On the Super Flavour Factory Target $\mathcal{L}_{\text{int}}$

or “SuperB with L>50/ab”

partially based on T.G. & A.Soni, hep-ph/0607230, to appear in J.Phys.G

Tim Gershon (Warwick)

BNM2006 II

Translations

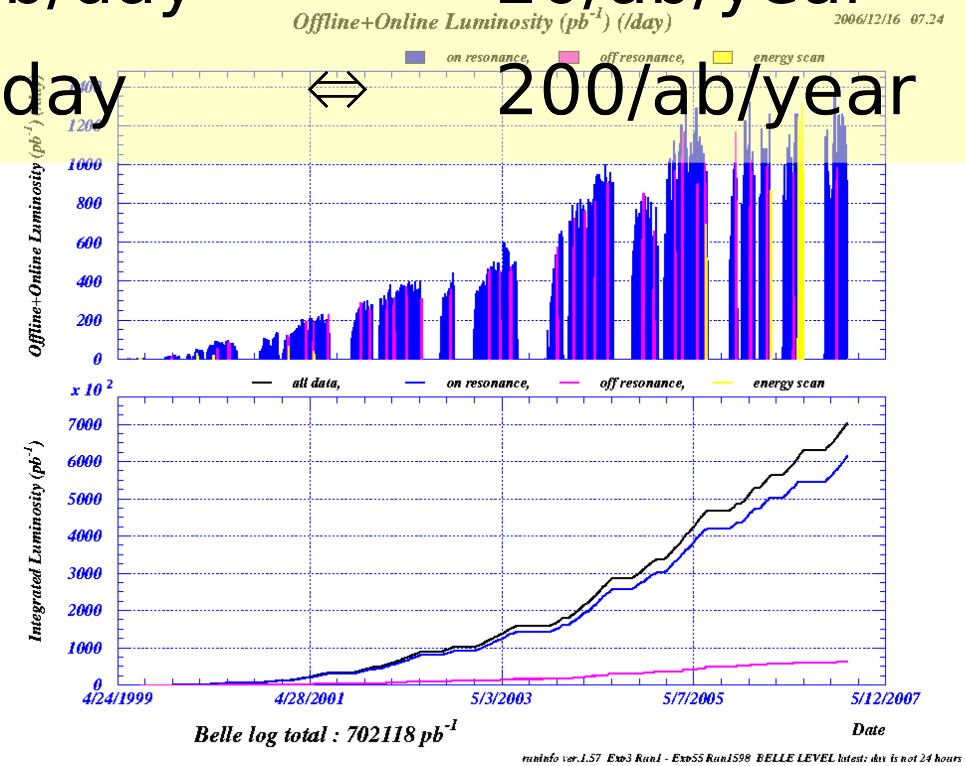
$\mathcal{L}_{peak} = 10^{34}/cm^2/s$	$\Leftrightarrow$	1/fb/day	$\Leftrightarrow$	200/fb/year
$\mathcal{L}_{peak} = 10^{35}/cm^2/s$	$\Leftrightarrow$	10/fb/day	$\Leftrightarrow$	2/ab/year
$\mathcal{L}_{peak} = 10^{36}/cm^2/s$	$\Leftrightarrow$	100/fb/day	$\Leftrightarrow$	20/ab/year
$\mathcal{L}_{peak} = 10^{37}/cm^2/s$	$\Leftrightarrow$	1/ab/day	$\Leftrightarrow$	200/ab/year

Assumes that:

- operating stability
- data taking efficiency
- useability of data

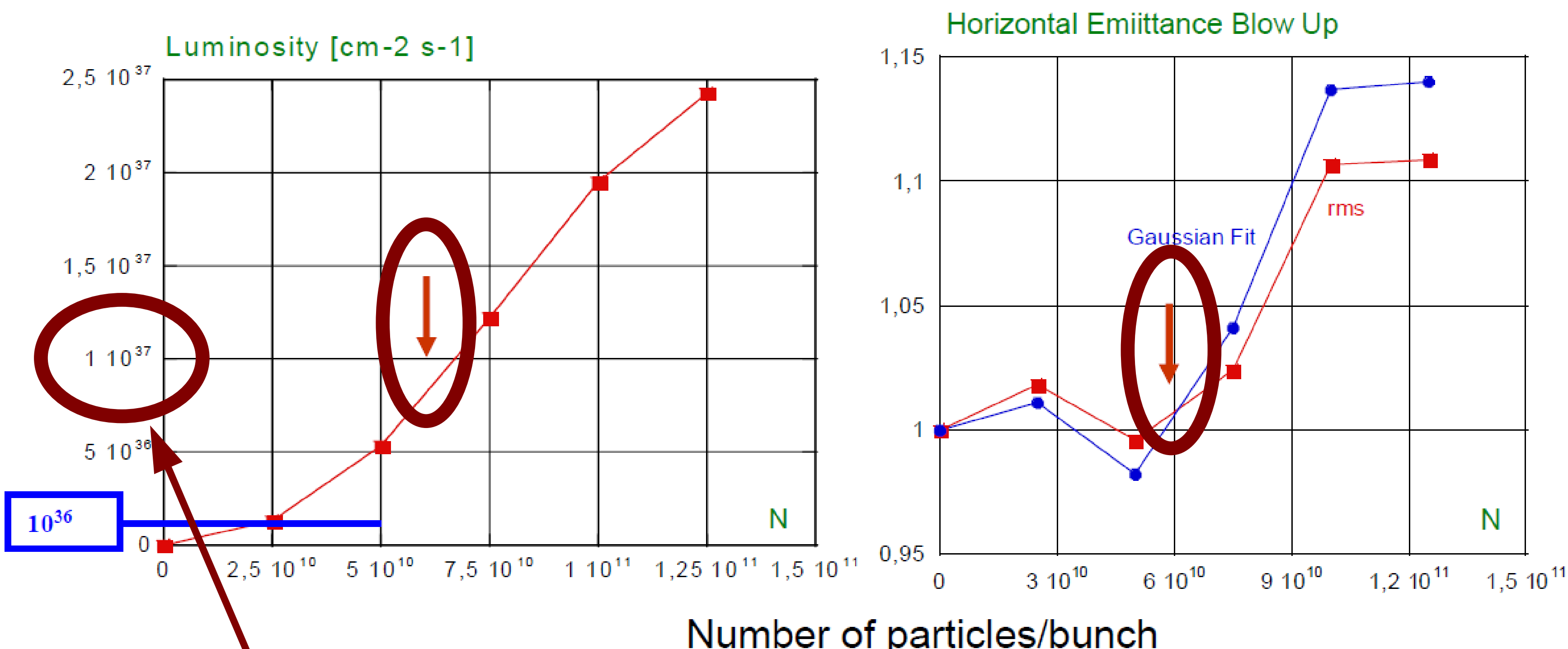
all remain similar to now

NB. 1000/ab = 1/zb



Shown in talk of M.Yamauchi (given by Y.Sakai), CKM2006, Nagoya, Dec. 15th 2006

Upgradeable



Talking about $10^{37}/cm^2/s$ might not be completely crazy?

M. Zobov, D. Shatilov

Main physics channels

- Precision CKM metrology
- Search for inconsistent CPV phenomena in (eg.) $b \to sss$
- New FCNCs
- Search for right-handed currents in (eg.) $b \to s\gamma$
- Inconsistent flavour-mixing (Δm, $\Delta\Gamma$, "ϵ") in B_d or D^0
- Enhanced v. rare decays, (eg.) $b \to s\nu\nu$, $B_d \to \mu\mu$
- Direct CP violation in charm
- τ lepton flavour violation &/or CP violation
- ...

Operating Energy

- I will stick to the physics at the Υ(4S)
- Clearly, much interesting physics at other centre-of-mass energies
- Higher luminosities will help!

CKM Metrology

- $\beta \equiv \varphi_1$ ($b \to c\bar{c}s$)
  - $J/\psi\ K^0$
    - systematics limited by ~ 2/ab (Yu.Nakahama @ CKM2006)
    - theory error << limiting experimental systematics
    - LHCb can do it anyway
  - $J/\psi\ K^{*0}$
    - Belle [PRL 95 (2005) 091601] N(BB)=275M
    - $\sin(2\varphi_1) = 0.24 \pm 0.31 \pm 0.05$ $\cos(2\varphi_1) = 0.56 \pm 0.79 \pm 0.11$
    - $\sigma[\cos(2\varphi_1)]_{stat} \sim 0.06$ with 50/ab; systematics???
  - $D^{(*)}D^{(*)}K^0$
    - hard to quantity theoretical errors

CKM Metrology

- $\beta \equiv \varphi_1$ ($b \to cud$)
  - Dh^0
    - $\sigma[\sin(2\varphi_1)]_{stat} \sim 0.04$, $\sigma[\cos(2\varphi_1)]_{stat} \sim 0.05$ with 50/ab; systematics???
    - $D_{CP}h^0$ will help for $\sigma[\sin(2\varphi_1)]_{stat}$
    - need to control model error (same problem as for $\gamma \equiv \varphi_3$)
    - theory error << limiting experimental systematics
    - LHCb could do $D_{CP}\pi^+\pi^-$ (challenging)

Experiment	$\sin(2\beta) \equiv \sin(2\varphi_1)$	$\cos(2\beta) \equiv \cos(2\varphi_1)$	$\|\lambda\|$	Correlations	Reference
BaBar N(BB)=311m	$0.45 \pm 0.36 \pm 0.05 \pm 0.07$	$0.54 \pm 0.54 \pm 0.08 \pm 0.18$	$0.975\ ^{+0.093}_{-0.085} \pm 0.012 \pm 0.002$	0.07 stat between sin(2β) & cos(2β)	hep-ex/0607105
Belle N(BB)=386m	$0.78 \pm 0.44 \pm 0.22$	$1.87\ ^{+0.40}_{-0.53}\ ^{+0.22}_{-0.32}$	-	-	PRL 97, 081801 (2006)
Average	0.57 ± 0.30 $\chi^2 = 0.3/1$ dof (CL=0.59 ⇒ 0.5σ)	1.16 ± 0.42 $\chi^2 = 2.5/1$ dof (CL=0.12 ⇒ 1.6σ)	-	uncorrelated averages	HFAG

CKM Metrology

- $\alpha \equiv \varphi_2$
  - $\pi\pi$, $\rho\rho$ (Gronau-London; isospin)
    - theory error few degrees
    - requires modes with multiple π^0s – LHCb not competitive
  - $\pi\pi\pi$ ($\rho\pi$) (Snyder-Quinn)
    - isospin only used for neutral penguin – smaller theory error
    - only one π^0 – LHCb can do it (challenging)
  - $a_1\pi$ & others
    - errors associated to SU(3) may be small when $|P/T|$ is small (see, eg. J.Zupan @ CKM2006)
    - all charged tracks in the final state – potentially good for LHCb

CKM Metrology

- $\gamma \equiv \varphi_3$
  - DK (Gronau-London-Wyler; Atwood-Dunietz-Soni; others ...)
    - theory error completely negligible
    - most channels with one or less neutrals – good for LHCb
      (see M.Patel @ CKM2006)
  - LHCb can also do $B_s \to D_s K$ (SFF cannot)

