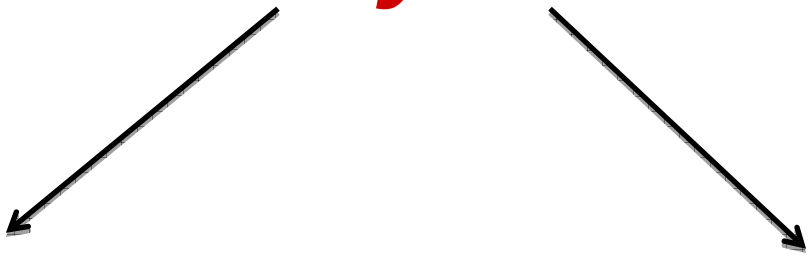
*Andrey Golutvin*
*ARGUS & ITEP/Moscow*

# *New Physics*
# *&*
# *Future B Physics Programs*



***CP violation*** ***Rare Decays***

## *Experimental Facilities*

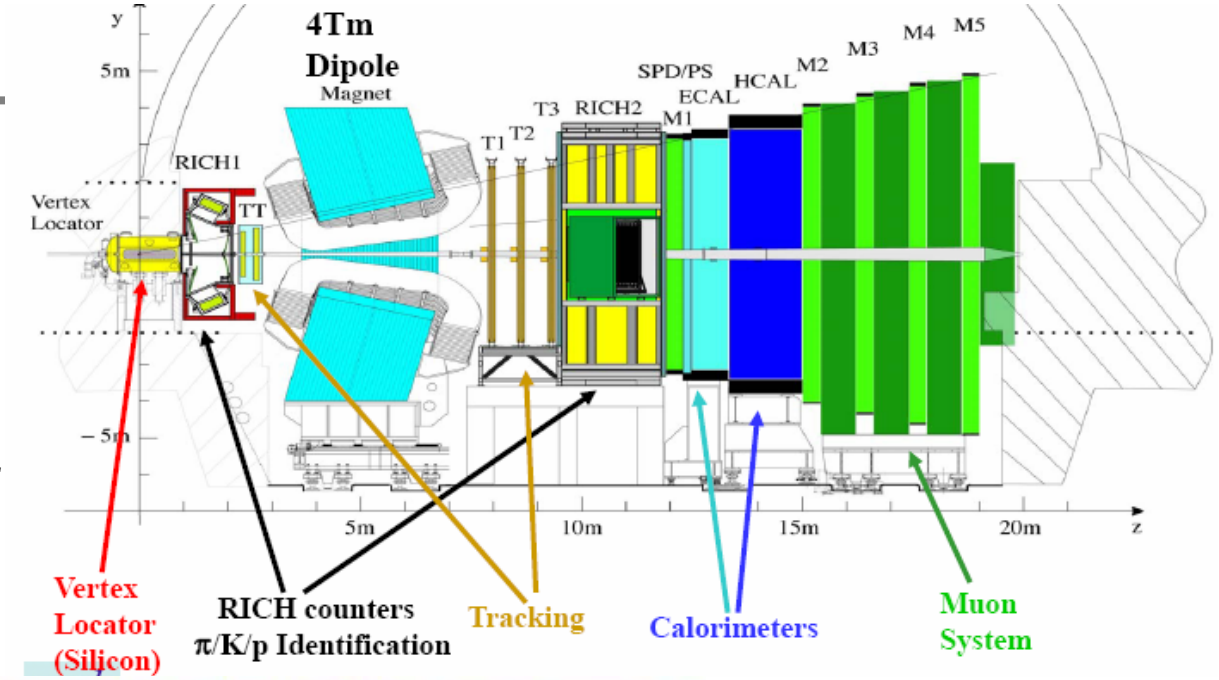
- ***LHCb*** *– forward spectrometer (running in pp – collider mode)*
  ***Data taking starts next year***
  *Expect ~10 $fb^{-1}$ by 2013*
  *B physics is also a part of the ATLAS and CMS early program*

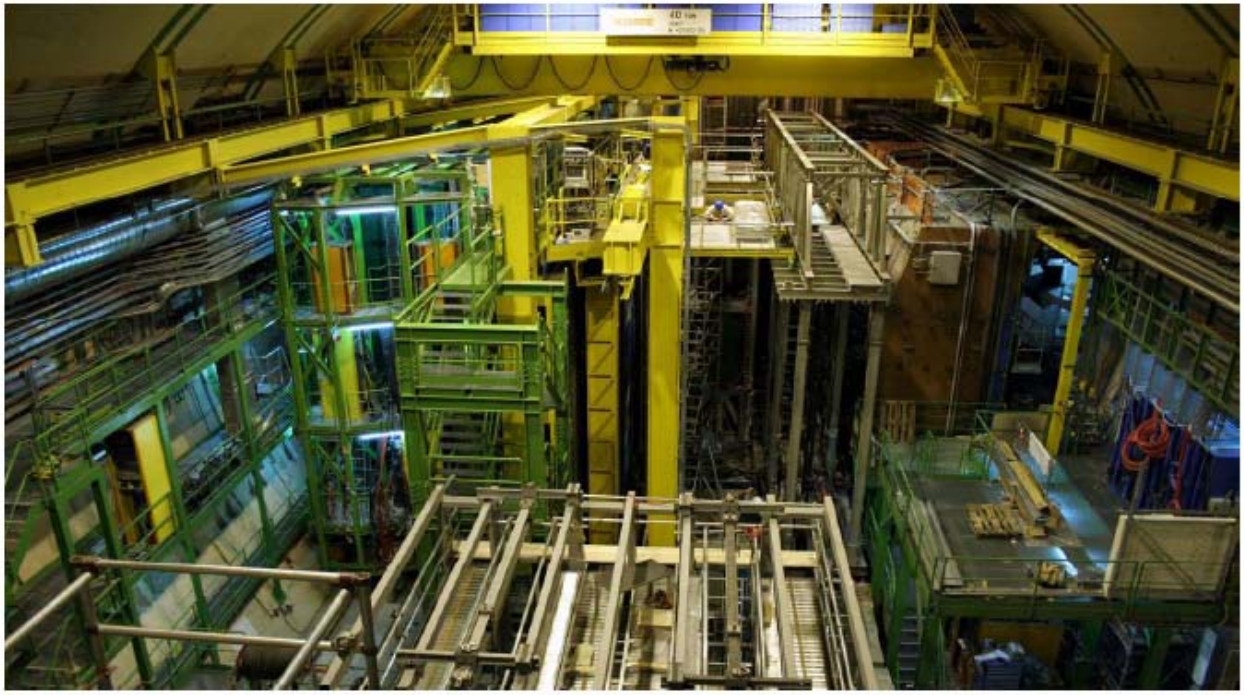
- ***Super Flavor Factory (SFF)*** *following either SuperKEKB or Super B proposal with an integrated luminosity of 50 – 75 $ab^{-1}$*
  *Start data taking > 2014*
  *(T.Browder et al arXiv:0710.3799v1)*

