
1954-2004
CERN
World Year of PHYSICS 2005
Flavour in the era of the LHC
a Workshop on the interplay of flavour and collider physics
First meeting:
CERN, November 7-10 2005
Report from Working Group 2
B/D/K Decays
• BSM signatures in B/K/D physics, and their complementarity with the high-p_T LHC discovery potential
• Flavour phenomena in the decays of SUSY particles
• Squark/slepton spectroscopy and family structure
Conveners
Gerhard Buchalla, Luca Silvestrini (theory)
Takeshi Komatsubara, Franz Muheim (experiment)
Local Organizing Committee
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D. Denegri (Saclay, Gif sur Ivette)
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Y. Semertzidis (BNL, Brookhaven)
S. Stone (Syracuse University)
M. Yamauchi (KEK, Tsukuba)
P. Zerwas (DESY, Hamburg)
http://mlm.home.cern.ch/mlm/FlavLHC.html

Outline

- Scope of WG2
- Benchmark processes
- Tasks
- Experimental Summary

Flavour Physics 2005-2015

- High energy collider ⟵ BSM ⟶ Precision flavour studies
  - New particle masses
    flavour couplings

- Precision flavour studies
  - Rare decays ↔ CP violation
  - B/D/K experiments beyond LHC
    - Super B factories
    - Fixed target D/K at PS/SPS or JPARC
  - Flavour mixing: quarks ↔ leptons
  - Hadronic uncertainties

Benchmark processes

- $b \to s\gamma$, $b \to d\gamma$, $b \to sll$, $b \to s\nu\nu$
- $B_{s,d} \to \mu^+\mu^-$
- $B \to \tau+\nu$, $D\tau+\nu$
- UT angles
  - $Bd \to \psi K_S$, DK, $\pi\pi$, $\rho\rho$
  - $Bs \to DsK$, KK
- B_s-$B_s$bar mixing
- $b \to s$ hadronic transitions
  - $Bd \to phiK_S$, …
- $K \to \pi\nu\nu$, $K_L \to \pi^0 ll$
- D^0-D^0bar mixing, D rare decays

➔ Need info on all possible flavour transitions

- $b \to s$ $b \to d$ $s \to d$

➔ Theoretically clean observables

th. error $\lesssim 10\%$
= exp. error $\lesssim 10\%$
= exp. error $\sim 30\%$

Table from G. Isidori

ELECTROWEAK STRUCTURE	FLAVOUR COUPLING: $b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s \to \psi\phi)$	ΔM_{Bd} $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4-quark box	$B_d \to \phi K$ $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s\gamma$ $B_d \to \phi K$ $B_d \to K\pi$, ...	$B_d \to X_d\gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
γ penguin	$B_d \to X_s l^+ l^-$ $B_d \to X_s\gamma$ $B_d \to \phi K$ $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to X_d\gamma$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
Z^0 penguin	$B_d \to X_s l^+ l^-$ $B_s \to \mu\mu$ $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to \mu\mu$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, $K \to \pi\nu\nu$, $K \to \mu\mu$, ...
H^0 penguin	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

Pattern of the deviation from the SM

Table from M. Hazumi

Unitarity triangle | Rare decays

	Bd-unitarity	e	D m(Bs)	B->fKs	B->Msg indirect CP	b->sg direct CP
mSUGRA	-	-	-	-	-	+
SU(5)SUSY GUT + n_R (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + n_R (non-degenerate)	-	-	+	++	++	+
U(2) Flavor symmetry	+	+	+	++	++	++

++: Large, +: sizable, -: sma

"DNA Identification" of New Physics from Flavor Structure

T.Goto, Y.Okada, Y.Shimizu,T.Shindou, M.Tanaka (2002, 2004) + SuperKEKB LoI

List of Tasks

- **Study complementarity between collider and flavour physics**
  - SUSY benchmark (e.g. SPS1a) in collider physics
  - Add flavour violation ($\rightarrow$ squark decays)
  - Compute effective Hamiltonian (OPE)
  - Evaluate flavour observables, check consistency with data
- **Beyond SUSY**
  - NP model independent studies, MFV

➔ Common session WG1 & WG2

- **Hadronic Uncertainties**

➔ dedicated session at next meeting

- **Experimental Studies**
  - Sensitivities – LHC, (super-)B & tau/charm factories, fixed target
  - Triggers, Backgrounds,

Future tasks:

- Most MC analyses at the LHC are done within MSUGRA only:
  mostly flavour diagonal, squark mass degeneracy
- Experimental issue of flavour tagging
- Necessary update to be done:
  $b \to s\ell^+\ell^-$, $A_{CP}(b \to s\gamma)$, $A_{FB}(b \to s\ell^+\ell^-)$,...
- Extension of the Les Houches Accord for flavour-nondiagonal quantities
  ($\to$ Peter Skands et al.)
- Need of program sets to connect collider with low-energy data
  (program sets existing on each side!)

(Experimental) Summary

- Gamma at tree level (includes Vub)
  - B-> DK Dalitz – Babar/Cavoto, Belle/Gershon, LHCb/Schneider
  - B_s->D_sK, B_s-> K+K- – LHCb/Schneider
- Sin2β with penguins
  - Belle/Gershon
  - Babar/Pierini
  - Super-B/Hazumi
  - Many theory talks
- Charm
  - D^0-D^0bar mixing, D rare decays, decay constants, comparison with Lattice QCD/ Stone
- Kaons
  - $K^+ \rightarrow \pi^+ \nu\nu$ NA48/Ruggiero, Littenberg
  - $K_L \rightarrow \pi^0 \nu\nu$ E391a/KEK Komatsubara, Littenberg
  - Theory talks / Buras, Scimemi

(Experimental) Summary

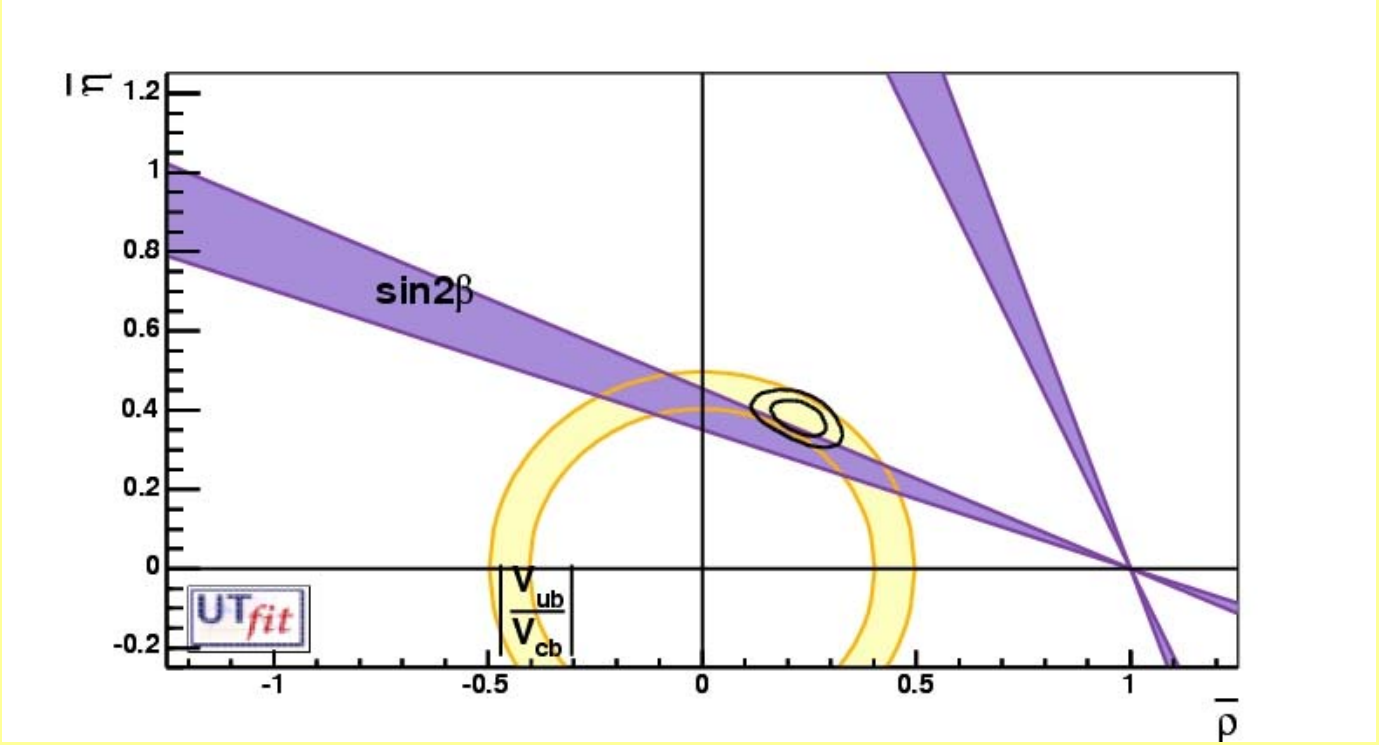
- Radiative Penguins b-> sγ, b->dγ, B->tau nu
  - Belle/Iijima
  - BaBar/ Playfer
- Electroweak Penguins B(s) -> ll K(*), ll s
  - Belle/Hazumi/Iijima
  - Babar/Playfer
  - LHCb/Koppenburg
  - Theory/Ligeti
- Bs->mumu
  - LHCb/Schneider
  - CDF/Oldeman
  - C0/Ay
  - Atlas/Nikitine
  - CMS/Speer

(Experimental) Summary

- Bs mixing
  - Mass difference Δm_s, weak mixing phase ϕ_s lifetime difference $\Delta\Gamma_s/\Gamma_s$,
  - CDF/Oldeman
  - D0/Ay
  - LHCb/Fernandez
- Unitarity fits
  - CKMfitter/ Robert
  - UTfit/Stocchi