B mode	D mode	σ(γ)
$B^+ \to DK^+$	$K\pi + KK/\pi\pi + K3\pi$	5º - 15º
$B^+ \to D^*K^+$	$K\pi$	Under study
$B^+ \to DK^+$	$K_s\pi\pi$	8º
$B^+ \to DK^+$	$KK\pi\pi$	15º
$B^+ \to DK^+$	$K\pi\pi\pi$	Under study
$B^0 \to DK^{*0}$	$K\pi + KK + \pi\pi$	7º - 10º
$B^0 \to DK^{*0}$	$K_s\pi\pi$	Under study
$B_s \to D_sK$	$KK\pi$	13º

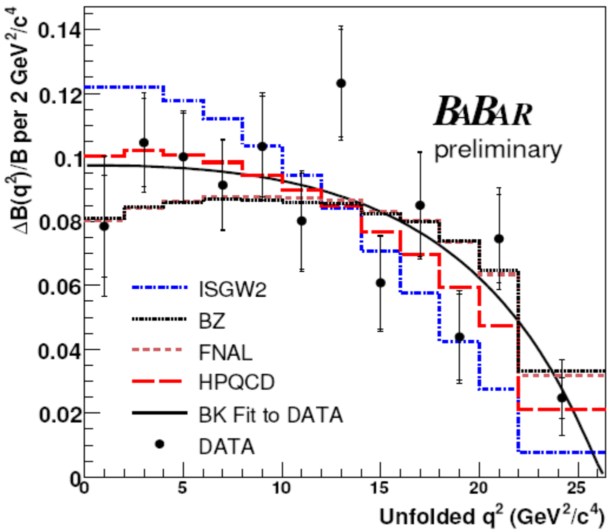
LHCb:
DK channels combined sensitivity
~ 5° from 2/fb (1 nominal year)

CKM Metrology

- $|V_{ub}|$
  - already theory dominated
  - do not expect any significant contribution from LHCb
  - more data from SFF will help, but improvements will be slow and hard

B → πlν Form Factor and $|V_{ub}|$

T.Onogi, CKM2006 WG2 Summary talk



$$f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m_{B^*}^2)\,(1 - \alpha_{\rm BK}\, q^2/m_B^2)}$$

QCD calculation	stat+syst errors χ^2	stat+syst errors $Prob(\chi^2)$ (%)
ISGW2 [7]	34.1	0.07
Ball-Zwicky [6]	13.0	37.2
FNAL [4]	12.5	41.0
HPQCD [3]	10.2	60.2

	q^2 (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
HPQCD [3]	> 16	1.46 ± 0.35	$4.1 \pm 0.2 \pm 0.2\,^{+0.6}_{-0.4}$
FNAL [4]	> 16	1.83 ± 0.50	$3.7 \pm 0.2 \pm 0.2\,^{+0.6}_{-0.4}$
LCSR [5]	< 16	5.44 ± 1.43	$3.6 \pm 0.1 \pm 0.1\,^{+0.6}_{-0.4}$
ISGW2 [6]	0-26.4	9.6 ± 4.8	$3.2 \pm 0.1 \pm 0.1\,^{+1.3}_{-0.6}$

CKM Metrology

- Precision measurements of the UT undoubtedly extremely important
- LHCb can do the angles
- Improvement in $|V_{ub}|$ limited by theoretical uncertainties

- SFF can contribute and make improvements in all measurements

not enough to motivate a major upgrade

- Does not tell us what luminosity to aim for!

Super Flavour Factory & LHCb Upgrade

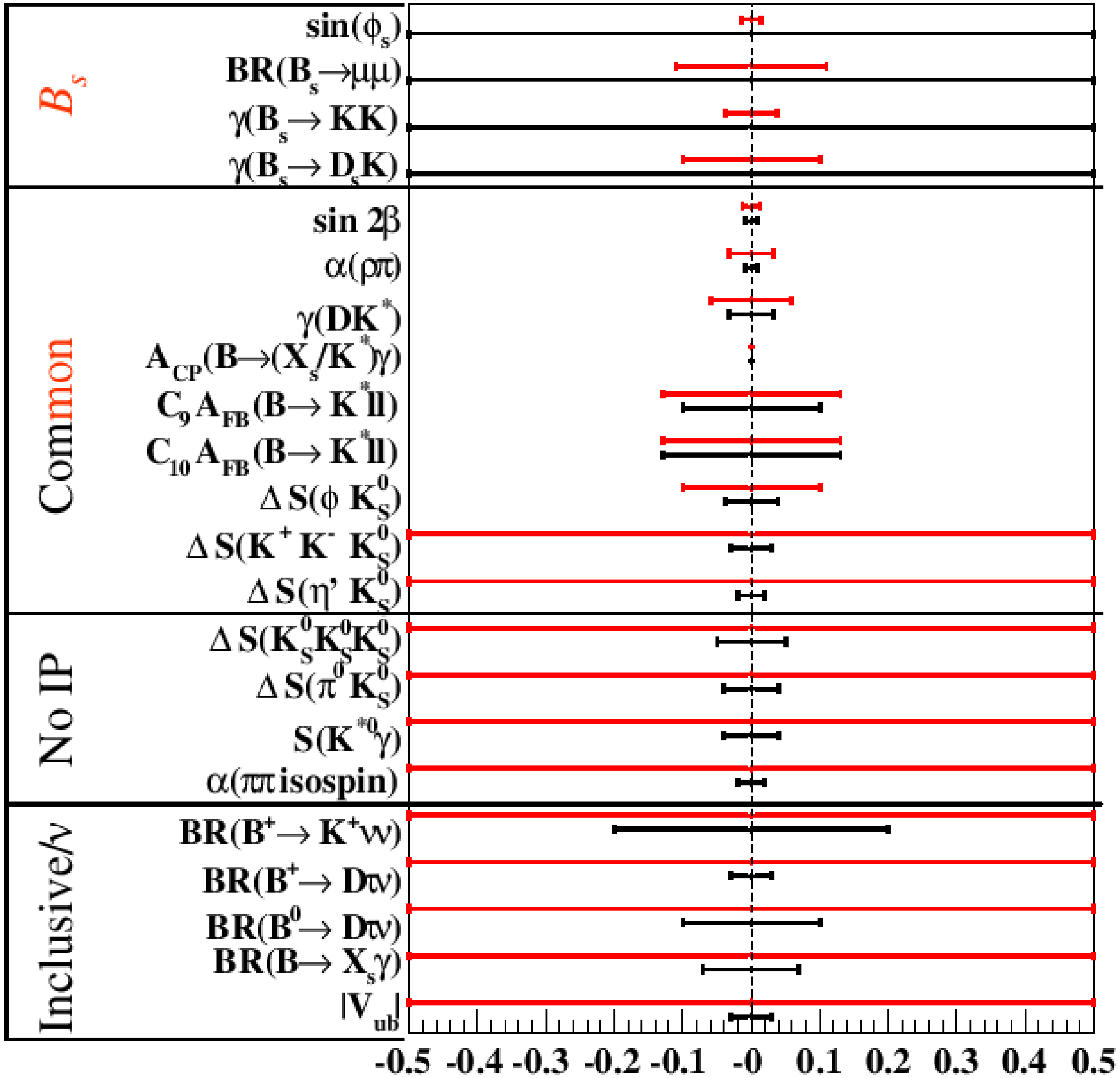
Warning:
can only be used as a guideline

