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New Physics
&
Future B Physics Programs

CP violation **Rare Decays**

Experimental Facilities

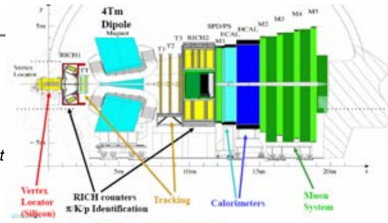
- **LHCb** – forward spectrometer (running in pp – collider mode)
  Data taking starts next year
  Expect ~10 fb^{-1} by 2013
  B physics is also a part of the ATLAS and CMS early program

- **Super Flavor Factory (SFF)** following either SuperKEKB or Super B proposal with an integrated luminosity of 50 – 75 ab^{-1}
  Start data taking > 2014
  (T.Browder et al arXiv:0710.3799v1)

- **Upgraded LHCb (SLHCb)** where they would run at 10 times the initial design luminosity with twice more efficient trigger and record data sample of > 100 fb^{-1}
  Start data taking after 2014

LHCb

- Large bb cross section (~230 μb)
- Forward geometry
- Low luminosity is sufficient
  At 2×10^{32} 10^{12} bb pairs are produced per year



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UT as a standard approach to test the consistency of SM

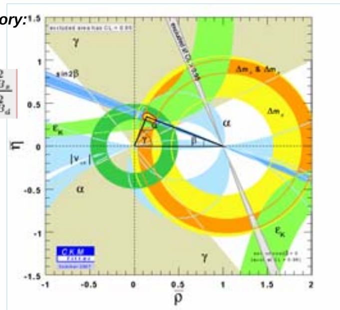
Mean values of angles and sides of UT are consistent with SM predictions

Accuracy of sides is limited by theory:

- Extraction of |Vub|
- Lattice calculation of $\xi^2 = \frac{\hat{B}_{B_s} f^2_{B_s}}{\hat{B}_{B_d} f^2_{B_d}}$

Accuracy of angles is limited by experiment:

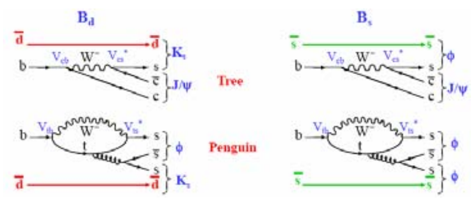
$\alpha = \pm 13°$
$\beta = \pm 1°$
$\gamma = \pm 25°$



Search for NP comparing observables measured in tree and loop topologies

β(tree+box) in B→ J/ψKs
γ(tree) in many channels
χ(tree+box) in B_s→ J/$\psi\phi$

γ(peng+tree) in B→$\rho\rho,\rho\pi,\pi\pi$
β(peng+box) in B→ϕKs
χ(peng+box) in Bs→$\phi\phi$



New heavy particles, which may contribute to d- and s- penguins, could lead to some phase shifts in all three angles:

$\delta\gamma$(NP) = γ(peng+tree) - γ(tree)
$\delta\beta$(NP) = β(B→ϕKs) - β(B→J/ψKs) ≠ 0
$\delta\chi$(NP) = χ(B_s→$\phi\phi$) - χ(B_s→J/$\psi\phi$)

Search for NP comparing observables measured in tree and loop topologies

Contribution of NP to processes mediated by loops
(present status)

- **to boxes:**

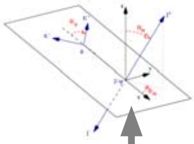
  β vs $|V_{ub}/V_{cb}|$ is limited by theory (~10% precision in $|V_{ub}|$) (d-box)
  χ not measured with any accuracy (s-box)

- **to penguins:**

  $\sigma(\delta\gamma(NP))$ ~ 30° (d-penguin)
  $\sigma(\delta\beta(NP))$ ~8° (s-penguin)
  $\sigma(\delta\chi(NP))$ not measured (s-penguin)