- ***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 $\mu$b)*
- *Forward geometry*
- *Low luminosity is sufficient*
  *At $2\times10^{32}$ $10^{12}$ bb pairs are produced per year*



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## *UT as a standard approach to test the consistency of SM*

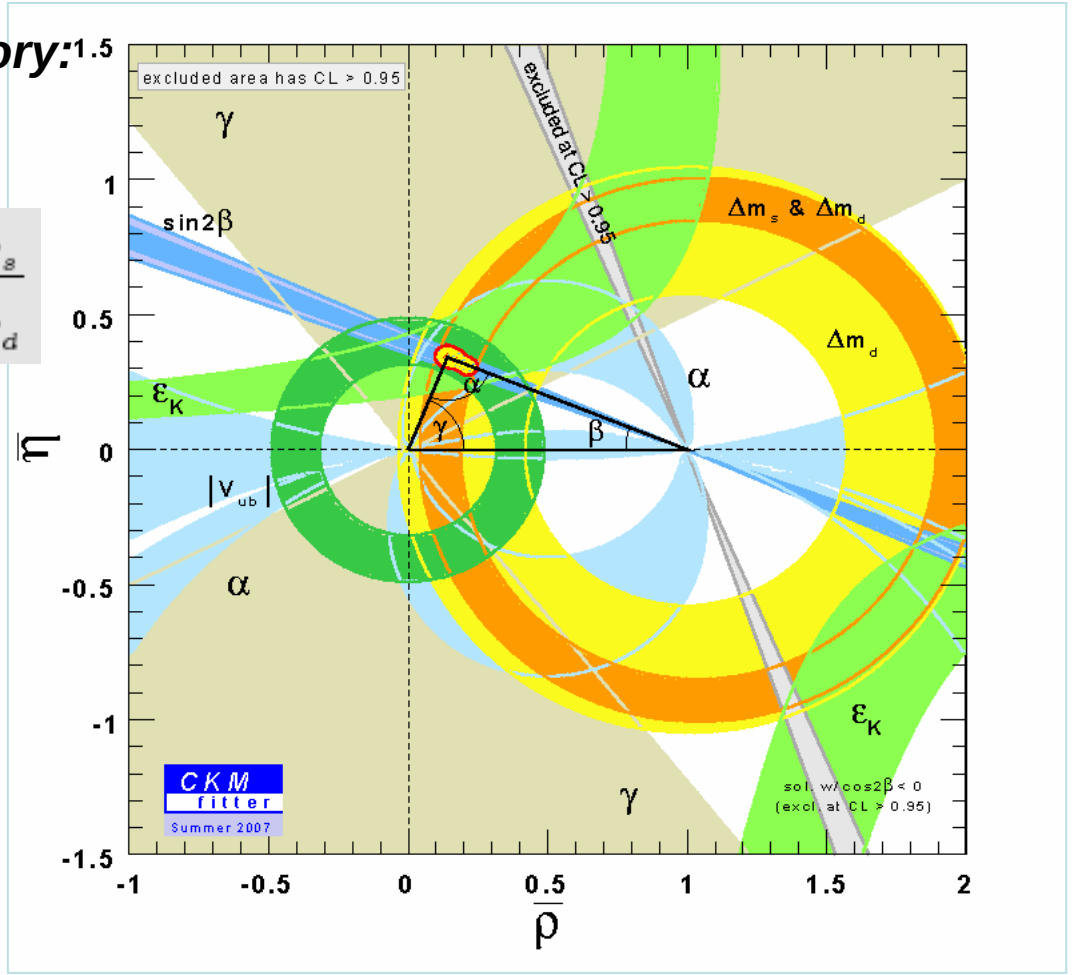
***Mean values of angles and sides of UT are consistent with SM predictions***