SM test - sin2β vs Vub

Stocchi



sin2β=0.687±0.032
From direct measurement

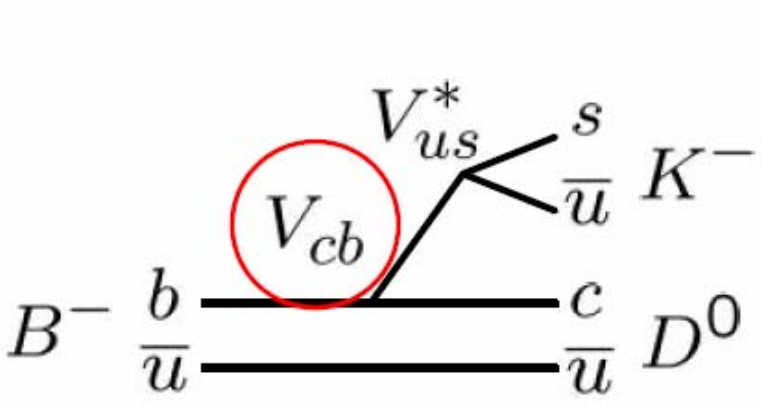
we have a weak sign of a disagreement

sin2β =0.791±0.034
from indirect determination

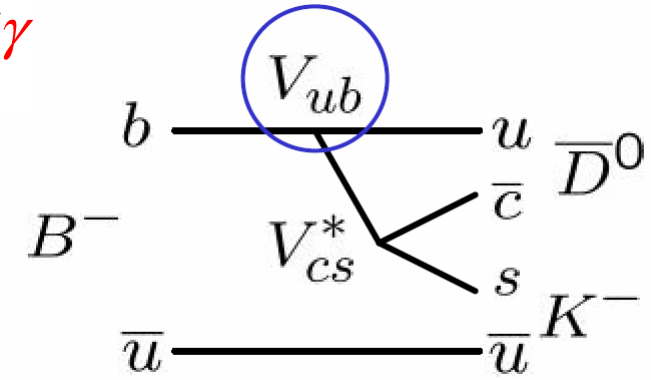
$$|V_{ub}|_{\mathrm{WAvg}} = (4.38 \pm 0.19_{\mathrm{expt}} \pm 0.27_{m_b,\ \mathrm{theory}}) \times 10^{-3}$$

γ from direct CP violation

Cavoto



$e^{i\delta_B}e^{-i\gamma}$



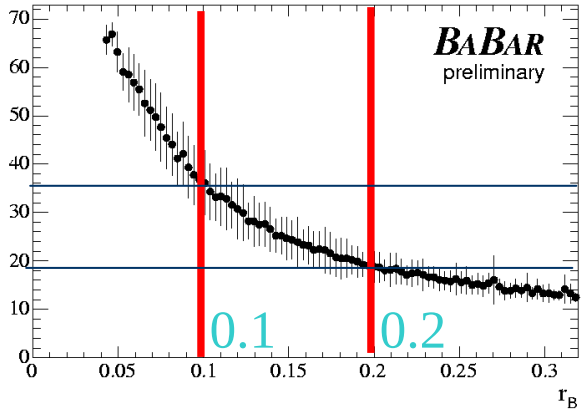
Interference when D final state common to both D^0 and D^0

Relative size (r_B) of B decay amplitudes

$$r_B = \left| \frac{A(b \to u)}{A(b \to c)} \right|$$

$\sigma(\gamma)$

(degrees)



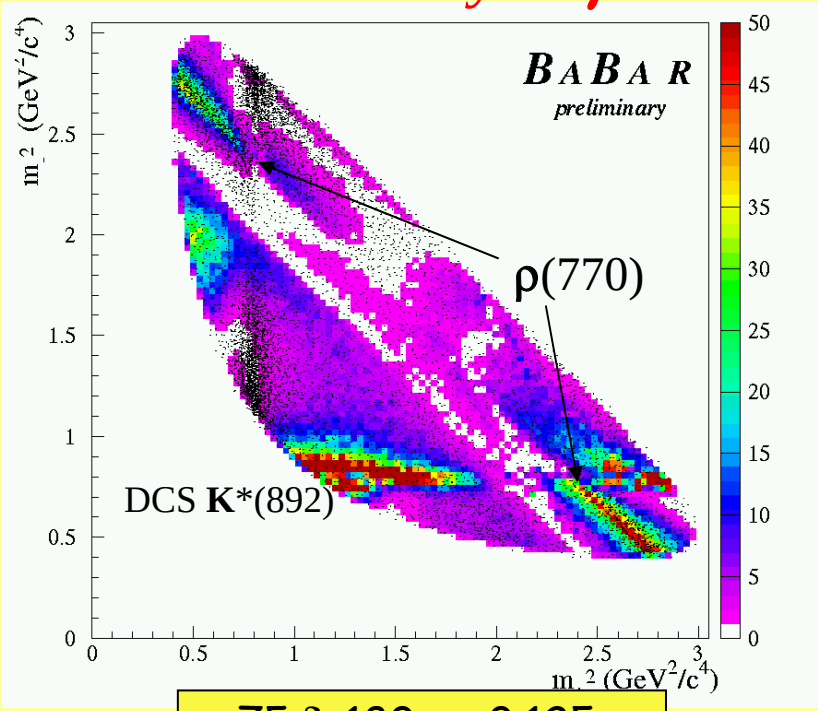
r_B

Larger r_B, larger interference,
better γ experimental precision

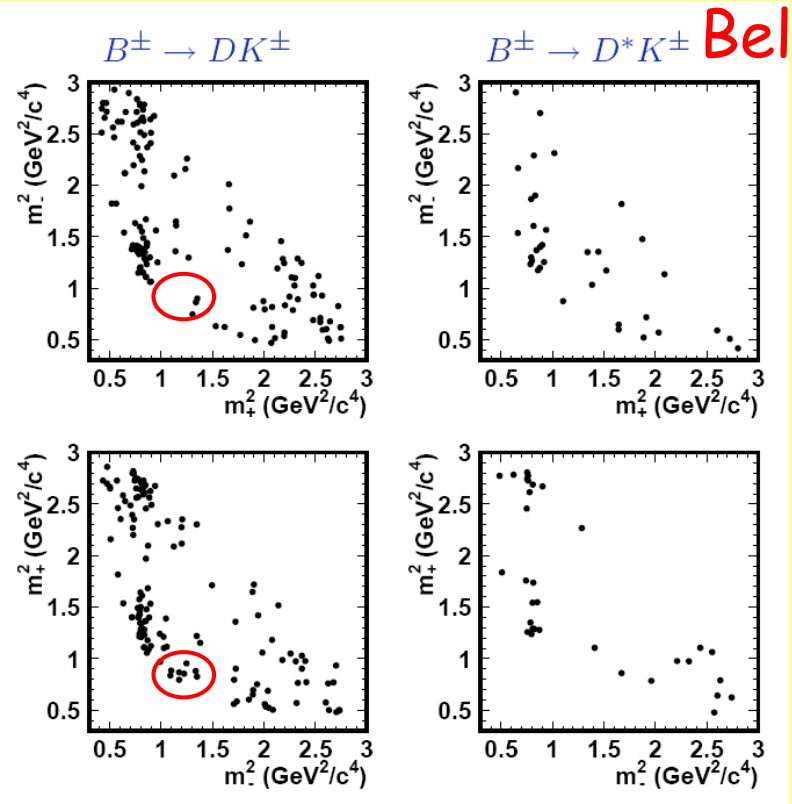
γ from B->DK Dalitz analysis

Cavoto
Gershon

Sensitivity to γ



γ=75,δ=180,r_B=0.125

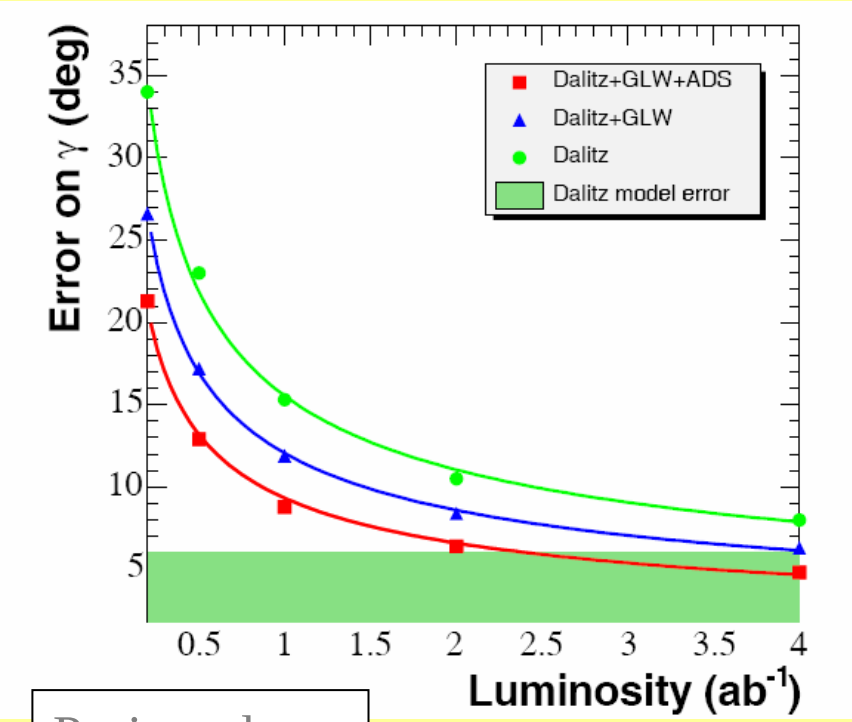


BaBar $\gamma = [67^\circ \pm 28^\circ$ *(stat.)* $\pm 13^\circ$ *(syst. exp.)* $\pm 11^\circ$ *(Dalitz model*)* $]$

Belle $\phi_3 = 68^\circ\ ^{+14^\circ}_{-15^\circ}\text{(stat)} \pm 13^\circ\text{(syst)} \pm 11^\circ\text{(model)}$