PS $\delta\beta$(NP) = $\delta\chi$ (NP)
$\delta\gamma$(NP) measured in B→$\pi\pi$ and B→$\rho\rho$ decays may differ depending on penguin contribution to $\pi\pi$ and $\rho\rho$ final states

χ: LHC prospects



$B_s \to J/\psi\phi$ is the B_s counterpart of $B^0 \to J/\psi K_S$

- ❑ In SM ϕ_S = - 2arg(V_{ts}) = - $2\lambda^2\eta$ ~ - 0.04
- ❑ Sensitive to New Physics effects in the B_s-$\bar{B}_s$ system mixing $\to$ $\phi_S = \phi_S(SM) + \phi_S(NP)$
- ❑ 2 CP-even, 1 CP-odd amplitudes, angular analysis needed to separate, then fit to ϕ_S, $\Delta\Gamma_S$, CP-odd fraction
- ❑ LHCb yield in 2 fb^{-1} 131k, B/S = 0.12

LHCb

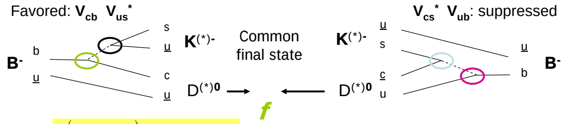
Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s \to J/\psi\, \eta(\pi^+\pi^-\pi^0)$	0.142	2.3
$B_s \to D_sD_s$	0.133	2.6
$B_s \to J/\psi\, \eta(\gamma\gamma)$	0.109	3.9
$B_s \to \eta_c\phi$	0.108	3.9
Combined (pure CP eigenstates)	0.060	12.7
$B_s \to J/\psi\phi$	0.021	87.3
Combined (all CP eigenstates)	0.021	100.0

ATLAS will reach s(ϕ_s) ~ 0.08 (10/fb, Δm_s=20/ps, 90k $J/\psi\phi$ evts)

UT angle γ: LHCb (BaBAr & BELLE & Tevatron ~12° precision for γ at best)

❑ **Interference between tree-level decays**

Favored: V_{cb} V_{us}^* — V_{cs}^* V_{ub}: suppressed



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

Parameters: γ, (r_B, δ_B) per mode

Three methods for exploiting interference (choice of D^0 decay modes):

- ➢ *(GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K^+K^-/\pi^+\pi^-$, $K_s\pi^0$*
- ➢ *(ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$*
- ➢ *(Dalitz): Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$*

❑ ***Mixing induced CPV measurement in $B_s \to D_s K$ decays***
Specific for LHCb

UT angle γ: LHCb summary table

B mode	D mode	Method	$\sigma(\gamma)$ with 2 fb^{-1}
$B^+ \to DK^+$	$K\pi$ + KK/$\pi\pi$ + $K3\pi$	ADS+GLW	5°–13°
$B^+ \to D^*K^+$	$K\pi$ ($D^* \to D+\pi, \gamma$)	ADS+GLW	Under study
$B^+ \to DK^+$	$K_S\pi\pi$	Dalitz	~8-12°
$B^+ \to DK^+$	$KK\pi\pi$	4-body "Dalitz"	18°
$B^+ \to DK^+$	$K\pi\pi\pi$	4-body "Dalitz"	Under study
$B^0 \to DK^{*0}$	$K\pi$ + KK + $\pi\pi$	ADS+GLW	~6-12°
$B^0 \to DK^{*0}$	$K_S\pi\pi$	Dalitz	Under study
$B_s \to D_sK$	$KK(\phi)\pi$	tagged, A(t)	~10°
$B^0 \to \pi^+\pi^-$, $B_s \to K^+K^-$	N/A	U-spin symmetry	5° - 10°