***Accuracy of sides is limited by theory:***

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

***Accuracy of angles is limited by experiment:***

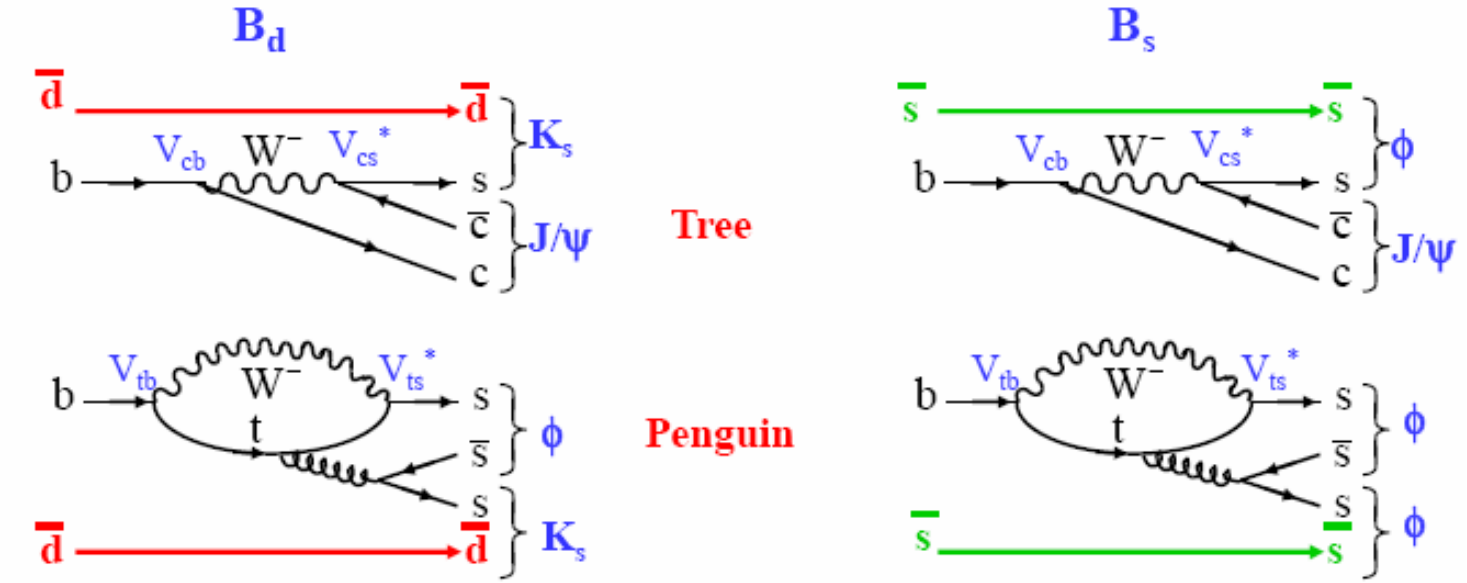
$\alpha = \pm 13°$
$\beta = \pm 1°$
$\gamma = \pm 25°$



## *Search for NP comparing observables measured in tree and loop topologies*

$\beta$(tree+box) in $B \rightarrow J/\psi Ks$
$\gamma$(tree) in many channels
$\chi$(tree+box) in $B_s \rightarrow J/\psi\phi$

$\gamma$(peng+tree) in $B \rightarrow \rho\rho, \rho\pi, \pi\pi$
$\beta$(peng+box) in $B \rightarrow \phi Ks$
$\chi$(peng+box) in $Bs \rightarrow \phi\phi$




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

$\delta\gamma(NP) = \gamma(peng+tree) - \gamma(tree)$
$\delta\beta(NP) = \beta(B \rightarrow \phi Ks) - \beta(B \rightarrow J/\psi Ks) \neq 0$
$\delta\chi(NP) = \chi(B_s \rightarrow \phi\phi) - \chi(B_s \rightarrow J/\psi\phi)$

## *Search for NP comparing observables measured in tree and loop topologies*

### *Contribution of NP to processes mediated by loops*

*(present status)*

- ***to boxes:***

$\beta$ *vs* $|V_{ub} / V_{cb}|$ *is limited by theory (~10% precision in* $|V_{ub}|$*)* *(d-box)*

$\chi$ *not measured with any accuracy* *(s-box)*

- ***to penguins:***

$\sigma(\delta\gamma(NP))$ *~ 30°* *(d-penguin)*

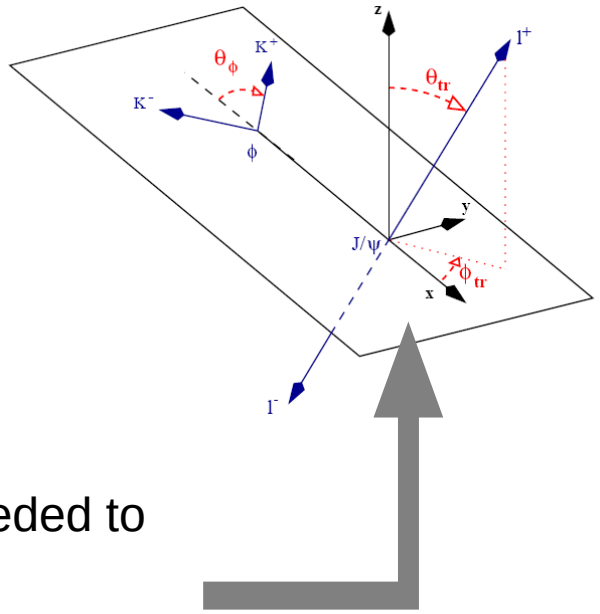
$\sigma(\delta\beta(NP))$ *~8°* *(s-penguin)*

$\sigma(\delta\chi(NP))$ *not measured* *(s-penguin)*

*PS* $\delta\beta(NP) = \delta\chi\,(NP)$

$\delta\gamma(NP)$ *measured in* $B \to \pi\pi$ *and* $B \to \rho\rho$ *decays may differ depending on penguin contribution to* $\pi\pi$ *and* $\rho\rho$ *final states*