Projected γ uncertainty from B->DK

Cavoto
Schneider



Projected sys error due to D^0 Dalitz plot

Candidate for LHCb's statistically most precise determination of γ

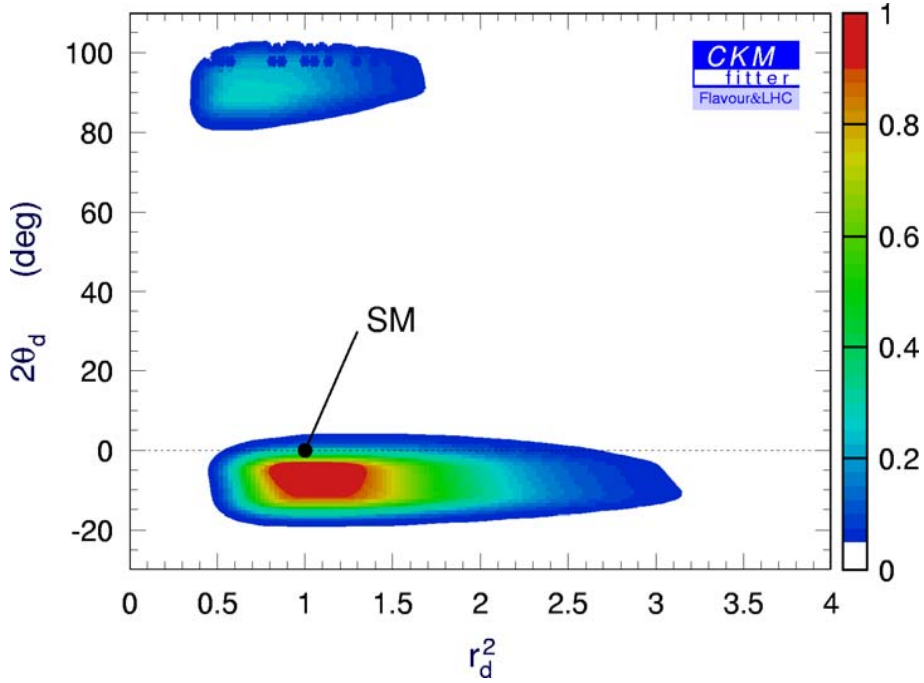
$\sigma(\gamma) \sim 5^\circ$ in one year ?

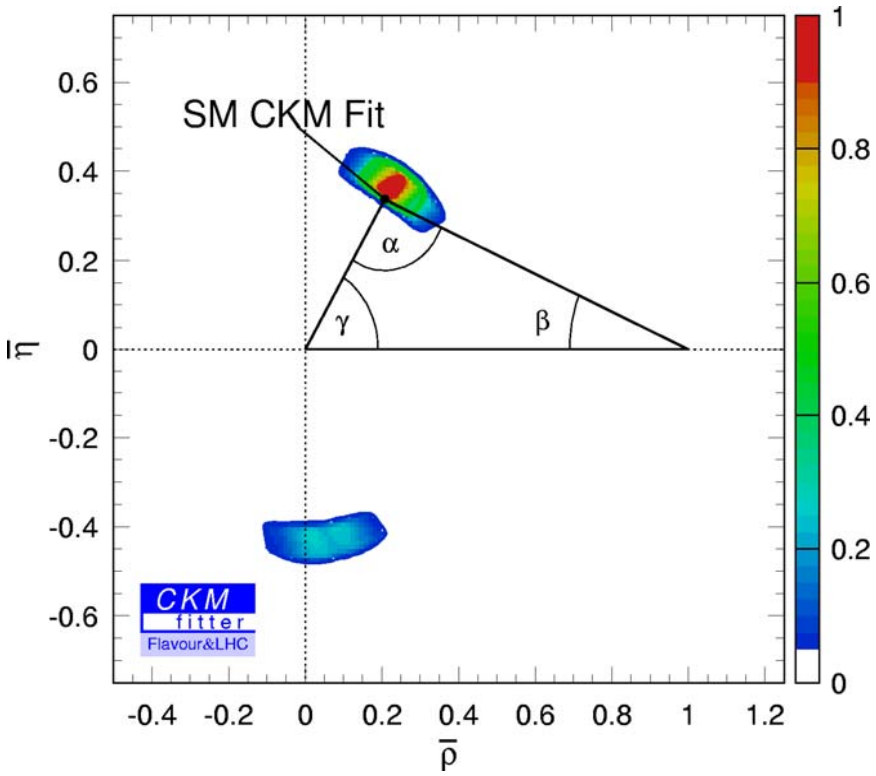
To be studied during this workshop …

Robert

NP in B_d-$\bar{B}_d$ mixing (IV)

- $\rightarrow |V_{ub}|/|V_{cb}|$
- $\rightarrow r_d^2 \Delta m_d$
- $\rightarrow \sin(2\beta + 2\theta_d)$
- $\rightarrow \cos(2\beta + 2\theta_d)$
- $\rightarrow \gamma \quad (ADS + GLW + GGSZ)$
- $\rightarrow \sin(2\beta + 2\theta_d + 2\gamma)$





γ and α are of major importance in constraining the NP parameters.

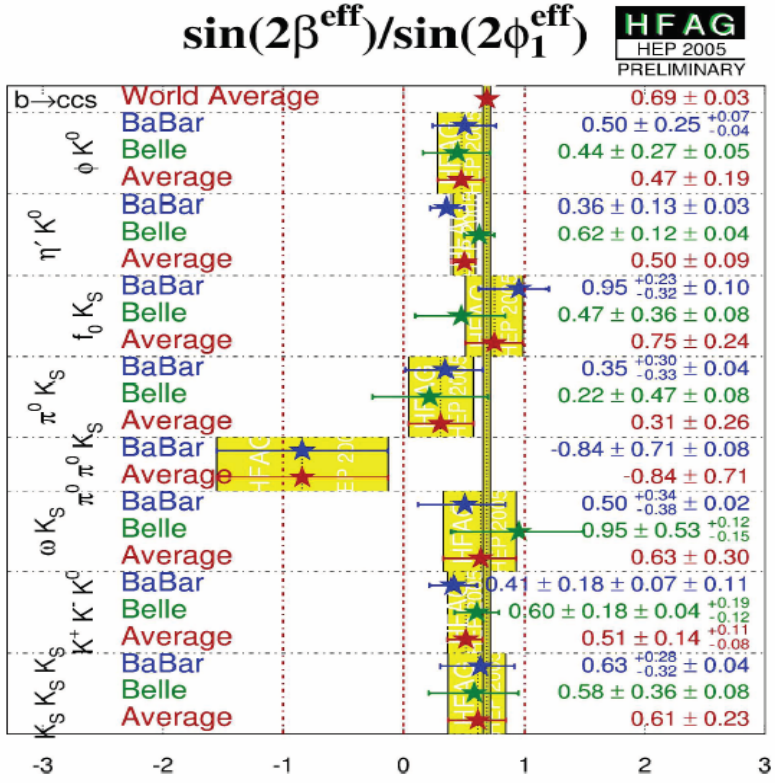
NB: $\sin(2\beta+2\theta_d+\gamma)$ is not included. (almost no influence.)

sin2β from Hadronic Penguins

Current Experimental Status

Good agreement between BaBar and Belle

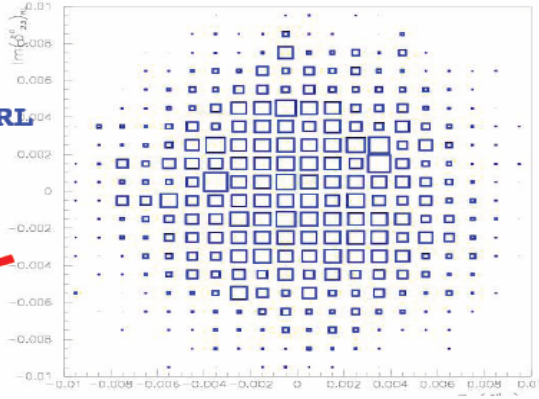
Consistency among different channels



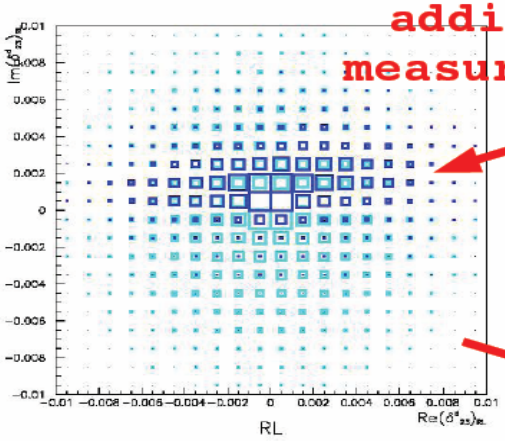
sin2β from Hadronic Penguins

Limits on SUSY mass insertion parameters

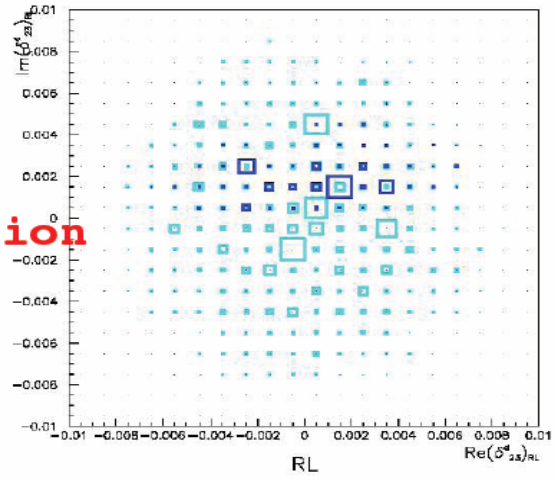
$\mathrm{Re}(\delta^d_{23})_{RL}$ vs $\mathrm{Im}(\delta^d_{23})_{RL}$



adding S measurements



extrapolation to 2008



No b→s time dep.

With b→s time dep.

