Rare decays at LHCb

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Outline

- Loop-induced rare decays
- Event Simulation
- Event selection at LHCb
  - Annual Event yields
  - Background estimates
- Summary

- LHCb detector and its status is presented in detail in plenary talk by T.Nakada

Loop induced rare decays

- Radiative penguins
  - $B \to K^{*0}\gamma$, $B_s \to \phi\gamma$, $B \to \omega\gamma$
- EW-penguins
  - $B \to K^{*0}\mu^+\mu^-$
- Gluonic penguins
  - $B_s \to \phi\phi$, $B \to \phi K_S$
- “Very rare”
  - $B \to \mu+\mu-$

Rare (="loop-induced") decays

- Loop-induced decays are the perfect place to search for New Physics hints
- SM model loops are suppressed
  - GIM cancellation
  - "rare decays"
- Penguins
  - $b \to s(d)\ \gamma, Z^0, g$
- Boxes

- Heavy particles are suppressed in trees
  - could appear in the loops
- New particles in loops:
  - Enhancement in decay rates
  - New phases
  - New asymmetries
  - … ?
- Ideal laboratory for New Physics search
- <u>But also some QCD tests</u>

Radiative penguin decays

- No so rare decays
  - PDG

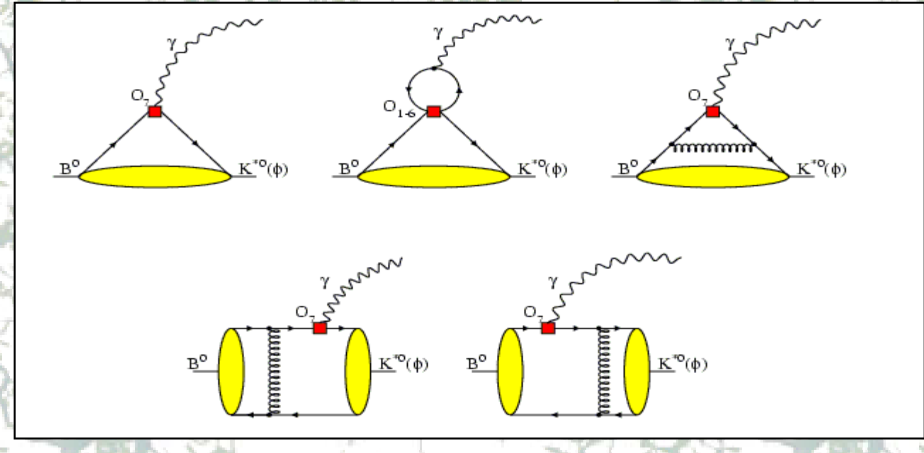
    $Br(B \to K^{*0}\gamma) = (4.3 \pm 0.4) \times 10^{-5}$

    $Br(B^- \to K^{*-}\gamma) = (3.8 \pm 0.5) \times 10^{-5}$

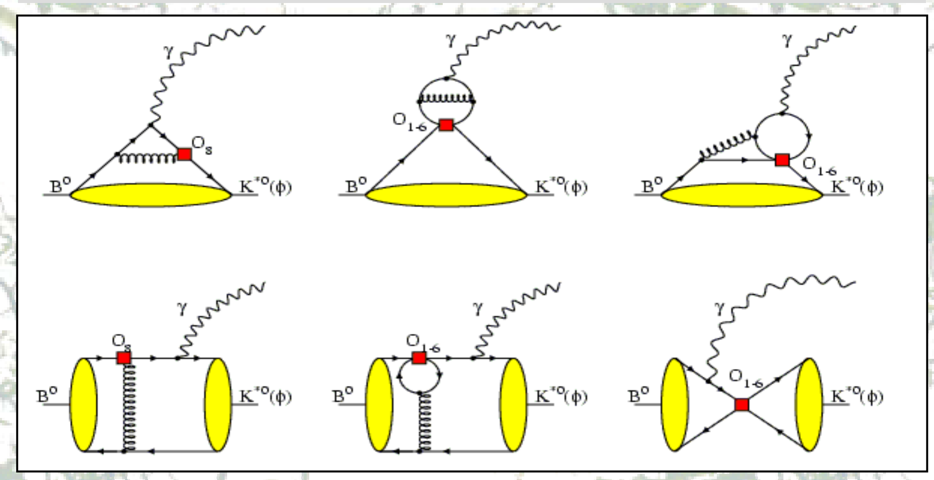
- Isotopic asymmetries

$$\mathcal{A}^{I}_{B\to K^*\gamma} = \frac{\Gamma_{B^0\to K^{*0}\gamma} - \Gamma_{B^-\to K^{*-}\gamma}}{\Gamma_{B^0\to K^{*0}\gamma} + \Gamma_{B^-\to K^{*-}\gamma}}$$