Guesstimates based on
- 10/fb LHCb
- 50/ab Super B Factory

COMPLEMENTARITY

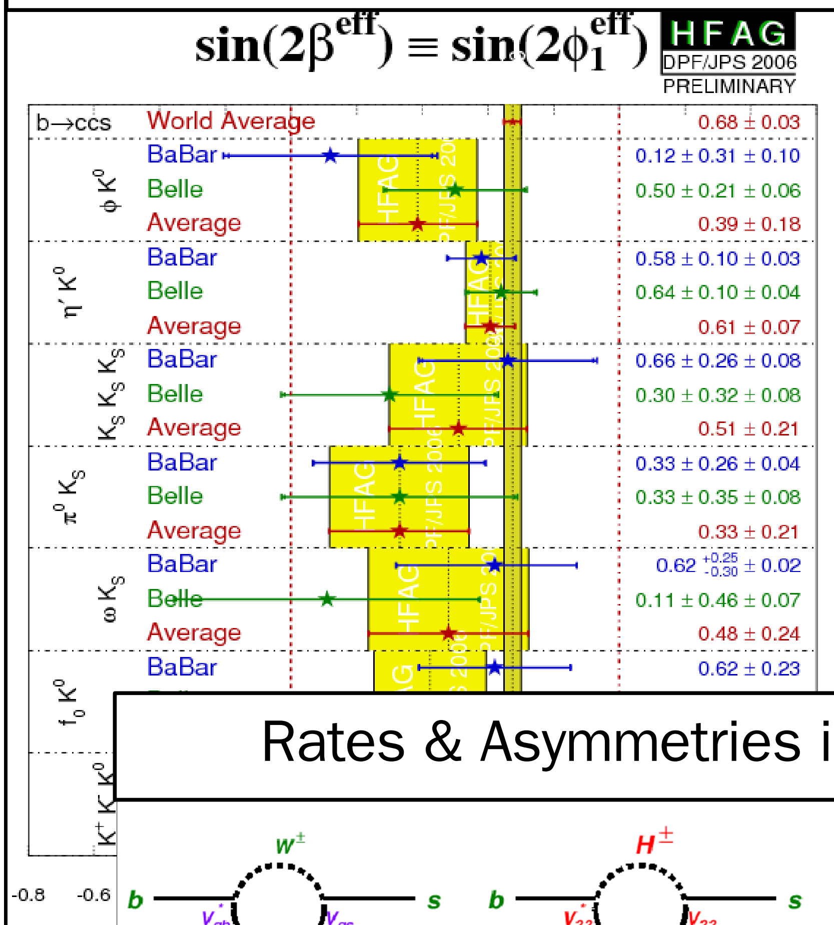
LHCb good for
- Bs decays & oscillations
- All charged track final states

Super Flavour Factory best for
- Inclusive measurements
- Modes with neutrals (π^0, K_S, neutrinos, *etc.*)

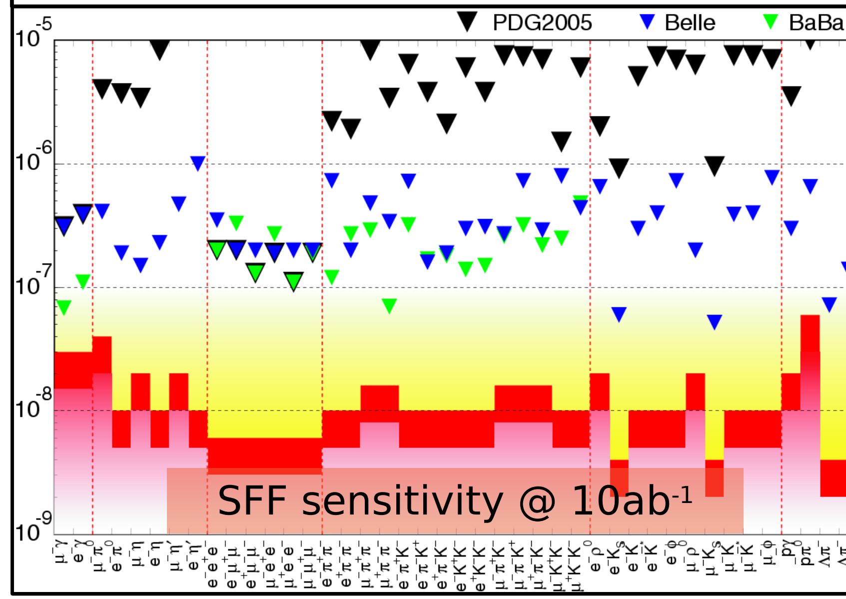


Key Measurements (Physics Case for SBF in 1 Slide)