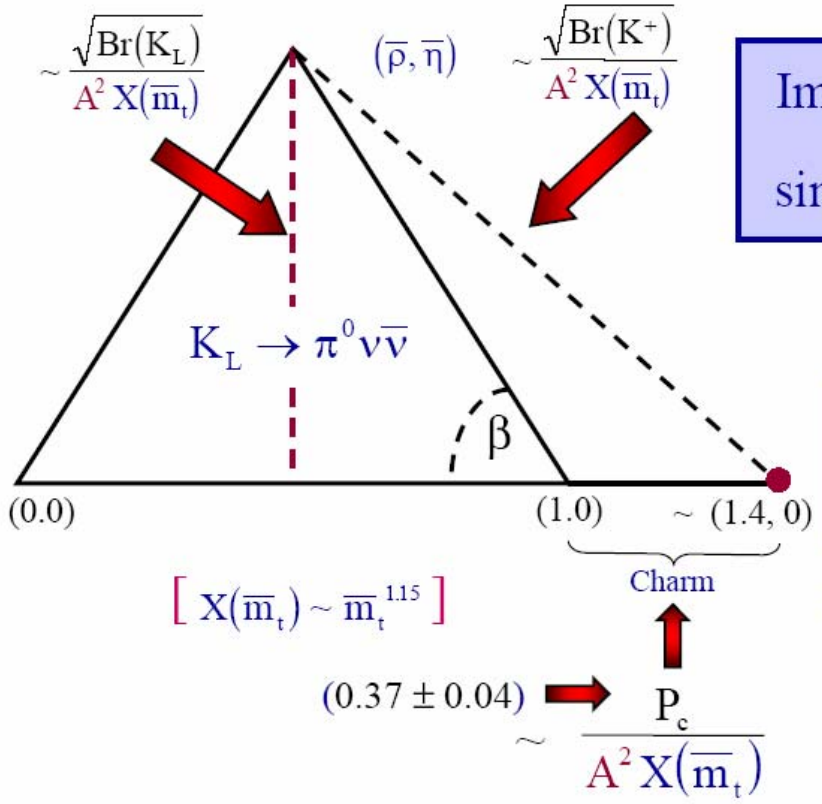
Maurizio Pierini
Flavor in the era of the LHC

Rare Kaon Decays

Buras

UT from $K \to \pi\nu\bar{\nu}$

Buchalla
AJB



$$\mathrm{Im}\,\lambda_t = F_1\left(\bar{m}_t, Br(K_L)\right)$$

$$\sin 2\beta = F_2\left(P_c, Br(K_L), Br(K^+)\right)$$

$$\lambda_t = V_{ts}^* V_{td}$$

$\sin 2\beta$ $(K \to \pi\nu\bar{\nu})$ $\Leftrightarrow$ $\sin 2\beta$ $(B \to J/\psi, K_s)$ $\to \varphi K_s$

K-Physics $\Leftrightarrow$ B - Physics

$[\, X(\bar{m}_t) \sim \bar{m}_t^{1.15} \,]$

$(0.37 \pm 0.04) \to \sim \frac{P_c}{A^2 X(\bar{m}_t)}$

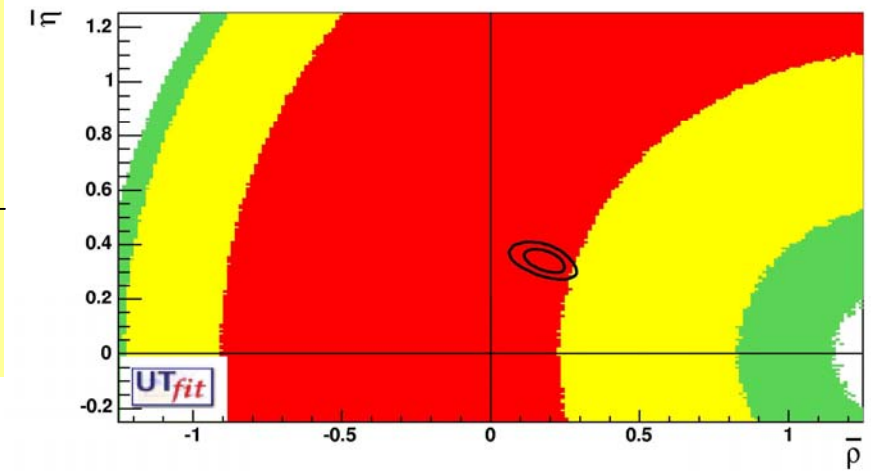
Test of SM and Beyond

Prospects for $K^+ \to \pi^+\nu\nu$ at CERN/SPS

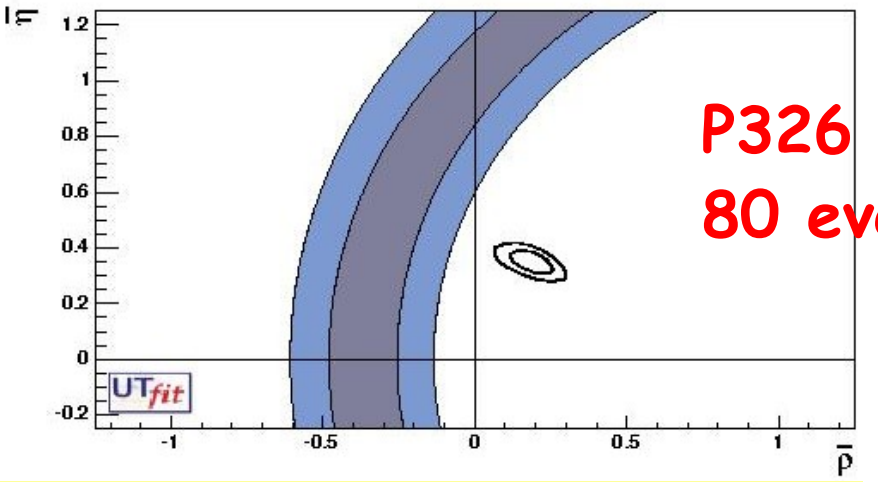
- Present (E787/949): $BR(K^+ \to \pi^+\nu\nu) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