## $\chi$ : LHC prospects




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

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

**LHCb**

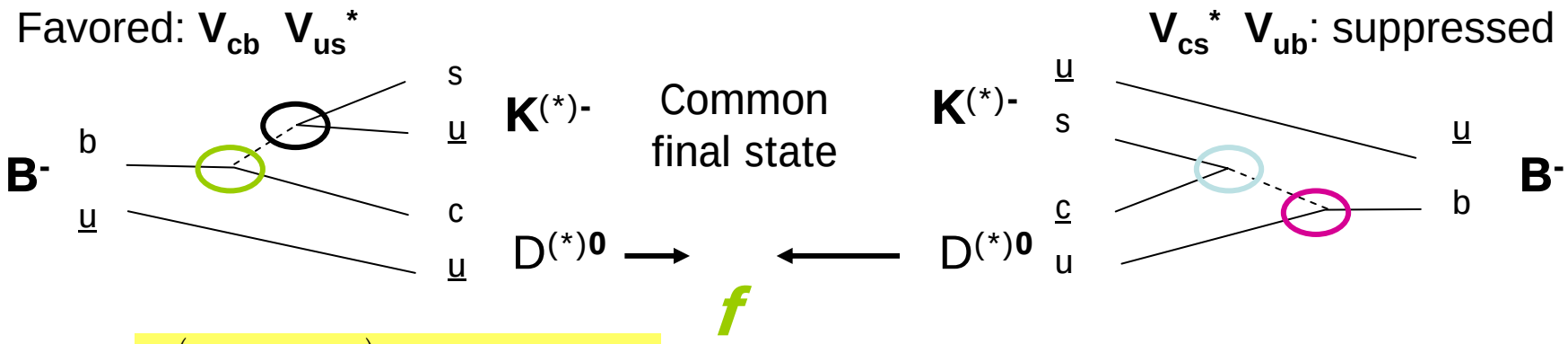
| Channels | $\sigma(\phi_s)$ [ rad ] | Weight $(\sigma/\sigma_i)^2$ [ % ] |
|---|---|---|
| $B_s \rightarrow J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$ | 0.142 | 2.3 |
| $B_s \rightarrow D_s D_s$ | 0.133 | 2.6 |
| $B_s \rightarrow J/\psi\ \eta(\gamma\ \gamma)$ | 0.109 | 3.9 |
| $B_s \rightarrow \eta_c\phi$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

**ATLAS**

**will reach $s(\phi_s) \sim 0.08$ (10/fb, $\Delta m_s$=20/ps, 90k $J/\psi\phi$ evts)**

## *UT angle $\gamma$: LHCb (BaBAr & BELLE & Tevatron ~12° precision for $\gamma$ at best)*

- ***Interference between tree-level decays***




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

*Parameters: $\gamma$, ($r_B$, $\delta_B$) 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 $\gamma$: LHCb summary table*

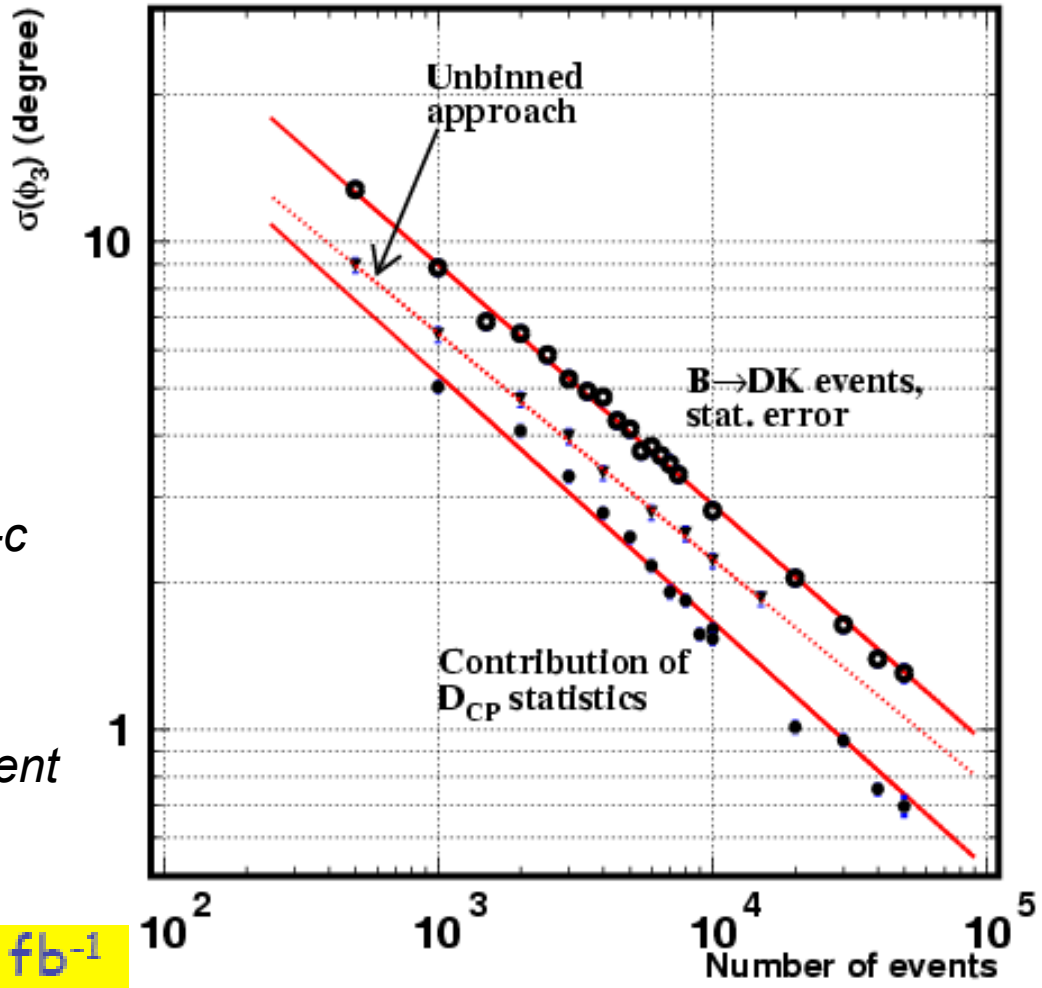
| B mode | D mode | Method | $\sigma(\gamma)$ with 2 fb$^{-1}$ |
|---|---|---|---|
| $B^+ \to DK^+$ | $K\pi$ + $KK/\pi\pi$ + $K3\pi$ | ADS+GLW | $5^o$–$13^o$ |
| $B^+ \to D^*K^+$ | $K\pi$ ($D^* \to D\pi, \gamma$) | ADS+GLW | Under study |
| $B^+ \to DK^+$ | $K_S\pi\pi$ | Dalitz | ~8-12$^o$ |
| $B^+ \to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