  - $\sim C_6 + C_5/N_C$
  - $\sim O(1\%)$



Suppressed by : α_s , $1/m_b$ or $|V_{CKM}|$



$b \to s(d)\gamma$: *CP*-asymmetries

- 1-amplitude dominance
- strong phase appears at order of α_s or $1/m_b$
  - →"Direct" asymmetries are small (≤1%)

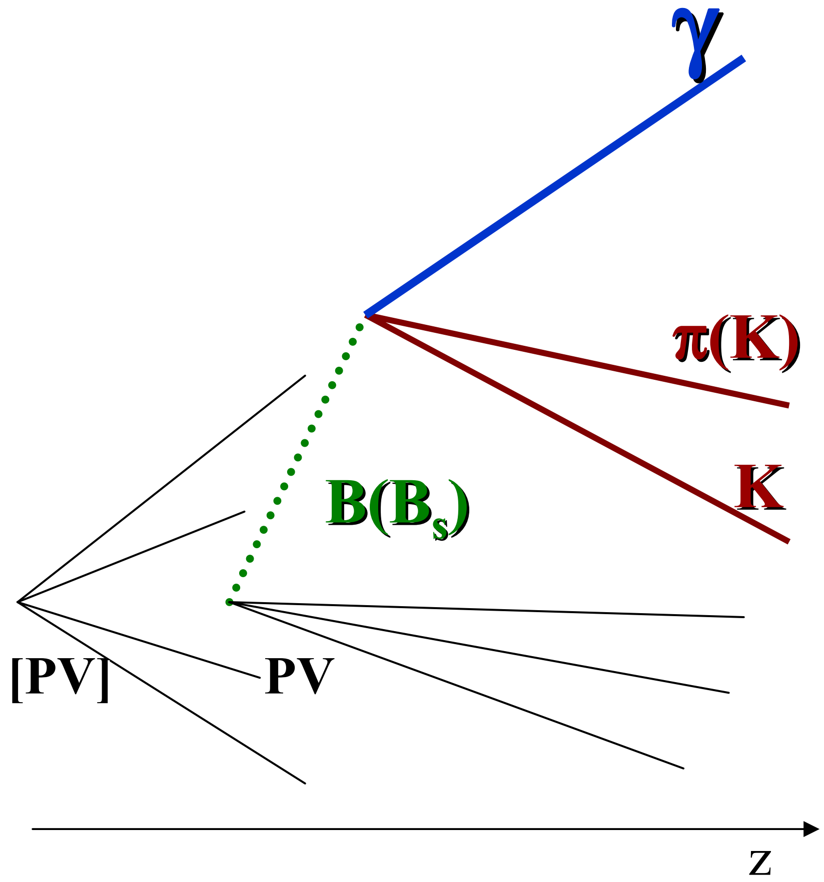
$$\mathcal{A}^{dir}_{B^0\to K^{*0}\gamma} = \frac{\Gamma_{B^0\to K^{*0}\gamma} - \Gamma_{\bar{B}^0\to \bar{K}^{*0}\gamma}}{\Gamma_{B^0\to K^{*0}\gamma} + \Gamma_{\bar{B}^0\to \bar{K}^{*0}\gamma}}$$

- $B_s \to \phi\gamma$:
  - not *CP*-eigenstate!
  - V-A: γ is circular polarized
    - "Wrong polarization": $\sim m_s(m_d)/m_b$
- Both A^{mix} and A^{dir} are small

$$\mathcal{A}_{B^0_{(s)}\to f_{CP}\gamma}(t) = \frac{\Gamma_{B^0_{(s)}\to f_{CP}\gamma}(t) - \Gamma_{\bar{B}^0_{(s)}\to f_{CP}\gamma}(t)}{\Gamma_{B^0_{(s)}\to f_{CP}\gamma}(t) + \Gamma_{\bar{B}^0_{(s)}\to f_{CP}\gamma}(t)} \approx \mathcal{A}^{dir}_{B^0_{(s)}\to f_{CP}\gamma}\cos\Delta m_{(s)}t + \mathcal{A}^{mix}_{B^0_{(s)}\to f_{CP}\gamma}\sin\Delta m_{(s)}t$$