Ruggiero

Current constraint on ρ, η plane

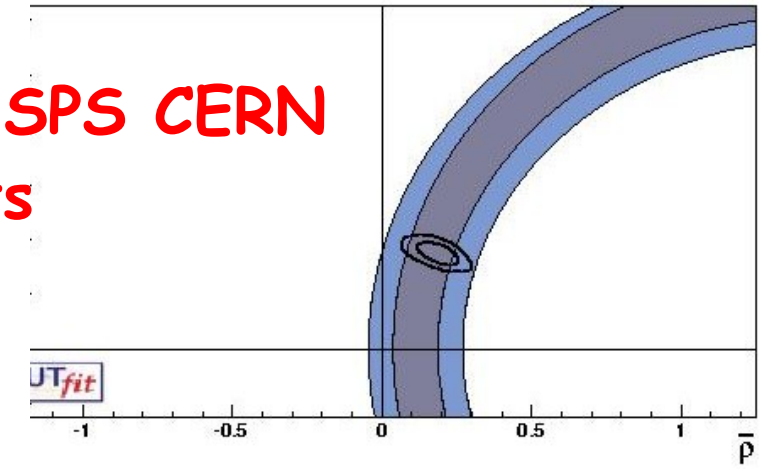


100 events
Mean: E787/949

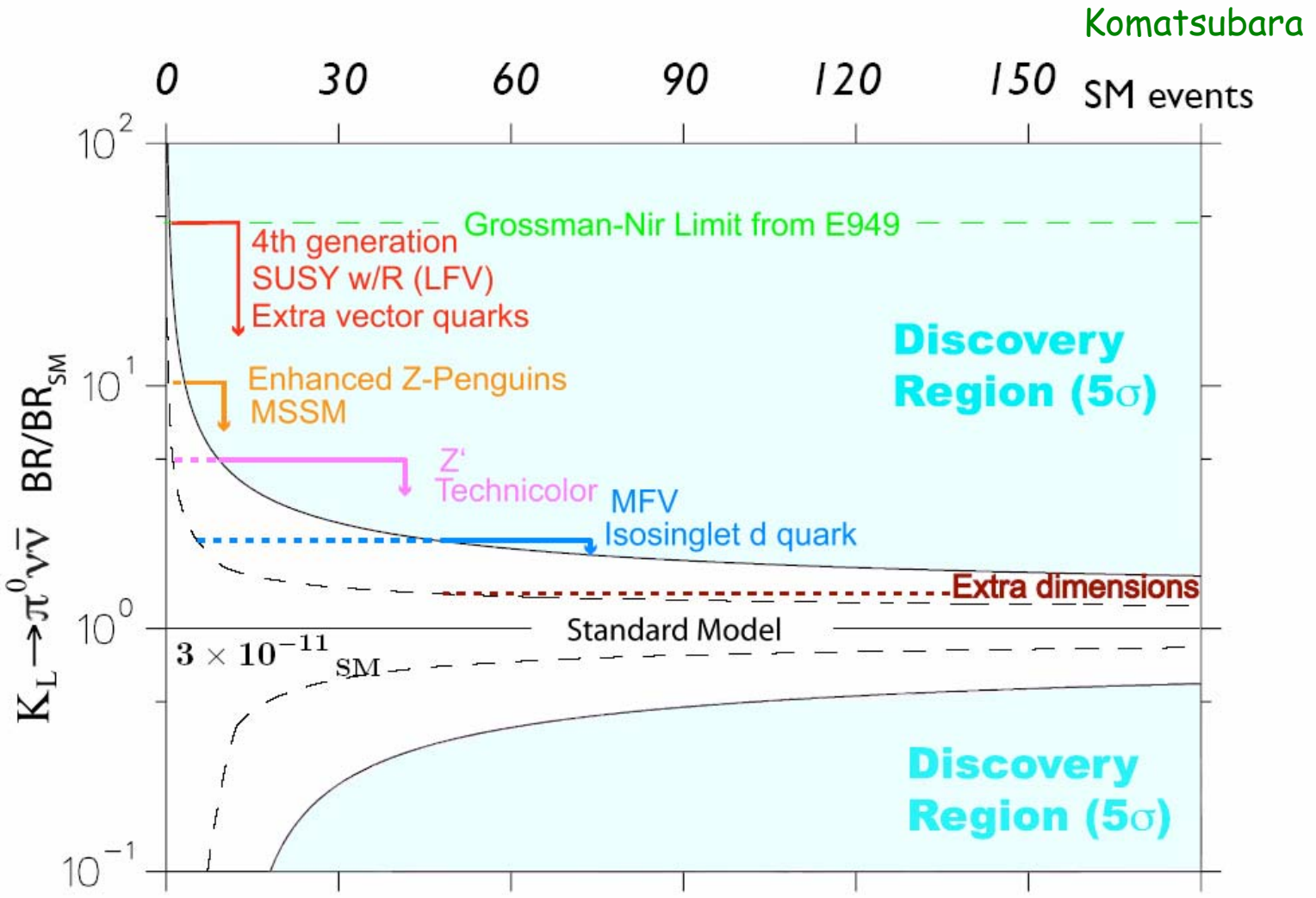


P326 at SPS CERN
80 events

100 events
Mean: SM



Prospects for $K^0_L \to \pi^0\nu\nu$ at JPARC



based on Bryman-Buras-Isidori-Littenberg, hep-ph/0505171

D^o- $\bar{D}^o$ mixing: the data

Stone

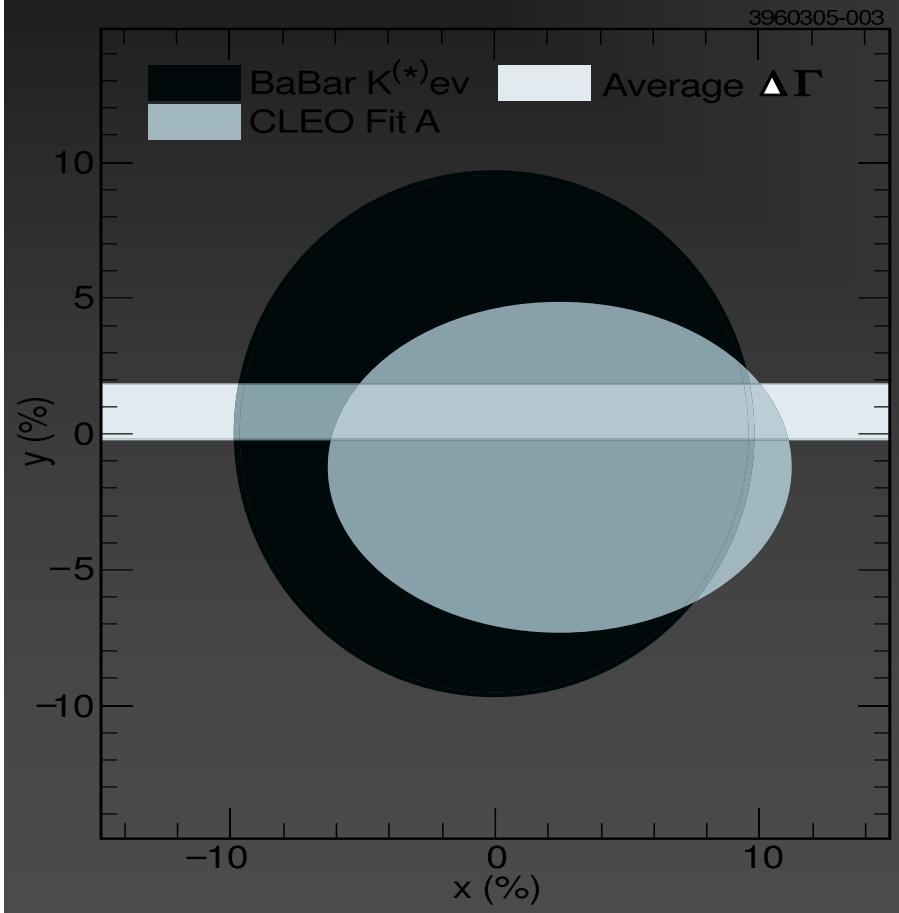
- The study of D^o wrong-sign $K\pi$ yields has been a key step in our experimental study of D^o $\bar{D}^o$ mixing.
- Caveats:
  - Complicated by interference between DCSD & mixing [strong phase $\delta \Rightarrow$ data constrain only x' & y']
  - Complicated by CP violation

Experiment	x'^2 (95 % C.L.) ($X10^{-3}$)	y'(95% C.L.) ($X10^{-3}$)
Belle (2004)	0.81	$-8.2<y'<16$
BaBar (2003)	2.2	$-56<y'<39$
FOCUS (2001)	1.52	$-124<y'<-5$
CLEO (2000)	0.82	$-58<y'<10$

Most general fit

D^0 $\bar{D}^0$ mixing: the data II

Stone



- D^0 semileptonic decays: $R_{ws} = \frac{1}{2}(x^2+y^2)$ [no strong phase δ]

Experiment	R_M(95% CL)	$\sqrt{x^2+y^2}$
BaBar 04	0.0046	0.1
Belle 05	0.0016	0.056

- Dalitz plot analysis of $D^0 \rightarrow K^0_s \pi^+\pi^-$ (CLEO II.V) comparable sensitivity

b -> d gamma

Playfer

$B \to \rho(\omega)\gamma$ at BaBar

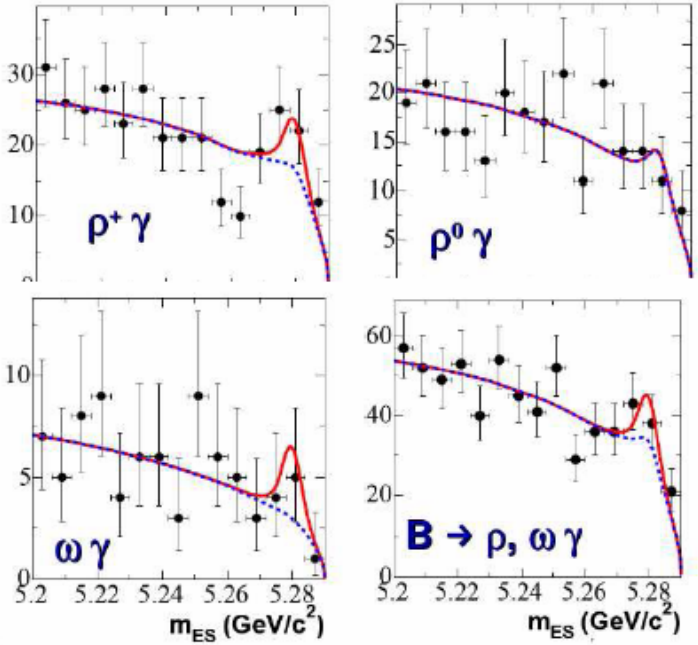
PRL 94, 011801 (2005)

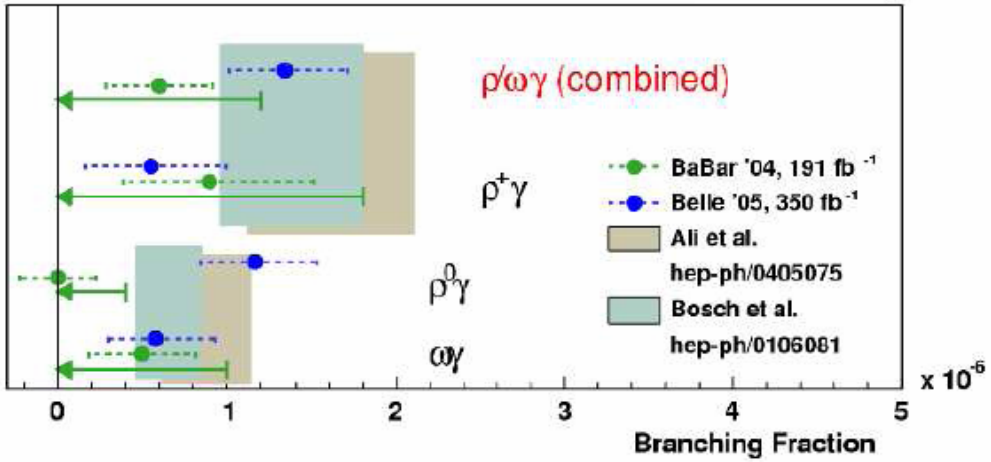
(210 million $B\bar{B}$ pairs)

BaBar sees 2σ excesses in $B^+ \to \rho^+\gamma$, $B^0 \to \omega\gamma$

Combined 90% C.L. upper limit:

$BF(B \to \rho(\omega)\gamma) < 1.2 \times 10^{-6}$





For $B^0 \to \rho^0\gamma$ Belle and BaBar differ by $\approx 3\sigma$!

B->K*l+l- F-B asymmetry

Belle, 2005

Iijima

- 357fb^{-1} (386M BB)
- N(K*ll)=114+-14 (purity 44%)
- Unbinned M.L. fit to $d\Gamma^2/d$ [illegible] $s\theta$)
  - 8 event categories
    - Signal + 3 cross-feed + 4 bkg.

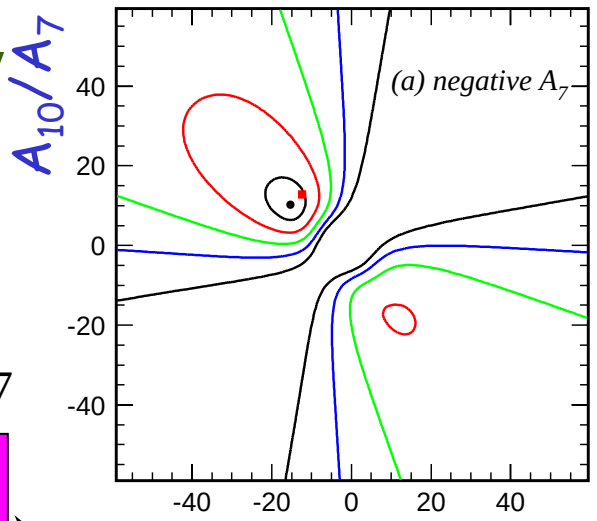
$$A_{FB}^{\text{bkg-sub}}(B \to K^*\ell\ell) = 0.56 \pm 0.13(\text{stat.})$$

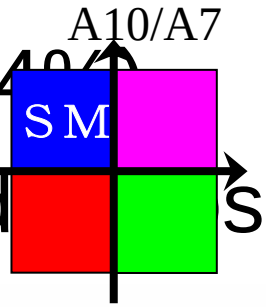
  - Fix $|A_7|$ to SM

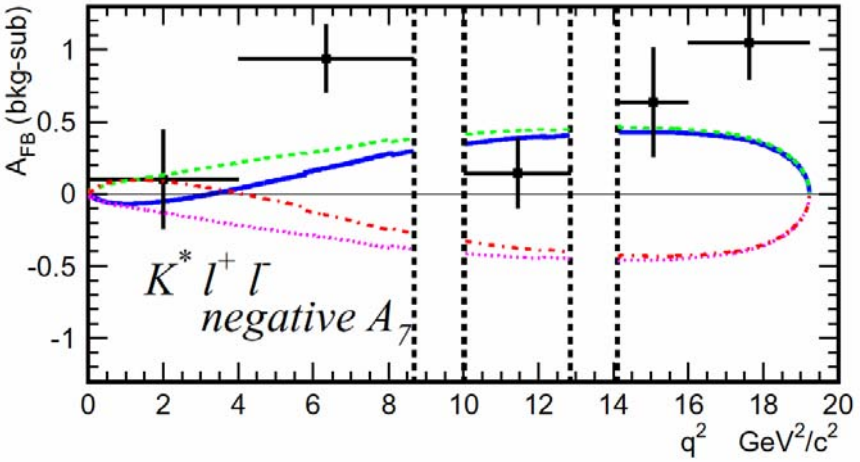
$$A_9/A_7 = -15.3\,^{+3.4}_{-4.8} \pm 1.1,$$
$$A_{10}/A_7 = 10.3\,^{+5.2}_{-3.5} \pm 1.8,$$

- Results:

$$A_9/A_7 = -16.3\,^{+3.7}_{-5.7} \pm 1.4,$$
$$A_{10}/A_7 = 11.1\,^{+6.0}_{-3.9} \pm 2.4,$$







Sign of A_9A_{10} is negative !

