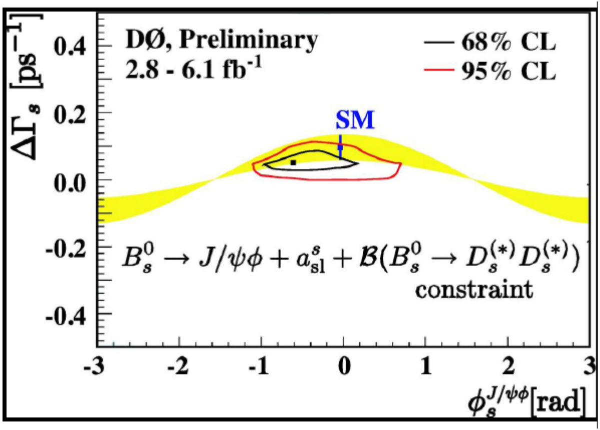
DØ measures $A^b_{sl} = (-0.957 \pm 0.251(\text{stat}) \pm 0.146(\text{syst}))\%$
SM prediction is $(-0.023^{+0.005}_{-0.006})\%$
Measurement is $\sim 3.2\sigma$ away from SM



without 2010 CDF/DØ results on $B^0_s \to J/\psi\phi$

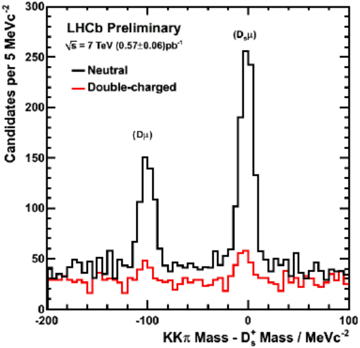
Hypothesis	p-value
$\Delta_d = 1$	$2.5\ \sigma$
$\Delta_s = 1$	$2.7\ \sigma$
$\Delta_d = \Delta_s = 1$	$3.4\ \sigma$

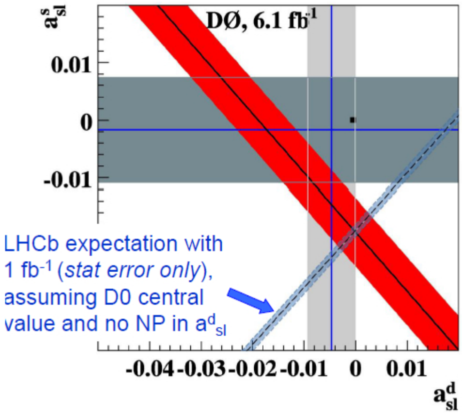
DØ ICHEP $B_s^0 \to J/\psi\phi$ results including asl and DsDs



LHCb projection of $a_{\rm fs}$

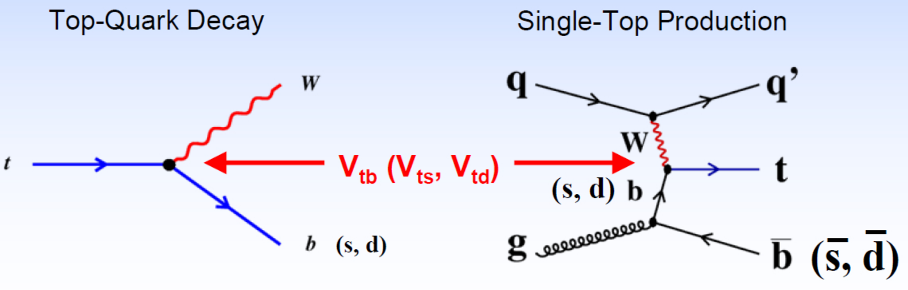
LHCb propose to measure $a_{\rm sl}^{\rm s} - a_{\rm sl}^{\rm d}$ by determining the difference in the asymmetry measured in $B_s^0 \to D_s^-(KK\pi)m\mu^+\nu$ & $B^0 \to D^-(KK\pi)m\mu^+\nu$. Same final state suppresses detector biases. Provide orthogonal constraint to DØ dileptons.