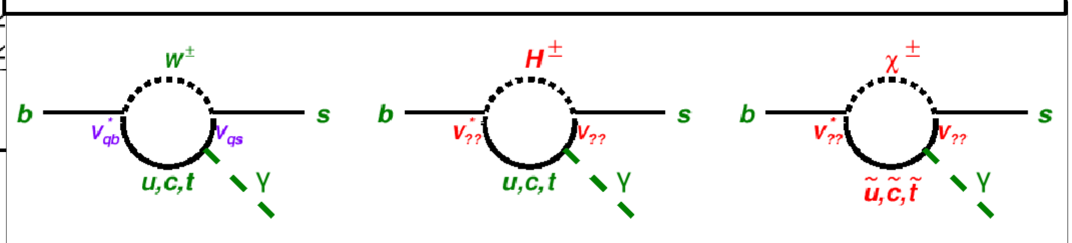
CP Violation in Hadronic b→s



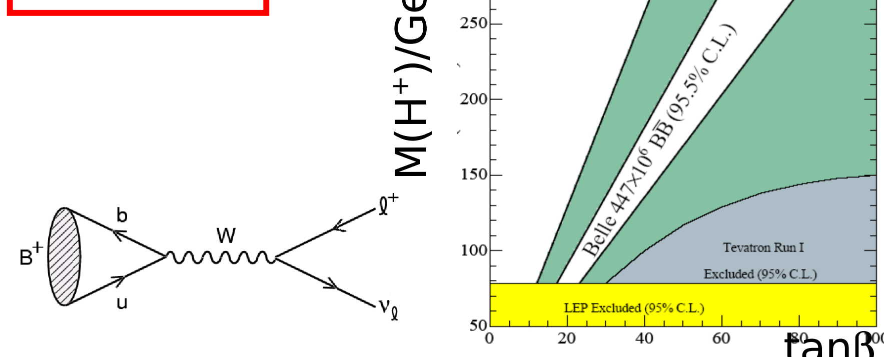
Lepton Flavour Violation in τ Decay



Rates & Asymmetries in b→sγ

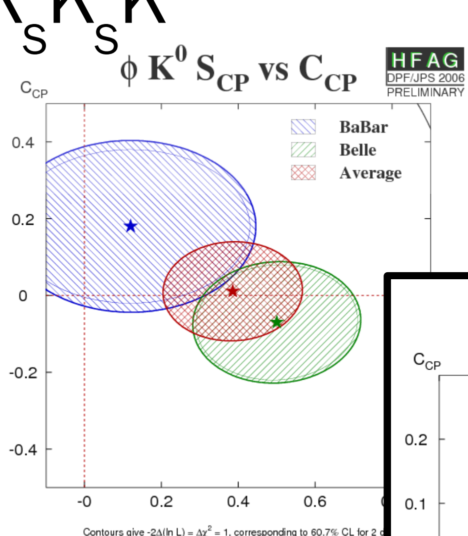


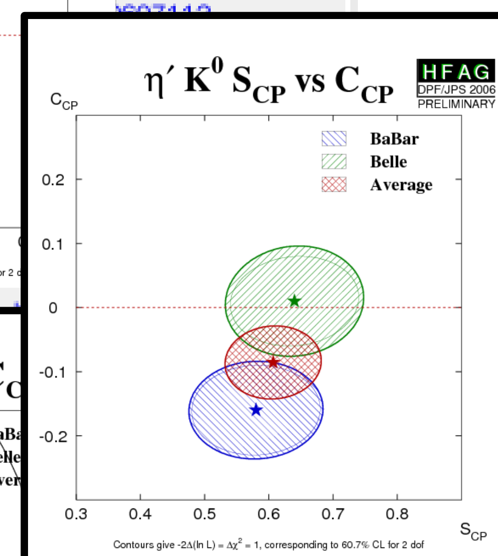
B → τν

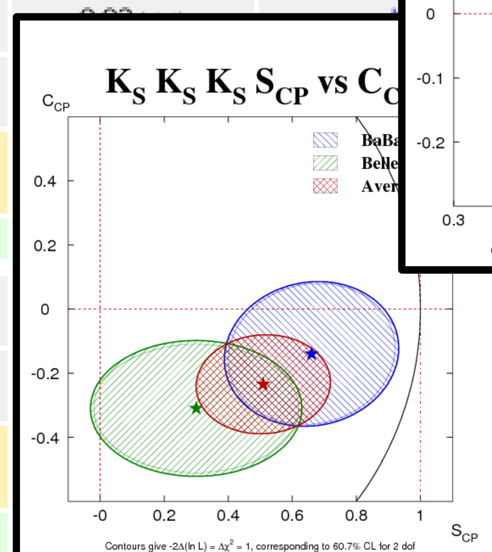


Hadronic b→s Penguins

- Cleanest modes are ϕK^0, $\eta' K^0$ & $K_S K_S K^0$
  - theory errors ~ few degrees







Mode	Experiment	$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$	C_{CP}	…ence
ϕK^0	BaBar (*) N(BB)=347M	0.12 ± 0.31 ± 0.10	0.18 ± 0.20 ± 0.10	
	Belle N(BB)=535M	0.50 ± 0.21 ± 0.06	−0.07 ± 0.15 ± 0.05	
	Average	0.39 ± 0.18	0.01 ± 0.13	
	Figures:	eps.gz png	eps.gz png	
$\eta' K^0$	BaBar N(BB)=384M	0.58 ± 0.10 ± 0.03	−0.16 ± 0.07 ± 0.03	
	Belle N(BB)=535M	0.64 ± 0.10 ± 0.04	0.01 ± 0.07 ± 0.05	
	Average	0.61 ± 0.07	−0.09 ± 0.06	
	Figures:	eps.gz png	eps.gz png	
$K_S K_S K_S$	BaBar N(BB)=347M	0.66 ± 0.26 ± 0.08	−0.14 ± 0.22 ± 0.05	…607108
	Belle N(BB)=535M	0.30 ± 0.32 ± 0.08	−0.31 ± 0.20 ± 0.07	…608039
	Average	0.51 ± 0.21	−0.23 ± 0.15	…ed average …=0.61 ⇒ 0.5σ)
	Figures:	eps.gz png	eps.gz png	