See Hep-ex/0508009 &
A.Ishikawa's talk at EPS05

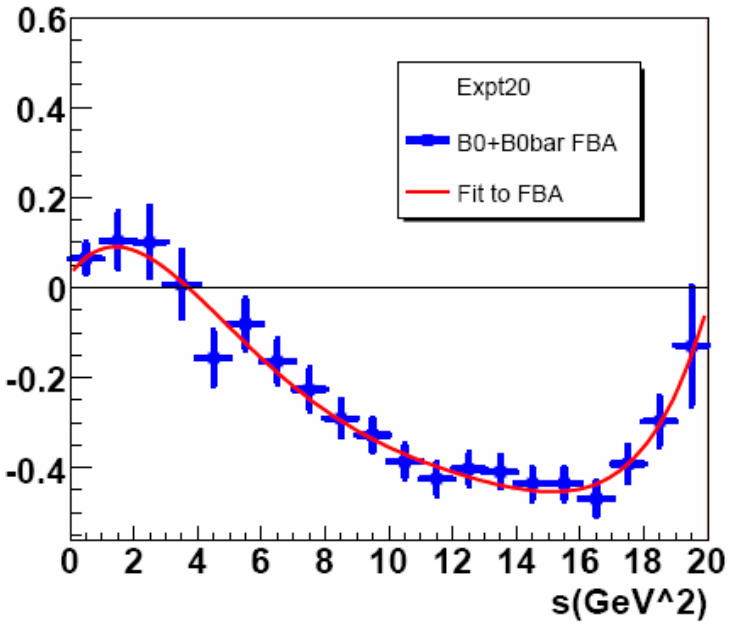
AFB in B->K*ll

Koppenburg
Iijima
Playfer

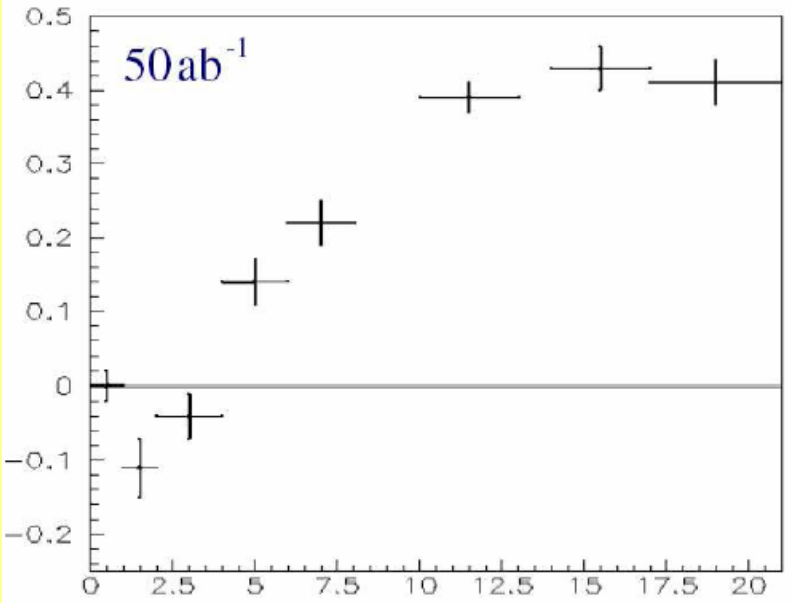
LHCb

- $2\ \text{fb}^{-1}$: $(4.0 \pm 1.2)\ \text{GeV}^2$
- $10\ \text{fb}^{-1}$: $(4.0 \pm 0.5)\ \text{GeV}^2$

$\Rightarrow$ 13% error on $C_7^{\text{Eff}}/C_9^{\text{Eff}}$



Super B-factory



$-A_{FB}$ vs q^2

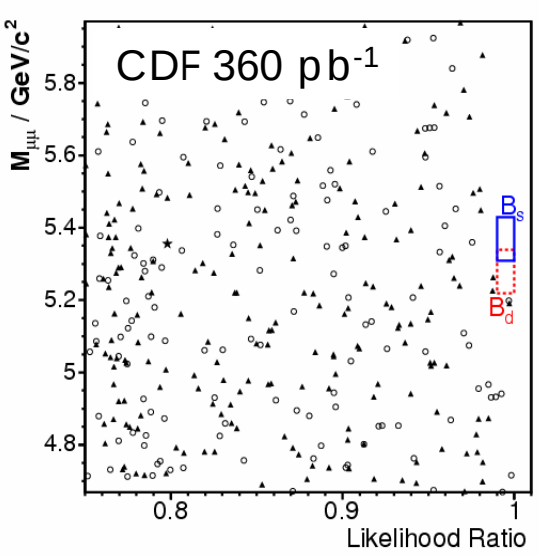
SuperB factory with $50/ab$

δC_{10} ~14%

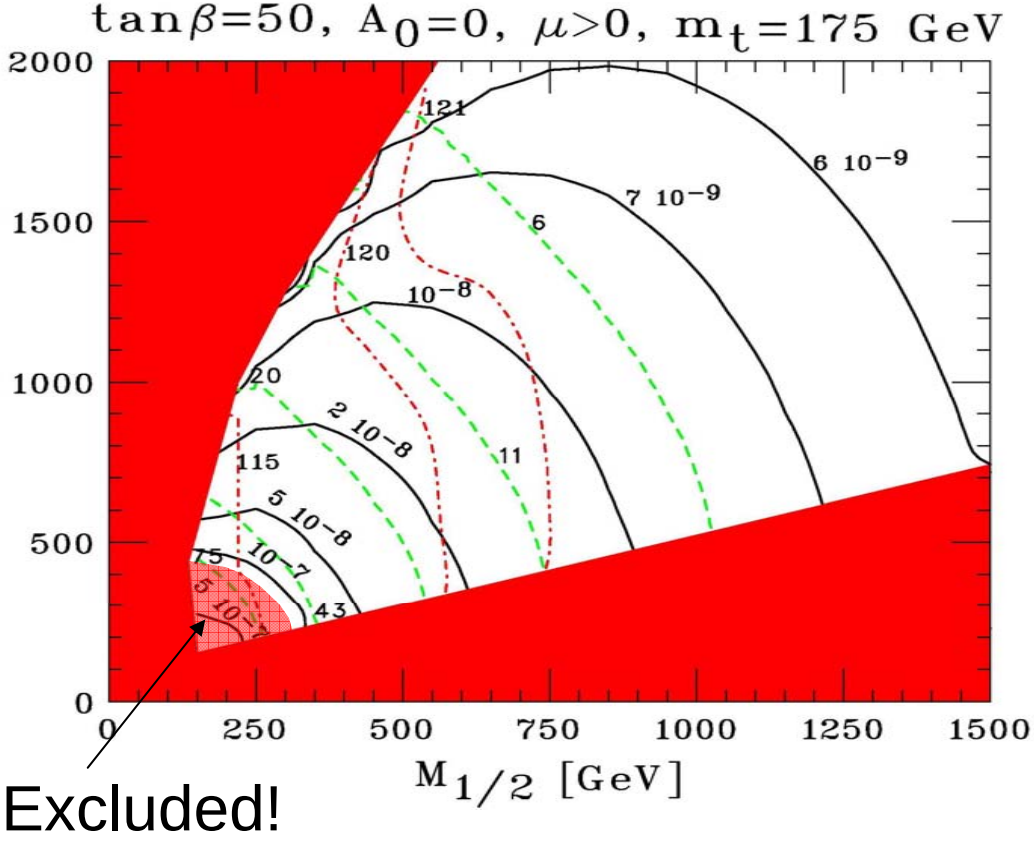
$\delta\, q_0^2/q_0^2$ ~11% ~5%

$B_s \to \mu^+\mu^-$ at Tevatron

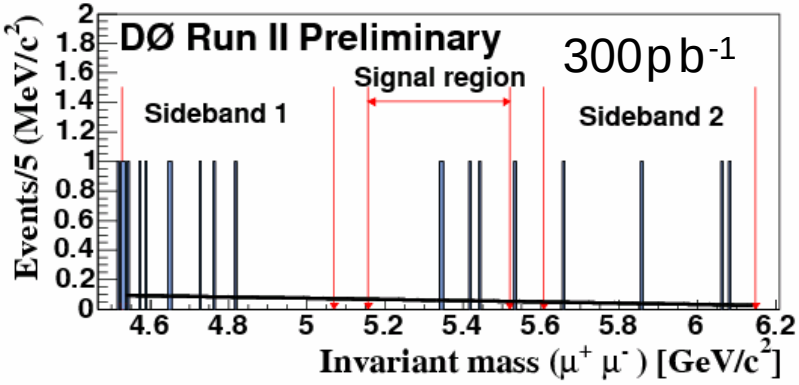
CDF & D0



$B_s \to \mu^+\mu^-$ <2.0×10^{-7}



Excluded!