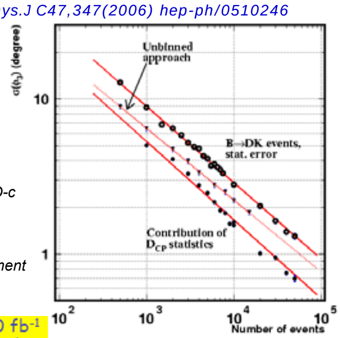
Combined precision after 2 fb^{-1} $\sigma(\gamma)$ ~ 5° (from tree only)

angle γ (φ_3) at SFF

Model-independent approach

A.Bondar, A.Poluektov Eur.Phys.J C47,347(2006) hep-ph/0510246

- ❑ 50 ab^{-1} at SFF factory should be enough for model-independent γ/φ_3 measurement with accuracy below 2°
- ❑ 1fb^{-1} at ψ(3770) corresponds 2100 CP-tagged $K_S\pi^+\pi^-$ events (first estimation based on CLEO-c data by David Asner)
- ❑ ~10 fb^{-1} at ψ(3770) needed to accompany SuperB measurement



•BESIII: 20 fb^{-1}
⇒1° systematic

LHCb (10fb^{-1}) and SFF (50-75 ab^{-1}) & SLHCb (>100 fb^{-1}) sensitivities

LHCb

	Channel	Yield	Precision
γ	From tree channels		$\sigma(\gamma)$ < 3°
α	$B_d \to \pi^+\pi^-\pi^0$ $B \to \rho^+\rho^0$, $\rho^+\rho^-$, $\rho^0\rho^0$	70k 45k,10k,5k	$\sigma(\alpha)$ < 4°
β	$B_d \to J/\psi(\mu\mu)K_S$ $B_d \to \phi K_S$	1200k 4k	$\sigma(\sin 2\beta)$ < 0.01 $\sigma(\sin 2\beta)$ ~ 0.1
ϕ_s	$B_s \to J/\psi(\mu\mu)\phi$ $B_s \to \phi\phi$	750k 20k	$\sigma(\phi_s)$ ~ 0.01 $\sigma(\phi_s)$ ~ 0.05

SFF & SLHCb
> 2014

Observable	Super Flavour Factory sensitivity	SLHCb (stat. only)
$\sin(2\beta)$ $(J/\psi K^0)$	0.005–0.012	~ 0.003
γ $(B \to D^{(*)}K^{(*)})$	1–2°	< 1° (Bs→DsK)
α $(B \to \pi\pi, \rho\rho, \rho\pi)$	1–2°	-
$\lvert V_{ub}\rvert$ (exclusive)	3–5%	-
$\lvert V_{ub}\rvert$ (inclusive)	2–6%	-
$\bar{\rho}$	1.7–3.4%	
$\bar{\eta}$	0.7–1.7%	
$S(\phi K^0)$	0.02–0.03	$S(\phi K^0_S)$ 0.02-0.03
$S(\eta' K^0)$	0.01–0.02	$S(\phi\phi)$ 0.01
$S(K^0_sK^0_sK^0_s)$	0.02–0.04	

Search for New Physics in Rare Decays

LHCb

- ❑ Exclusive $b \to s\gamma$
- ❑ $B \to K^*\mu\mu$
- ❑ $Bs \to \mu\mu$

We are just approaching sensitivity promising for discovery…

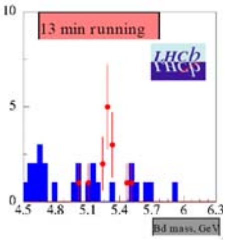
SFF

- ❑ $B \to \tau\nu$, $h\nu\nu$, ...
- ❑ $B \to s\gamma$, sll inclusive

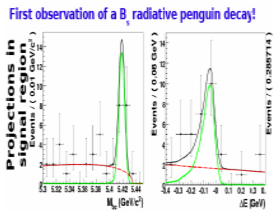
Experimental challenge: keep backgrounds under control