Events already being accumulated

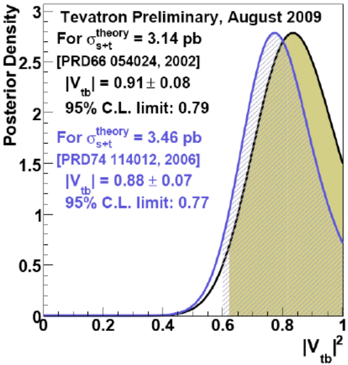
$V_{\rm td}$, $V_{\rm ts}$ and $V_{\rm tb}$

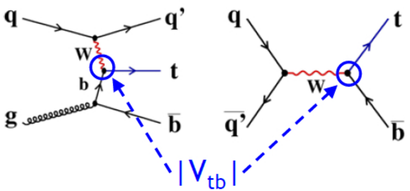


$$R_b = \frac{\mathcal{B}(\mathrm{t})\mathrm{Wb}}{\mathcal{B}(\mathrm{t})\mathrm{Wq}} = \frac{|V_{\rm tb}|^2}{|V_{\rm tb}|^2 + |V_{\rm ts}|^2 + |V_{\rm td}|^2}$$

DØ result Phys. Rev. Lett. 100 (2008) 192003 ($\mathcal{L}^{\rm int}$= 0.9 fb^{-1}):
$R_b = 0.97^{+0.09}_{-0.08}$(stat.+sys.) $R_b > 0.79$ at 95% CL
$\Rightarrow \quad |V_{\rm ts}|^2 + |V_{\rm td}|^2 < 0.263 \cdot |V_{\rm tb}|^2$

Direct V_{tb} Tevatron result





$|V_{tb}| = 0.88 \pm 0.07$ (stat+syst) $\pm$ 0.07 (theory)

CDF and DØ Collaborations:
arXiv: 0908.2171 [hep-ex]

Tevatron starts to be limited by systematics

Charm Theory I

Usual definitions:

$$x = \frac{\Delta M}{\Gamma}\,, \quad y = \frac{\Delta \Gamma}{2\Gamma}$$

In principle the same formalism as in the B-system
BUT Keep in mind: now $\Gamma_{12}/M_{12} \approx \mathcal{O}(1)$

Still no satisfactory theoretical approach available

- Exclusive approach: Falk, Grossmann, Ligeti, Nir, Petrov
- Inclusive apporach: Georgi; Ohl, Ricciardi, Simmons; Bigi, Uraltsev

Very important question:
How large can CP-violation in D-mixing in the SM be?

- sometimes in the literature: 10^{-3} is an unambigous sign of new physics
- Petrov: at most $\approx 10^{-3}$ in SM; 10^{-2} is a “smoking gun” signature of NP
- Bobrowski, Lenz, Riedl, Rohrwild: not excluded: up to $5 \cdot 10^{-3}$ in SM

Charm Theory II

Despite the big problems to determine the SM expectations to D-mixing:
D-mixing gives very strong bounds on new Physics models

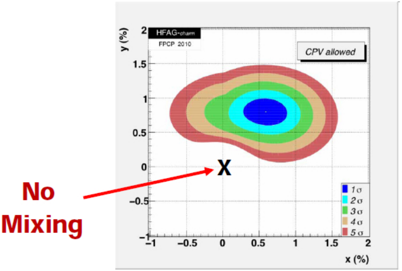
Petrov; Golowich, Hewett, Pakvasa, Petrov 2007

Sensitive up to scales of $10^2 ... 10^3$ TeV

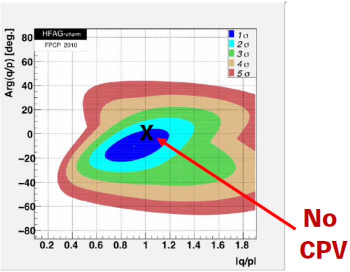
Also very interesting effects in decays of charmed baryons - see Alexejs Petrov's talk

Charm experimental status

Combined result of Belle, BaBar and CDF



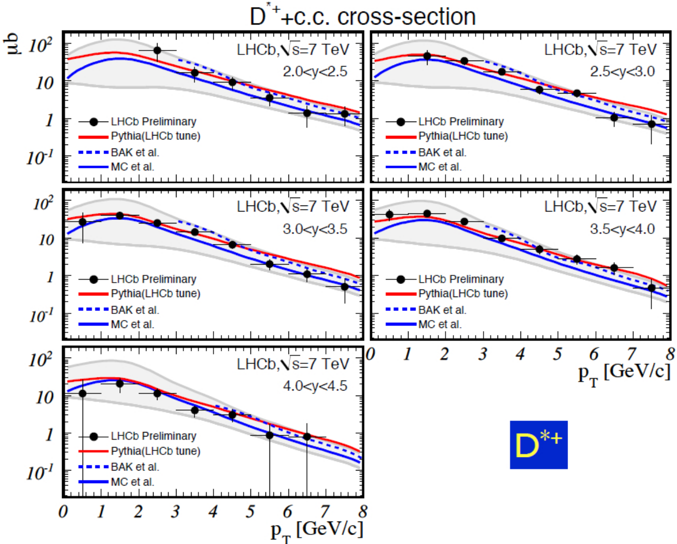
A. Schwartz *et al.*
arXiv:0803.0082
(updated FPCP 2010)