Hadronic $b \to s$ Penguins

- Naïve scaling of current experimental errors
  - N(BB) required to reach theory error:
    - ~ 10^{10} for $\eta' K^0$
    - ~ 5 x 10^{10} for ϕK^0
    - ~ 5 x 10^{10} for $K_S K_S K^0$

    } 50/ab needed
  - Beyond naïve scaling?
    - time-dependent Dalitz plot analysis of $K^+K^-K^0$ (BaBar; hep-ex/0607112)
    - larger $f_0 K^0$ contribution under ϕK^0 ⇒ error on S *in*creases
  - Improvements in theory uncertainties?
    - likely to be data driven
    - eg. SU(3) relations, understanding η' form factor ($B \to \eta' l \nu$)
    - unlikely to go below 1% level

Radiative $b \to s$ Penguins

- Key to NP sensitivity : measure the photon polarization
  - Many approaches proposed
    - time-dependent asymmetry in $K^{*}\gamma$, $K_{s}\pi^{0}\gamma$, etc.

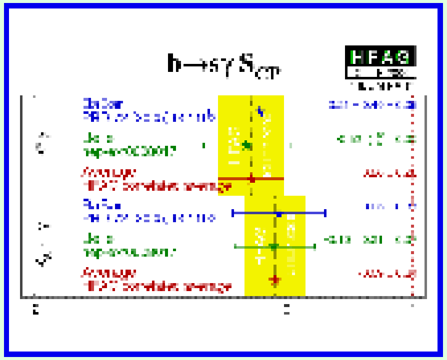
      only approach attempted to date!
    - interferences between resonances in $K\pi\pi\gamma$
    - conversions in $K^{*}\gamma \to K^{*}e^{+}e^{-}$
    - study of radiative Λ_{b} decays
    - angular distributions in $K\phi\gamma$, etc.

      see talk of A.Soni in this workshop

Radiative b→s Penguins

Mode	Experiment	S_{CP} (b → sγ)	C_{CP} (b → sγ)	Correlation	Reference
K*(892)γ	BaBar N(BB)=232M	−0.21 ± 0.40 ± 0.05	−0.40 ± 0.23 ± 0.04	0.07 (stat)	PRD 72 (2005) 051103
	Belle N(BB)=532M	$-0.32\ ^{+0.36}_{-0.33} \pm 0.05$	0.20 ± 0.24 ± 0.05	0.08 (stat)	hep-ex/0608017
	Average	−0.28 ± 0.26	−0.11 ± 0.17	0.07	HFAG correlated average χ^2 = 3.2/2 dof (CL=0.20 ⇒ 1.3σ)
$K_S\pi^0\gamma$ (incl. K*γ)	BaBar N(BB)=232M	−0.06 ± 0.37	−0.48 ± 0.22	0.05 (stat)	PRD 72 (2005) 051103
	Belle N(BB)=532M	−0.10 ± 0.31 ± 0.07	0.20 ± 0.20 ± 0.06	0.08 (stat)	hep-ex/0608017
	Average	−0.09 ± 0.24	−0.12 ± 0.15	0.06	HFAG correlated average χ^2 = 5.1/2 dof (CL=0.08 ⇒ 1.8σ)

Figures:



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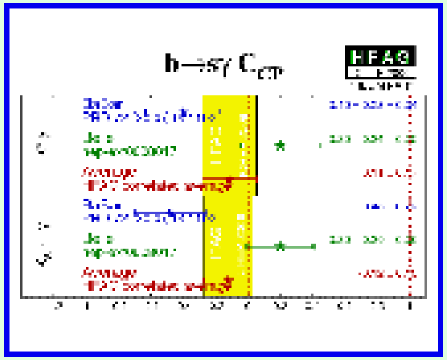

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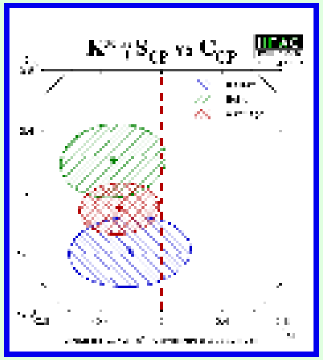

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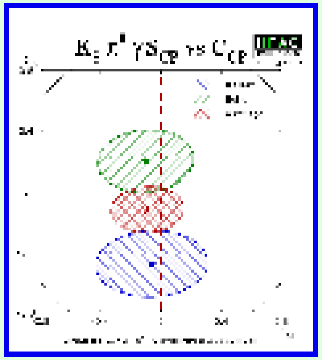

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Radiative $b \rightarrow s$ Penguins

- Naïve scaling of current experimental errors
  - Assuming theory uncertainties of few % due to higher order corrections
    see talk of A.Soni in this workshop
  - N(BB) required to reach theory error:
    - ~ 5 x 10^{10} for $K_s \pi^0 \gamma$ } **50/ab needed**
    - only mode for which measurements currently exist
  - Improvements in theory uncertainties?
    - in this case there is a data driven method to reduce the error
    - ⇒ study dependence of polarization on hadronic final state
      - eg. $S(K_s \pi^0 \gamma)$ vs. $m(K_s \pi^0)$, $S(K_s \pi^0 \gamma)$ with $S(K_s \eta \gamma)$, etc.
    - ⇒ much larger data samples necessary

Radiative $b \to s$ Penguins

- Observables sensitive to new physics fall into two categories:

  - (CKM favoured) x (helicity suppressed)
    - eg. $S(B_d \to K_s \pi^0 \gamma) \sim \sin(2\beta) \times (2m_s/m_b) \sim \sin(2\varphi_1) \times (2m_s/m_b)$
    - SM uncertainty few %
    - requires new RH current but **does not require new CP phase**

  - (CKM suppressed) x (helicity suppressed)
    - eg. $S(B_s \to \varphi \gamma) \sim \sin(\varphi_s) \times (2m_s/m_b)$
    - tiny SM uncertainty (extremely clean null test)
    - requires new RH current **and** new CP phase

Radiative b→s Penguins

- Observables sensitive to new physics fall into two categories:
  - (CKM favoured) x (helicity suppressed)
    - eg. $S(B_d \to K_s \pi^0 \gamma) \sim \sin(2\beta) \times (2m_s/m_b) \sim \sin(2\varphi_1) \times (2m_s/m_b)$
    - SM uncertainty few %
    - requires new RH current but **does not require new CP phase**
  - (CKM suppressed) x (helicity suppressed)
    - eg. $S(B_s \to \varphi\gamma) \sim \sin(\varphi_s) \times (2m_s/m_b)$
    - tiny SM uncertainty (extremely clean)
    - requires new RH current **and** new CP phase

Essential to reduce the SM error

Can be done with data

Requires > 50/ab

A Word on b→d Penguins

- To get required N(BB) for b→d penguins
  1) Take b→s number and scale: N(BB)[b→s] / $|V_{td}/V_{ts}|^2$
  2) Scale from existing measurements, eg. $\sigma[S(K_S K_S)]_{stat}$ ~ 0.07 @ 50/ab
  3) Guesstimate based on measurements, $\sigma[S(\rho\gamma)]_{stat}$ ~ 0.07 @ 50/ab

theory uncertainties due to c- and u- penguin contributions

Experiment	S_{CP} ($K_S K_S$)	C_{CP} ($K_S K_S$)	Correlation	Reference
BaBar N(BB)=350m	$-1.28^{+0.80}_{-0.73}{}^{+0.11}_{-0.16}$	$-0.40 \pm 0.41 \pm 0.06$	−0.32	hep-ex/0608036

You selected the following table or plot entries:

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
226	$\rho^0\gamma$	< 0.4	$0.77^{+0.21}_{-0.19} \pm 0.07$	$1.25^{+0.37+0.07}_{-0.33-0.06}$	< 17	$0.91^{+0.19}_{-0.18}$

References for the data:
PDG2006: W.-M. Yao *et al.*, J. Phys. Lett. G 33, 1 (2006).
Babar Collaboration hep-ex/0607099
Belle Collaboration *Phys. Rev. Lett.* **96**, 221601 (2006)
CLEO Collaboration *Phys. Rev. Lett.* **84**, 5283 (2000)

~40 events in 350M BB

~20 events in 380M BB

~100 events/ab ⇒ 5000 events in 50/ab

More Penguins

- $b \to sll$ also very important probe of new physics
  - eg. forward-backward asymmetry in $B \to K^* l^+ l^-$

    ... but this is a very good channel for LHCb
  - LHCb cannot do fuly inclusive modes: $X_s l^+ l^-$, $X_s \gamma$ also $X_{s+d} \gamma$, etc.
    - theoretically cleaner
    - requires full reconstruction
    - much larger data samples, typically > 100/ab