$b \to s\gamma$ exclusive

LHCb control channel: $B_d \to K^*\gamma$
~75k signal events per 2fb^{-1}

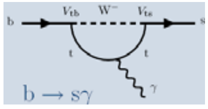


$Bs \to \phi\gamma$
BELLE observed 16±8 events
2 weeks run at Υ(5S); no TDCPV



LHCb annual yield ~11k
with B/S < 0.6

$b \to s\gamma$ exclusive



$b \to \gamma(L) + (m_s/m_b) \times \gamma(R)$

Measurement of the photon helicity is very sensitive test of SM

Methods:

- Mixing induced CP asymmetries in $B_s \to \phi\gamma$, $B \to K_s \pi^0\gamma$
- Photon helicity can be measured directly in radiative B decays to final state with ≥ 3 hadrons.

Promising channels for LHCb are $B \to \phi K\gamma$ and $B \to K\pi\pi\gamma$ decays

		Expected yield per 2 fb^{-1}
$BR(B^+ \to K^+\pi\pi\gamma) \sim 2.5 \times 10^{-5}$	rich pattern of resonances	~60k
$BR(B^+ \to K^+\phi\gamma) \sim 3 \times 10^{-6}$	highly distinctive final state	~ 7k

$b \to s\gamma$ exclusive

Mixing induced CP asymmetries

- **$B \to K_s\pi^0\gamma$ (B-factories)**

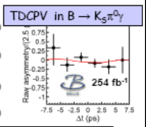
$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(t) \to K_S^0\pi^0\gamma) - \Gamma(B^0(t) \to K_S^0\pi^0\gamma)}{\Gamma(\overline{B}^0(t) \to K_S^0\pi^0\gamma) + \Gamma(B^0(t) \to K_S^0\pi^0\gamma)} = S \sin\Delta m \Delta t + A \cos\Delta m \Delta t$$

$$A_{\rm Belle} = -C_{\rm BaBar}$$

$S = -(2+O(\alpha_s))\sin(2\beta)m_s/m_b$ + (possible contribution from $b \to s\gamma g$) = - 0.022 ± 0.015
P.Ball and R.Zwicky hep-ph/0609037

Present accuracy:
S = - 0.21 ± 0.40 (BaBar : 232M BB)
S = - 0.10 ± 0.31 (BELLE: 535M BB)

$S(K_S\pi^0\gamma)$ = (-0.10±0.31±0.07)
$A(K_S\pi^0\gamma)$ = (-0.20±0.20±0.06)
$S(K^*\gamma)$ = (-0.32±0.36±0.05)
$A(K^*\gamma)$ = (-0.20±0.24±0.05)



Phys.Rev. D74, 111104 (2006)

- **$B_s \to \phi\gamma$ (LHCb)**

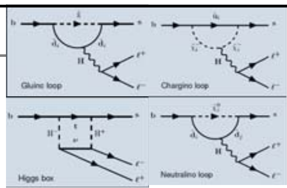
$$\mathcal{A}_{CP}(\Delta t) = \frac{S \sin\Delta m_s \Delta t + A \cos\Delta m_s \Delta t}{\cosh\frac{\delta\Gamma t}{2} - \mathcal{A}^\Delta \sinh\frac{\delta\Gamma t}{2}}$$

$$S = \sin 2\psi \sin\phi_s \approx 0$$

$$\mathcal{A}^\Delta = \sin 2\psi \cos\phi_s \approx \frac{2m_s}{m_b}$$

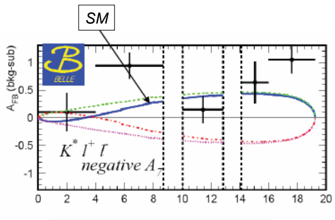
LHCb sensitivity with 10fb^{-1} :
$\sigma(A^\Delta) = 0.09$

$B \to K^*\mu\mu$



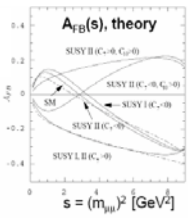
In SM this $b \to s$ penguin decay contains right-handed calculable contribution but this could be added to by NP resulting in modified angular distributions