$B_s \to \mu^+\mu^-$ <3.9×10^{-7}

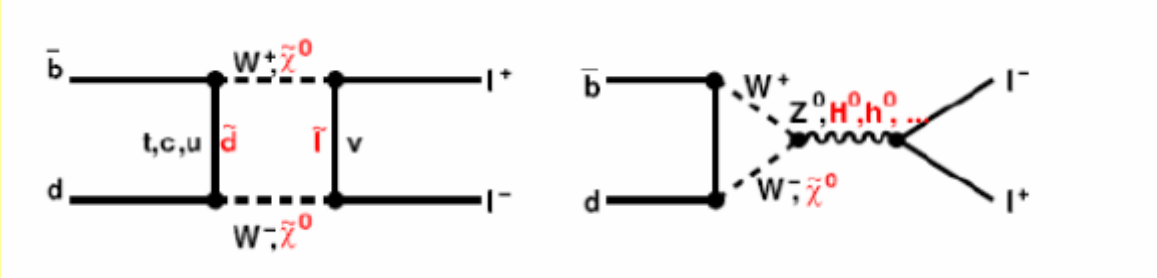
Combined limit:

- $B_s \to \mu^+\mu^-$ <1.5×10^{-7}
  hep-ex/0508058

$B_s \to \mu^+\mu^-$ at LHC

- Very rare decay, sensitive to new physics:
  - BR ~ 3.5×10^{-9} in SM, can be strongly enhanced in SUSY
  - Current limit from Tevatron (CDF+D0): 1.5×10^{-7} at 95% CL

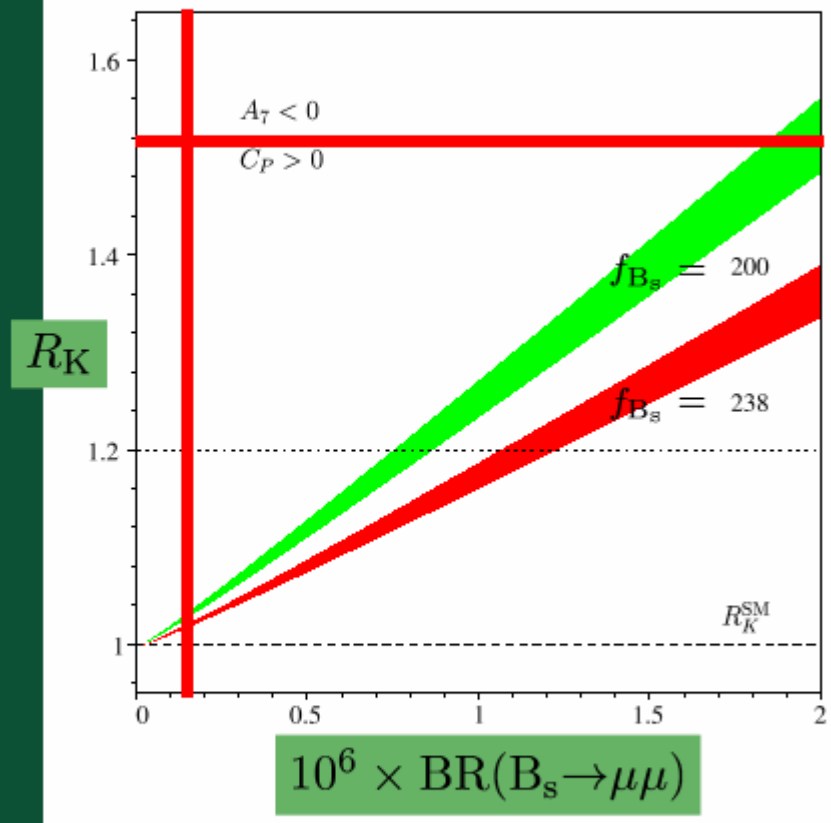
Schneider
Speer
Nikitine



		$B_s \to \mu^+\mu^-$ signal (SM)	$b \to \mu$, $b \to \mu$ background	Inclusive bb background	Single event sensit. [10^{-10}]
LHCb	1 yr - 2 fb^{-1}	17	< 100	< 7500	
ATLAS	10 fb^{-1} 30 fb^{-1}	7 21	~ 20 ~ 60		2.7 0.9
CMS	10 fb^{-1} 100 fb^{-1}	7 26	< 1 < 6.4		

Relation to $B_s \to \mu\mu$

$R_K = \Gamma(B \to K\mu\mu) / \Gamma(B \to Kee)$



[Hiller & Krüger, hep-ph/0310219]

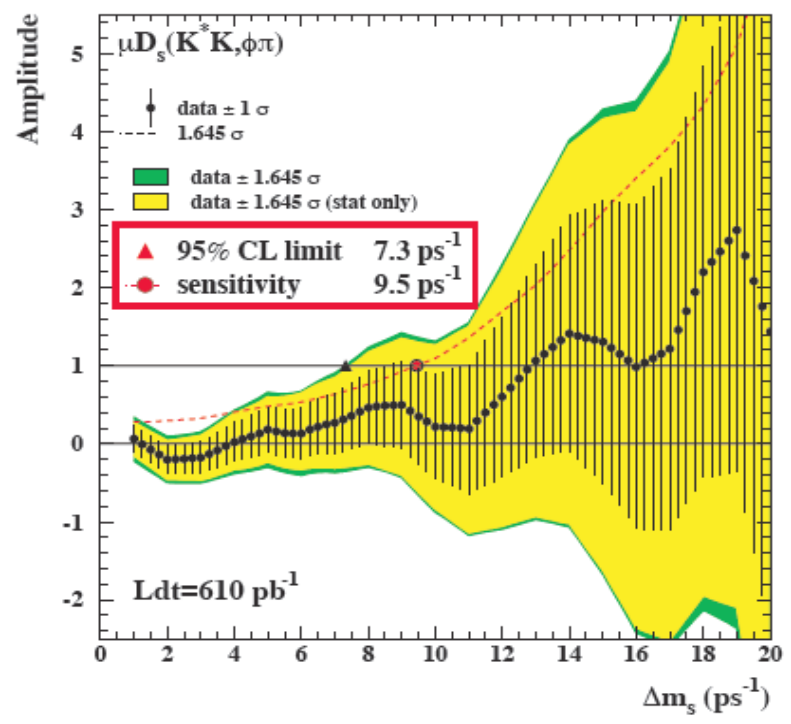
Experimental status:

R_X	BaBar ($208\ fb^{-1}$) [hep-ex/0507005]
R_K	$1.06 \pm 0.48 \pm 0.05$
R_{K^*}	$0.93 \pm 0.46 \pm 0.12$
	Belle ($250\ fb^{-1}$) [hep-ex/0410006]
R_K	$1.38\ ^{+0.39}_{-0.41}\ ^{+0.06}_{-0.07}$
R_{K^*}	$0.98\ ^{+0.30}_{-0.31} \pm 0.08$

$B_s \to \mu\mu$: The present CDF limit is $1.5 \cdot 10^{-7}$ at 90% CL [hep-ex/0508036]