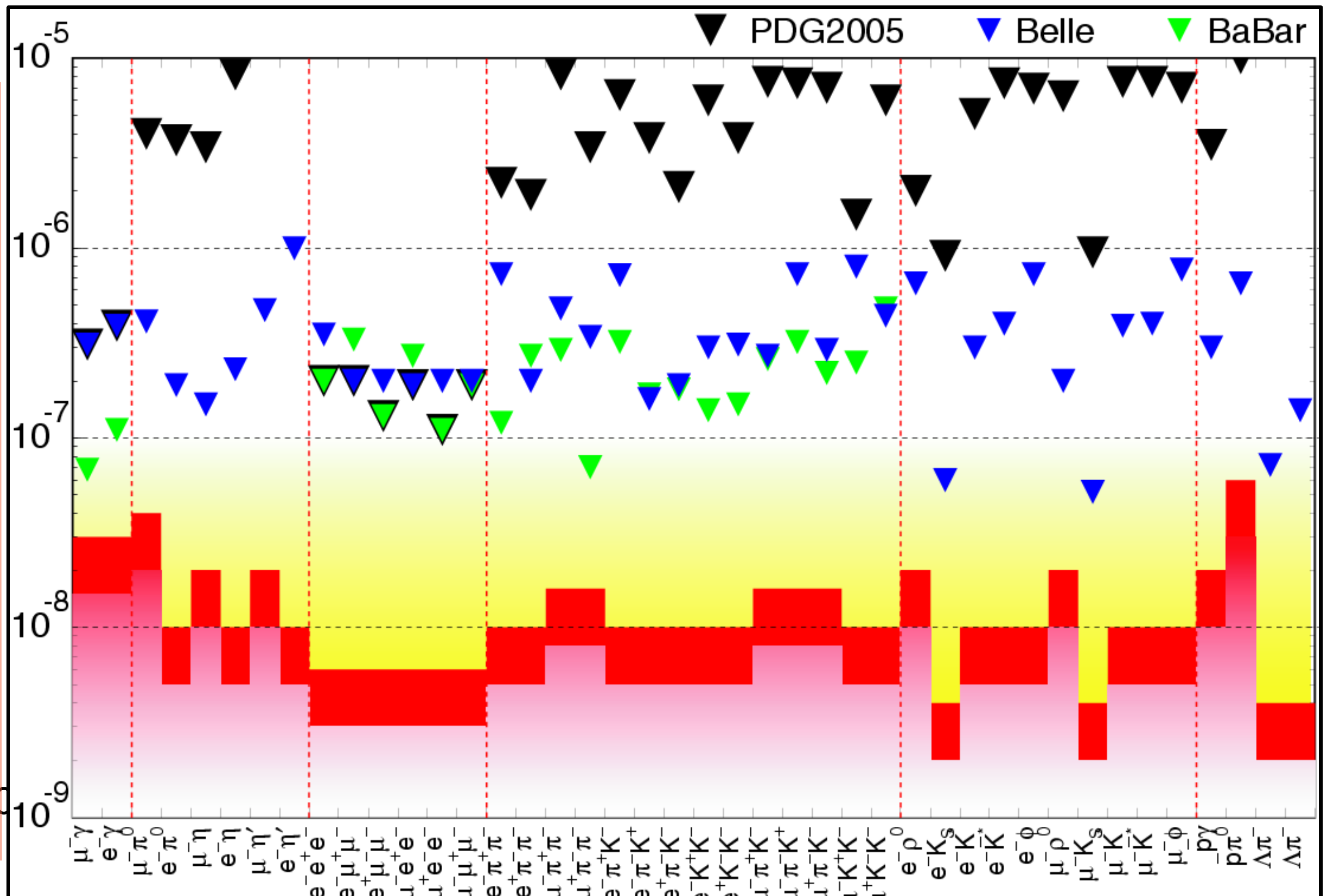
    see also talk by M.Nakao

- Can also study inclusive hadronic final states

Lepton Flavour Violation

- Importance recently emphasised by many people
- No SM background ⇔ $\mathcal{L}_{int}$ as high as possible

SFF sensitivity @ 10ab^{-1}

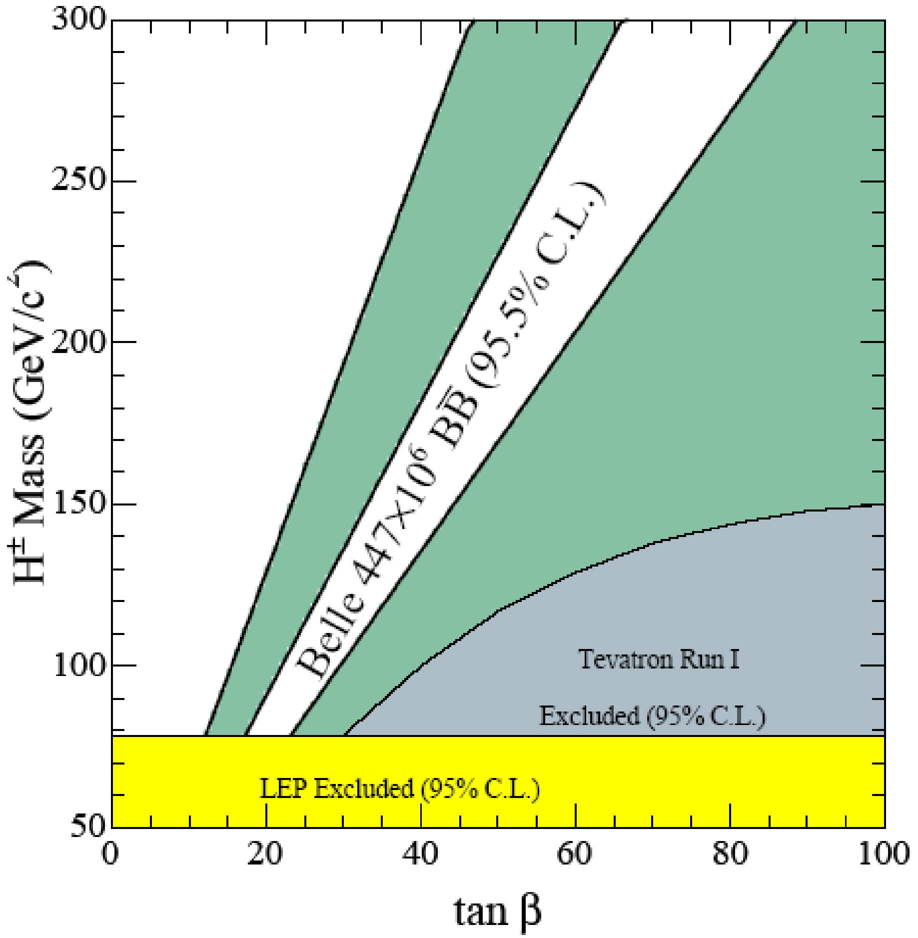


Leptonic Decays

- Assume B→τν will hit limits by 50/ab
  - $|V_{ub}|$
  - f_B (lattice)
  - experimental systematics

  see talk by T.Iijima
- B→μν & B→eν require more data
- Some uncertainties can be reduced or removed using ratios
- $B \rightarrow D^{(*)}\tau\nu$ provides additional observables and requires larger $\mathcal{L}_{int}$
- B→μμ & B→ee will be done by LHCb

  B→ττ only at SFF, requires huge $\mathcal{L}_{int}$



Summary

- Of the main channels that motivate a Super Flavour Factory
  - CPV in hadronic $b \to s$ penguins hits theory limit at about 50/ab
  - almost everything else will not be limited

better to aim for a rounder number?

- Of the interesting channels
  - most **do not** require time-dependent analysis
  - many require full reconstruction

$\Rightarrow$ **smaller energy asymmetry** (but with good vertexing)

$\Rightarrow$ **hermetic detector**

The FCNC Matrix

th. error $\lesssim 10\%$
(grey oval) = exp. error $\lesssim 10\%$
(open oval) = exp. error $\sim 30\%$

FLAVOUR COUPLING:

ELECTROWEAK STRUCTURE	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ 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	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

kaon physics

From G.Isidori, via O.Schneider

BEAUTY2003 panel discussion