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

# *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 $\gamma/\varphi_3$ 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 ($50\text{-}75\ ab^{-1}$) & SLHCb ($>100\ fb^{-1}$) sensitivities

**LHCb**

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

**SFF & SLHCb**

**> 2014**

| Observable | Super Flavour Factory sensitivity | SLHCb (stat. only) |
|---|---|---|
| $\sin(2\beta)$ $(J/\psi K^0)$ | 0.005–0.012 | ~ 0.003 |
| $\gamma$ $(B \to D^{(*)}K^{(*)})$ | 1–2° | < 1° (Bs→DsK) |
| $\alpha$ $(B \to \pi\pi, \rho\rho, \rho\pi)$ | 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 |
| $S(K^0_S K^0_S K^0_S)$ | 0.02–0.04 | |

# *Search for New Physics in Rare Decays*

**LHCb**

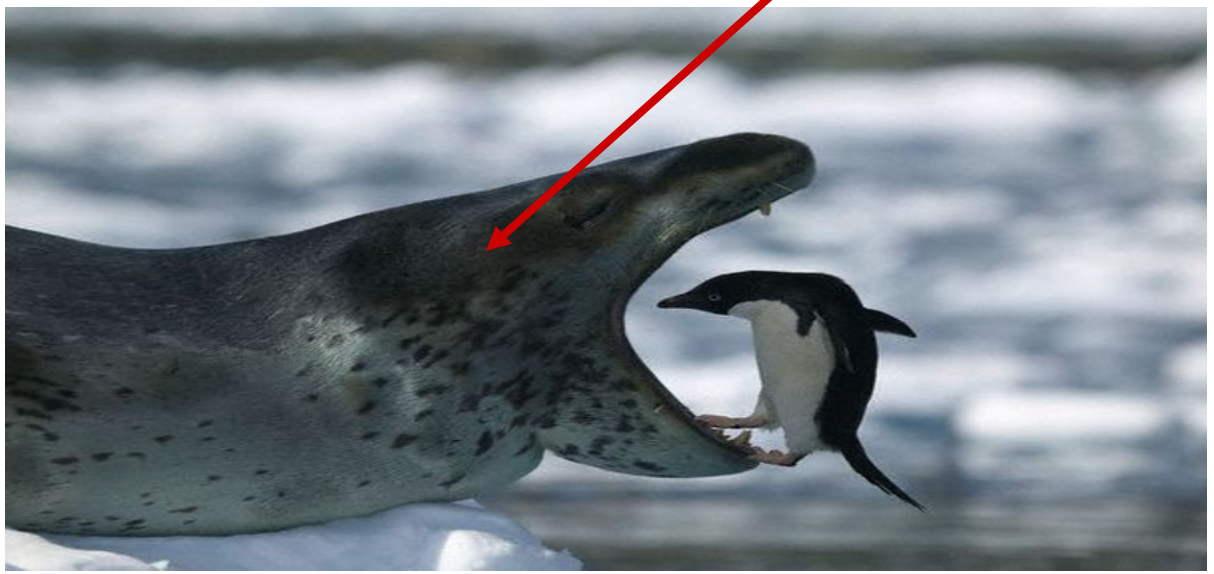
- Exclusive $b \rightarrow s\gamma$
- $B \rightarrow K^*\mu\mu$
- $Bs \rightarrow \mu\mu$

**SFF**

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

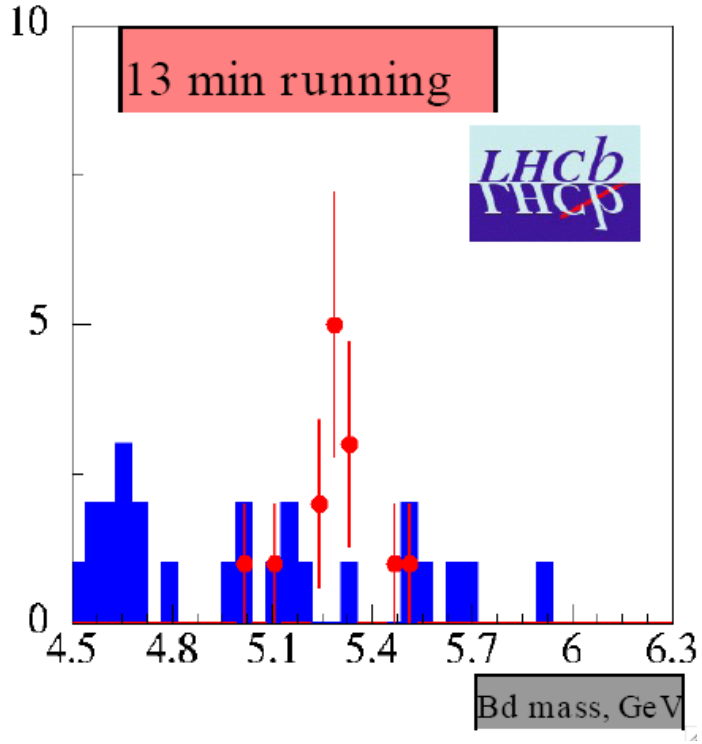
***We are just approaching sensitivity promising for discovery…***