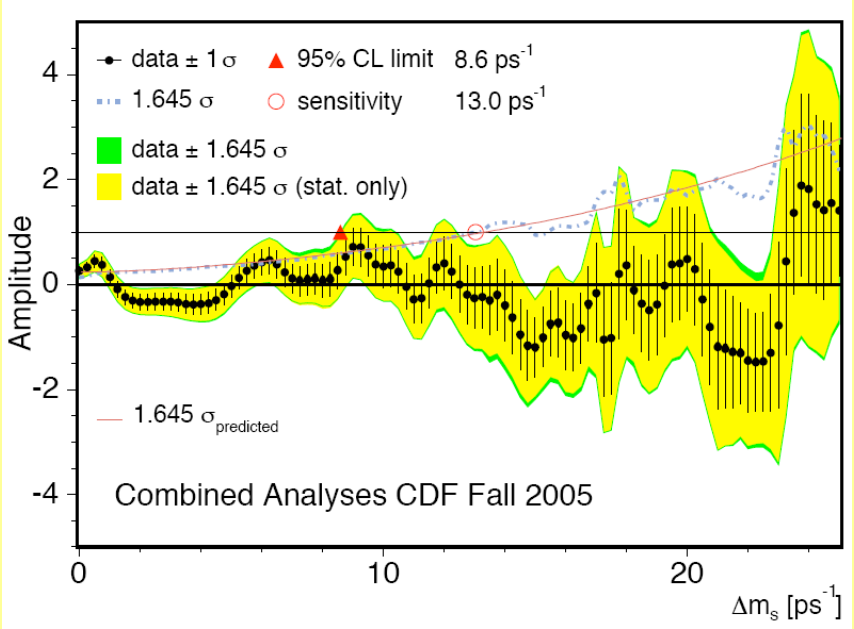
New Bs mixing results from Tevatron

D0



CDF

Ay Oldeman



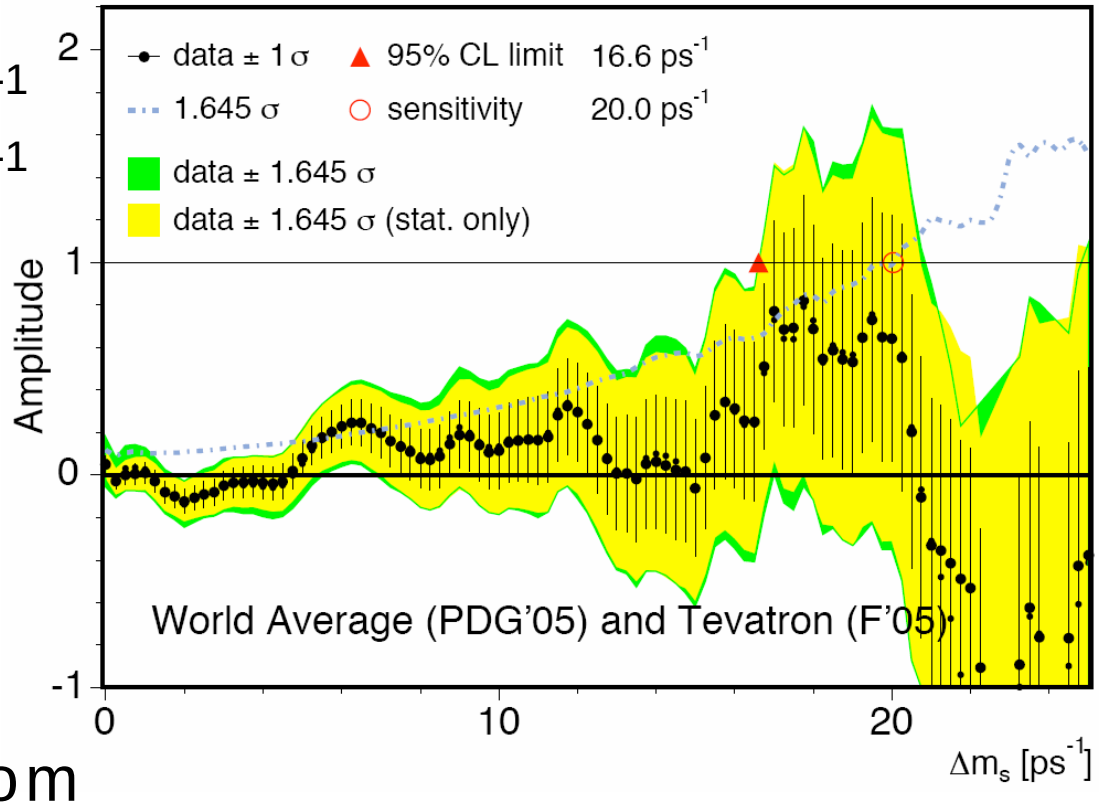
$\varepsilon D^2 = 1.55 \pm 0.09\%$

$\Delta m_s > 8.6 ps^{-1}$,
sensitivity $13.0 ps^{-1}$

New world average

limit $14.5 \rightarrow 16.6\ ps^{-1}$

sensitivity $18.3 \rightarrow 20.0\ ps^{-1}$



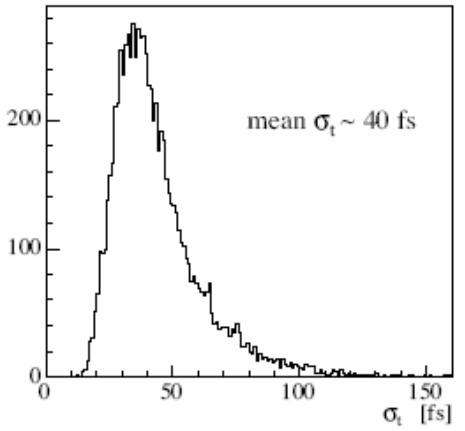
Further improvements from

- more data
- more decay channels (e.g. $B_s \rightarrow D_s^* \pi$)
- Same-side and opposite-side kaon tags

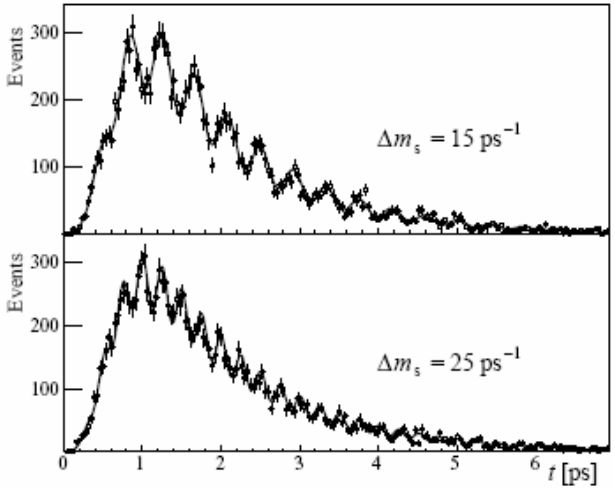
B_s^0 *oscillation frequency with* $B_s^0 \to D_s\pi$

Unbinned likelihood fit:

- rates weighted with acceptance, tagging dilution
- proper-time error σ_t obtained from full MC
  $\to$ uncertainty to generated events
- $\Delta\Gamma_s/\Gamma_s = 0.1$



Once oscillations observed, precise value of ΔM_s obtained: uncertainty $\sim 0.06\%$ $(2\ \mathrm{fb}^{-1})$



Statistical precision on ΔM_s after 1 year $(2\ \mathrm{fb}^{-1})$

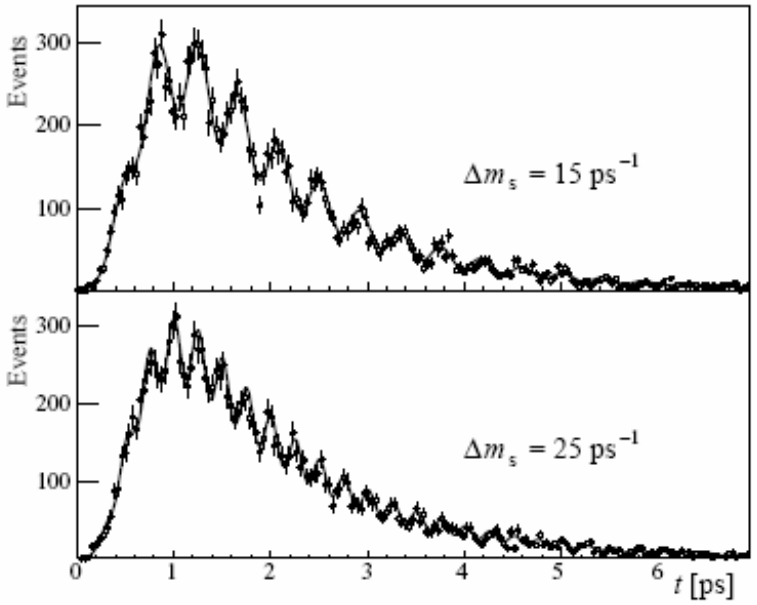
ΔM_s $[\mathrm{ps}^{-1}]$	15	20	25	30
$\sigma(\Delta M_s)$ $[\mathrm{ps}^{-1}]$	0.009	0.011	0.013	0.016

- $\sigma(\Delta M_s)$ will probably be dominated by systematics, e.g. t scale
  $\to$ even if $\sigma_{\mathrm{sys}} \sim 10 \cdot \sigma_{\mathrm{stat}}$, uncertainty $< 1\%$

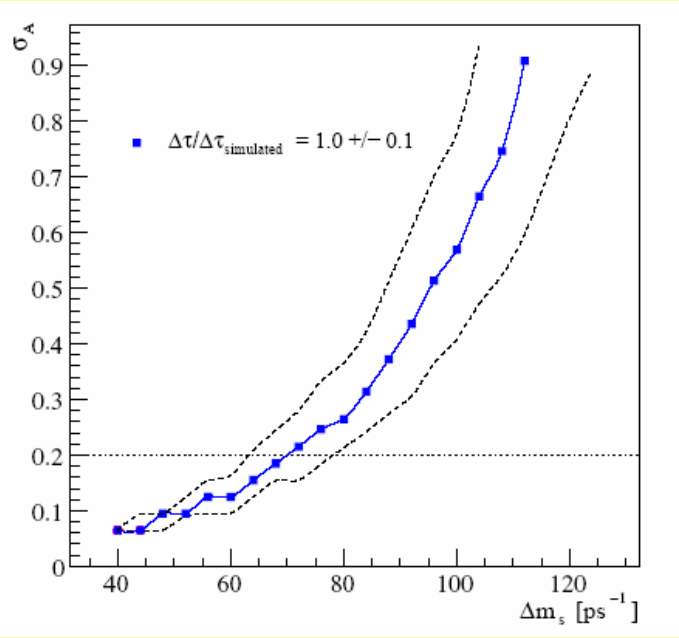
Decay rate for unmixed B_s^0

LHCb Δm_s sensitivity

Fernandez



Decay rate for unmixed $\mathrm{B_s^0}$



Statistical uncertainty on amplitude factor A (σ_A) versus ΔM_s

Sensitivity limit:
ΔM_s for which $5 \cdot \sigma_A = 1 = A$

In 1 year, $\geq 5\sigma$ observation of $\mathrm{B_s^0}$ oscillations up to $\Delta M_s = 68\ \text{ps}^{-1}$

$\rightarrow$ could exclude full SM range

'Immediate' measure of ΔM_s if small: $1/8$ year LHCb running! ($0.25\ \text{fb}^{-1}$, $\Delta M_s = 40\ \text{ps}^{-1}$)

LHCb ϕ_s sensitivity

ϕ_s sensitivities

Physics input values

ϕ_s [rad]	ΔM_s [ps^{-1}]	$\Delta\Gamma_s/\Gamma_s$	$\tau_{B_s^0}$ [ps]	R_T
-0.04	20.0	0.1	1.472	0.2

Fit results ($2\ \mathrm{fb}^{-1}$)

Sensitivity	$J/\psi\ \eta(\gamma\gamma)$	$J/\psi\ \eta(3\pi)$	$\eta_c\phi$	$J/\psi\ \phi$
$\sigma(\Delta\Gamma_s/\Gamma_s)$	0.019	0.024	0.025	0.011

$\sigma(R_T) = 0.0047$

Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s^0 \to J/\psi\ \eta(\gamma\ \gamma)$	0.112	6.4
$B_s^0 \to J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$	0.148	3.6
$B_s^0 \to \eta_c\ \phi$	0.106	7.1
Combined three pure CP eigenstates channels	0.068	17.1
$B_s^0 \to J/\psi\ \phi$	0.031	82.9
Combined all four CP eigenstates channels	0.028	100.0

Contribution from pure CP eigenstates: $\sim 17\%$

With $10\ \mathrm{fb}^{-1}$ (5 years): $\sigma(\phi_s) \sim 0.013$ rad $\longrightarrow$ $\sim 3\sigma$ for $\phi_s = -0.04$ rad (SM)

Conclusions

- This meeting
  - many talks by people about New Physics and experimental status and prospects
- Major Tasks
  - Study complementarity between collider and flavour physics
  - ➔ Common session WG1 & WG2
  - Hadronic Uncertainties
  - Experimental Studies
- Real "work" in WG2 starts now
  - Encourage people to come forward
  - Study groups will be formed soon
- Thank you to all involved