- D-mixing established at 10σ level while no single experiment has yet a 5σ observation
- the most significant contribution are the least constraining in term of excluding "no-mixing"
- Babar and CDF find $x'^2 < 0$

Charm at LHCb

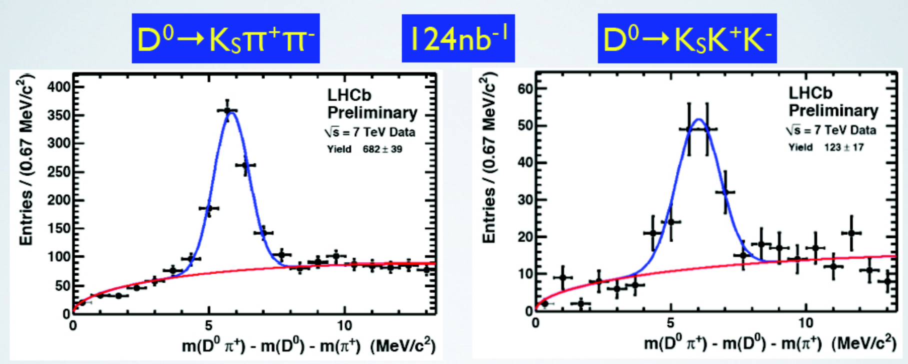
First presentation of charm cross-section results
In broad agreement with theory



D*+

Charm at LHCb

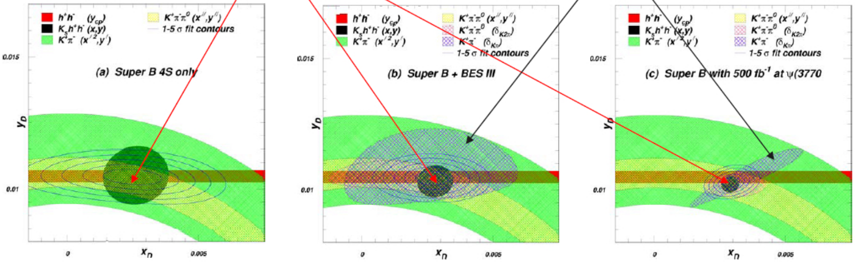
Many D decay already reconstructed
Acquired LHCb data sets approach existing data sets of other experiments



Mixing and CPV analyses in preparation
Expect to acquire enough data to significantly increase sensitivities in the course of next year

Charm prospects

- Dalitz plot model uncertainty shrinks
- Information on overall strong phase $\delta_{K\pi}$ is added



$$x_D = (xx^{+7.2}_{-7.5}) \times 10^{-4} \qquad y_D = (xx \pm 1.9) \times 10^{-4}$$

BES III →

$$x_D = (xx \pm 4.2) \times 10^{-4} \qquad y_D = (xx \pm 1.7) \times 10^{-4}$$

SuperD →

$$x_D = (xx \pm 2.0) \times 10^{-4} \qquad y_D = (xx \pm 1.2) \times 10^{-4}$$

Real improvement would come from running at the $\psi(3770)$

Conclusions

- Good progress since last CKM workshop
- New experimental results from this year in the B_s sector
- Final $\sin 2\beta$ from Belle expected in near future
- Lattice QCD keeps up improving precision
- Several numerical updates on theory side
- Charm mixing still waits for single 5σ measurement
- CP Violation in charm starts to touch region where it will be hard to claim new physics

Prospects

- Tevatron is still accumuating data
- Belle has 120 fb^{-1} at $\Upsilon(5S)$ to analysis compared to 23.5 fb^{-1} analysed now
- LHCb collects data quickly
- Super B factory is going to happen and can provide new improvements
- We had few interesting discussions (specially about penguin contributions to CPV), hopefully we can make progress in next two years

Backups