***Experimental challenge: keep backgrounds under control***

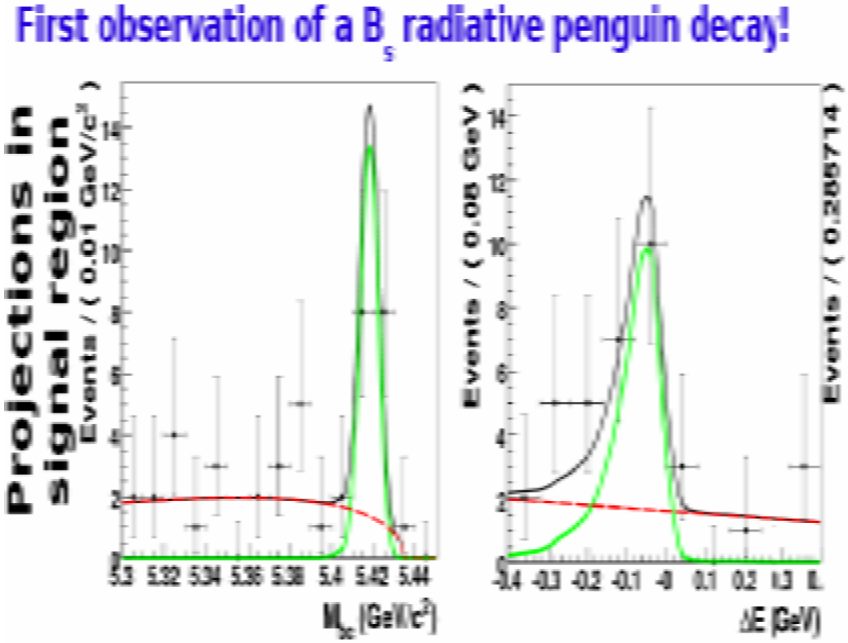


## $b \rightarrow s\gamma$ exclusive

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

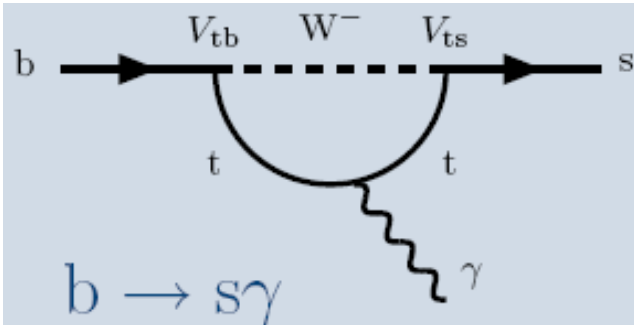



***Bs → $\phi\gamma$***
***BELLE observed 16±8 events***
***2 weeks run at $\Upsilon$(5S); no TDCPV***




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

## $b \rightarrow s\gamma$ exclusive




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

***Measurement of the photon helicity is very sensitive test of SM***

***Methods:***

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

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

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

## Mixing induced CP asymmetries

### ❑ $B \rightarrow K_S\pi^0\gamma$ (B-factories)

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

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

$S$ = - (2+O($\alpha_s$))sin(2$\beta$)$m_s/m_b$ + (possible contribution from $b \rightarrow s\gamma g$) = - 0.022 ± 0.015

P.Ball and R.Zwicky hep-ph/0609037

*Present accuracy:*

**$S$ = - 0.21 ± 0.40 (BaBar : 232M BB)**

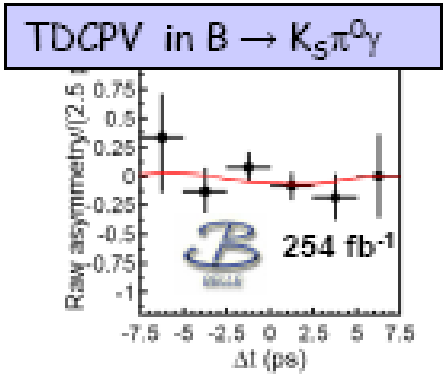
**$S$ = - 0.10 ± 0.31 (BELLE: 535M BB)**

$S(K_S\pi^0\gamma)$ = (-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)

### ❑ $B_s \rightarrow \phi\gamma$ (LHCb)

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

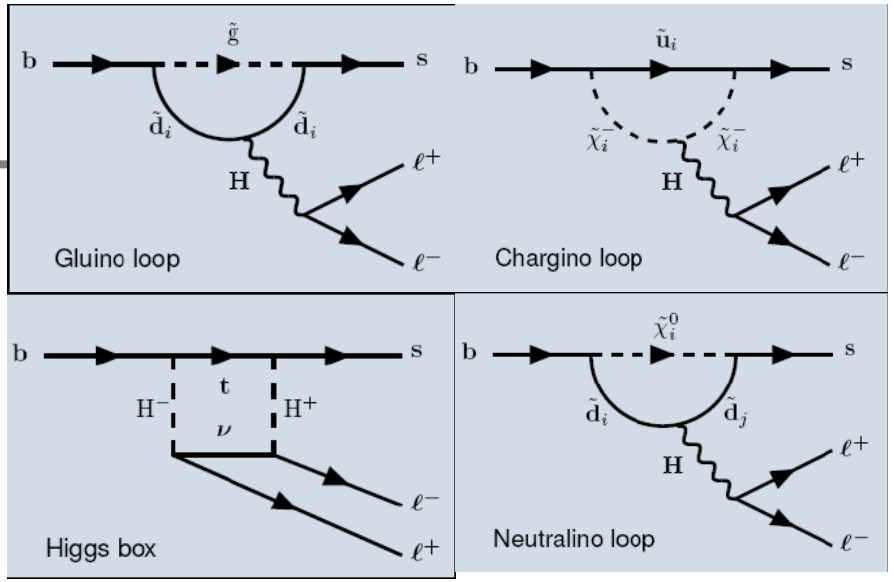
$$S = \sin 2\psi \sin \phi_s \approx 0$$