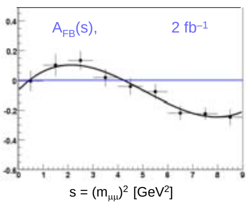
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_0\sin^2\theta_\ell + \frac{3}{8}F_T(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$



$B \to K^*\mu\mu$: LHCb prospects

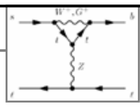
- Forward-backward asymmetry A_{FB} (s) in $\mu\mu$-rest frame is a sensitive NP probe
- Predicted zero of A_{FB} (s) depends on Wilson coefficients C_7^{eff} / C_9^{eff}





- 7.2 k events / 2fb^{-1} with B/S ~ 0.4
- After 10 fb^{-1} zero of A_{FB} located to ±0.28 GeV^2 providing 7% stat. error on C_7^{eff} / C_9^{eff}
- Full angular analysis gives better discrimination between models. Looks promising

$Bs \to \mu\mu$



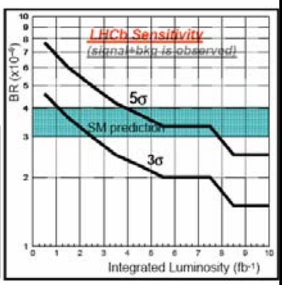
Very smal BR in SM
(3.4 ± 0.5) x 10^{-9}

This decay could be strongly enhanced in some SUSY models. Example: CMSSM

Current limit from CDF
$BR(Bs \to \mu\mu) < 5.8 \times 10^{-8}$

LHCb

0.05 fb^{-1}	⇒	overtake CDF+D0
0.5 fb^{-1}	⇒	exclude BR values down to SM
2 fb^{-1}	⇒	3σ evidence of SM signal
10 fb^{-1}	⇒	>5σ observation of SM signal



→ 90% CL exclusion down to SM BR requires: 0.5 fb^{-1} for LHCb, ~ 10 fb^{-1} for ATLAS/CMS
→ 3σ sensitivity if BR(SM) requires: 2 fb^{-1} for LHCb and > 30 fb^{-1} for ATLAS/CMS

SFF sensitivities for Rare Decays

Channels complementary to LHCb / SLHCb

$\mathcal{B}(B \to \tau\nu)$	3–4%
$\mathcal{B}(B \to \mu\nu)$	5–6%
$\mathcal{B}(B \to D\tau\nu)$	2–2.5%
$\mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^*\gamma)$	3–4%
$A_{CP}(b \to s\gamma)$	0.004–0.005
$A_{CP}(b \to (s+d)\gamma)$	0.01
$S(K_S^0\pi^0\gamma)$	0.02–0.03
$S(\rho^0\gamma)$	0.08–0.12
$A^{\mathrm{FB}}(B \to X_s\ell^+\ell^-)\ s_0$	4–6%
$\mathcal{B}(B \to K\nu\bar{\nu})$	16–20%

OUTLOOK

Clean experimental signature of NP is unlikely at currently operating experiments

From now to 2014

A lot of opportunities ***(LHCb will start data taking next year)***

Important measurements to search for NP and test SM in CP violation

- *χ: if non-zero → NP in boxes* ***< 2010***
- *β vs Rb and γ vs Rt (Input from theory !)*
- *$\delta\beta$(NP) and $\delta\chi$(NP): if non-zero → NP in penguins*

in Rare decays

- *BR(B_s → $\mu\mu$) down to SM prediction* ***< 2010***
- *Photon helicity in exclusive b→sγ decays*
- *FBA & transversity amplitudes in exclusive b→sll decays* ***< 2010***

After 2014

ATLAS and CMS might or might not discovered New Particles. At the same time LHCb might or might not see NP phenomena beyond SM.
In either case it is important to go on with B physics at SFF & Upgraded LHCb

high p_T ⟺ ***B's***

Need much improved precision because any measurement in b-system constrains NP models