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

**LHCb sensitivity with 10fb$^{-1}$ :**

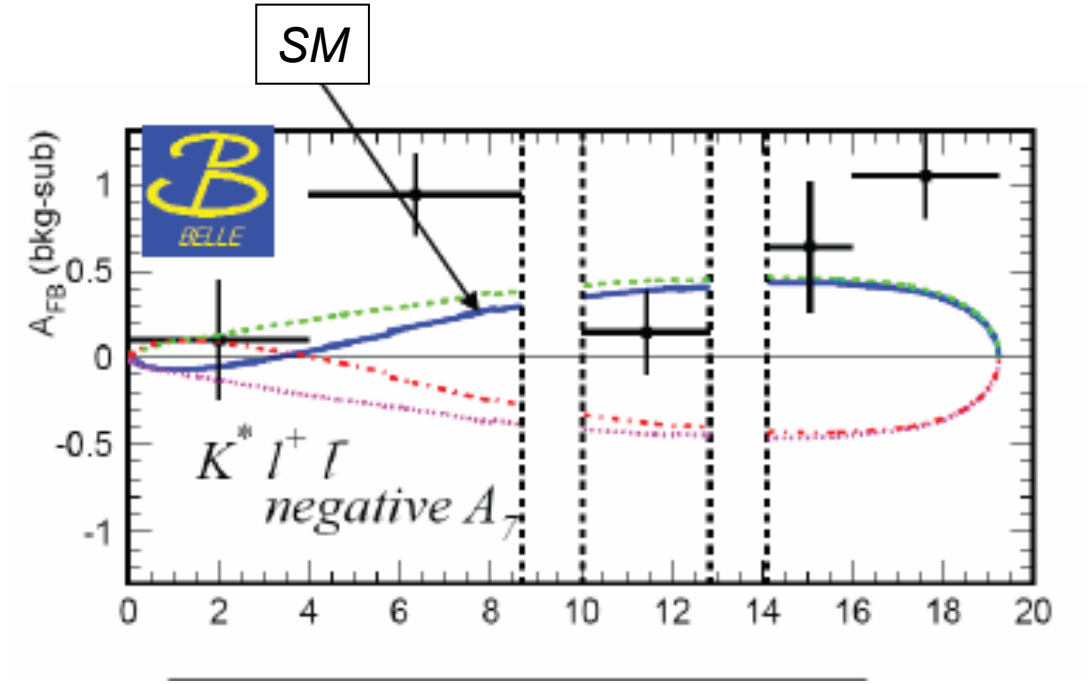
**$\sigma(A^{\Delta}) = 0.09$**

## $B \rightarrow K^* \mu\mu$



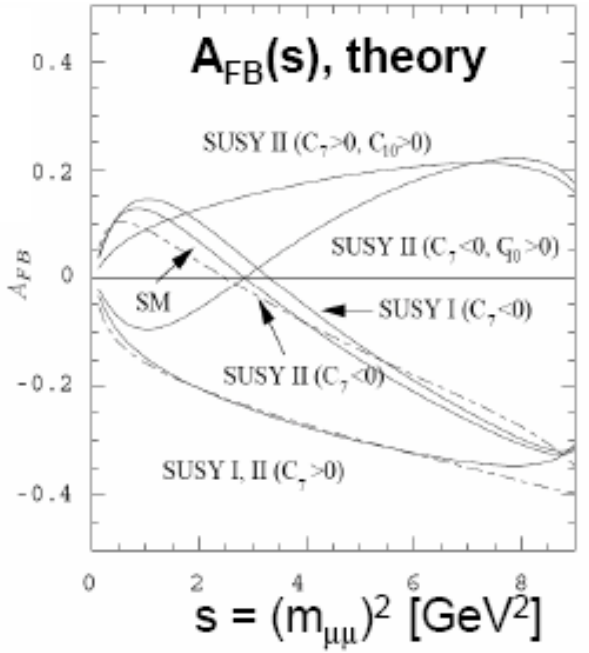

*In SM this b→s penguin decay contains right-handed calculable contribution but this could be added to by NP resulting in modified angular distributions*

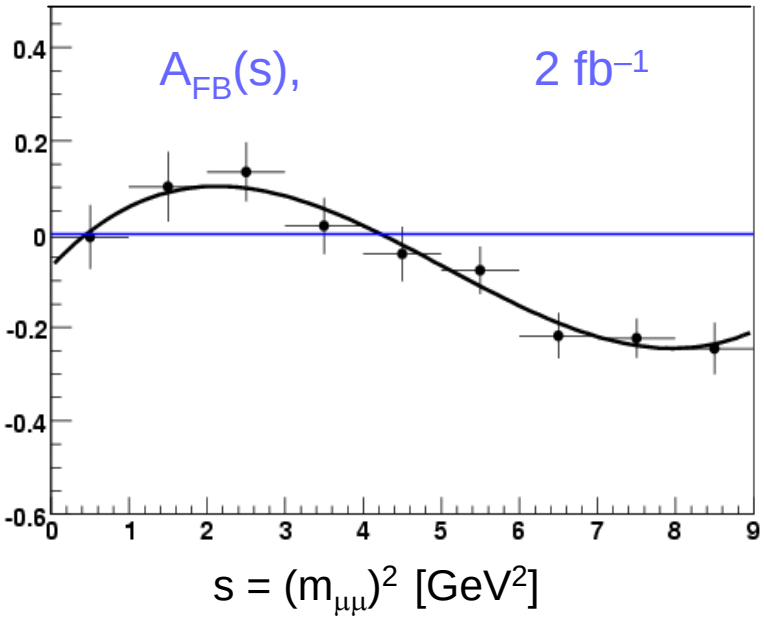
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_0\sin^2\theta_\ell + \frac{3}{8}F_T(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$



## $B \rightarrow K^* \mu\mu$: LHCb prospects

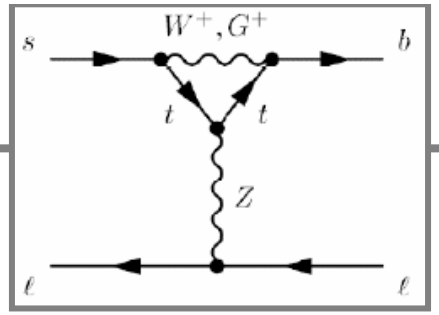
- *Forward-backward asymmetry $A_{FB}$ (s) in $\mu\mu$-rest frame is a sensitive NP probe*
- *Predicted zero of $A_{FB}$ (s) depends on Wilson coefficients $C_7^{eff}$ / $C_9^{eff}$*




- *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 → μμ




***Very smal BR in SM***

***$(3.4 \pm 0.5) \times 10^{-9}$***

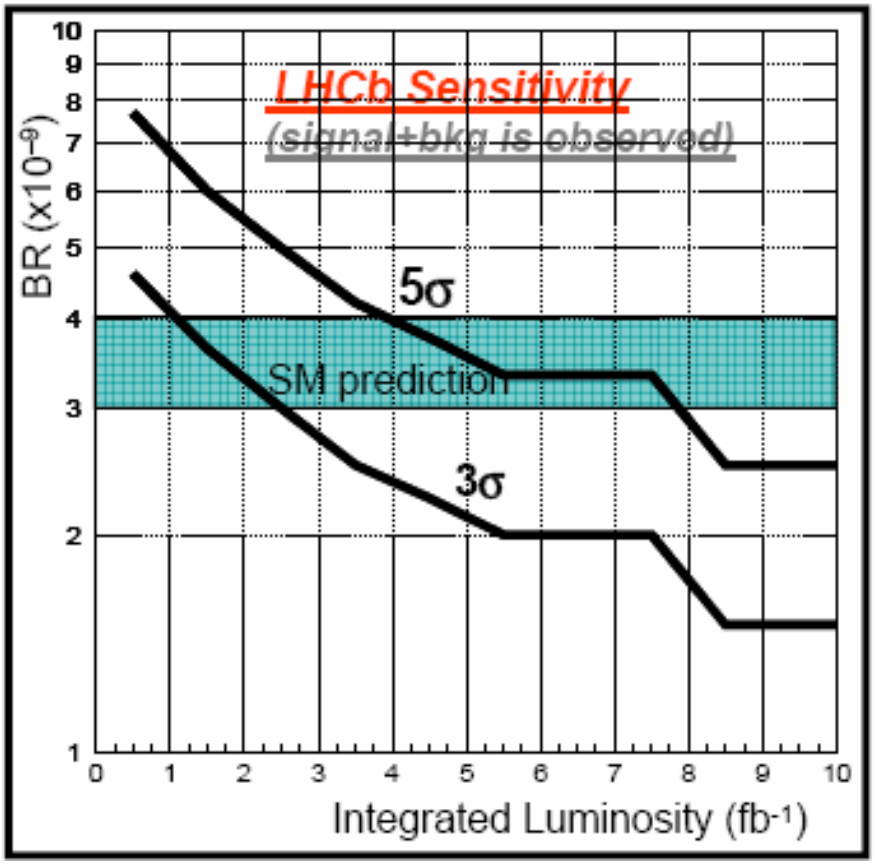
*This decay could be strongly enhanced in some SUSY models. Example: CMSSM*

***Current limit from CDF***

***$BR(Bs \rightarrow \mu\mu) < 5.8 \times 10^{-8}$***

**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 |
| $A^{\rm FB}(B \to X_s\ell^+\ell^-)\ s_0$ | 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***

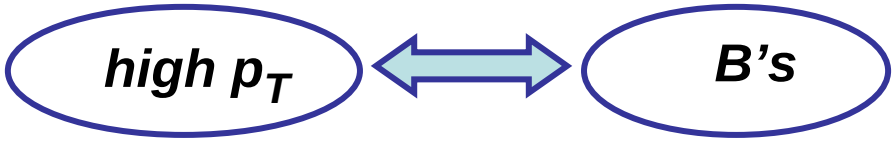
- *$\chi$: if non-zero → NP in boxes* ***< 2010***
- *$\beta$ vs Rb and $\gamma$ vs Rt (Input from theory !)*
- *$\delta\beta$(NP) and $\delta\chi$(NP): if non-zero → NP in penguins*

***in Rare decays***

- *BR($B_s \rightarrow \mu\mu$) down to SM prediction* ***< 2010***
- *Photon helicity in exclusive b→s$\gamma$ 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*




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