Event Simulation

- PYTHIA as pp-event generator as $\sqrt{s} = 14$ TeV
- QQ for weak-decays
- GEANT 3.21
  - Realistic geometry & material description
- The pile-up is included
- "Realistic" digitization, reconstruction algorithms & L0/L1 trigger simulation
- Background: "forward" $b\bar{b}$-production in 400mrad cone
  - 10^7 available events



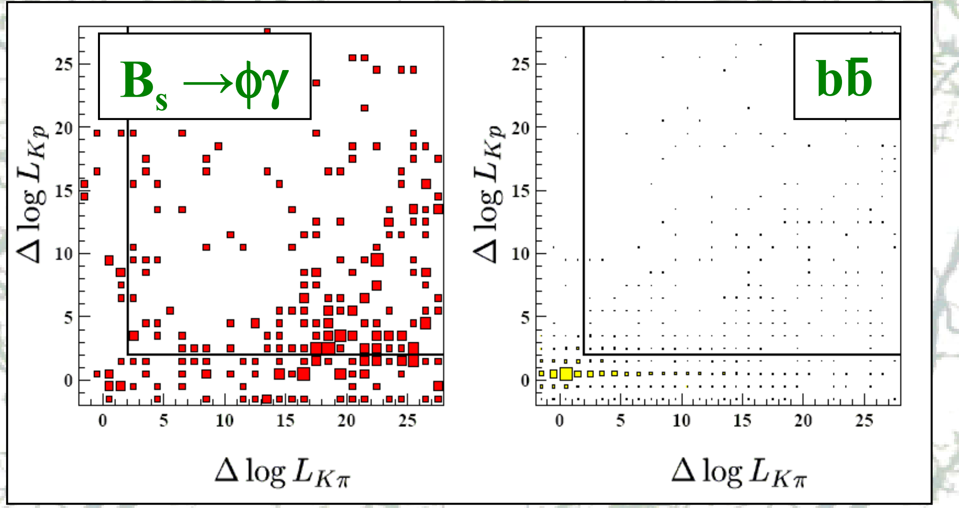
Background suppression

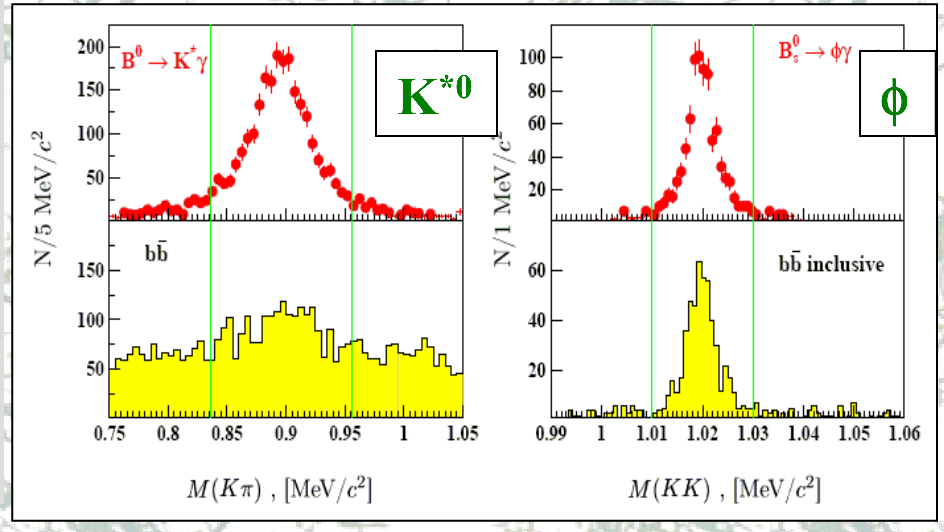
- Beauty particles:
  - $m_b \sim 5$ GeV/c^2
  - $\beta\gamma c\tau \sim O(1\text{cm})$
- Particles from B-decays:
  - Large p_T
    - L0 (hardware) trigger:
      - leptons ($e^{\pm}$,$\mu^{\pm}$,$\mu\mu$),
      - photons
      - hadrons
  - Large impact parameters
    - L1 (software) trigger
- Background:
  - $b\bar{b}$-production with at least one B within 400mrad cone

- High Level Trigger and Off-line background suppression continues to utilize these properties
- B-decay products do not point to reconstructed primary vertices
- Exclusively reconstructed B-candidate does point to primary vertex
- B-candidate is associated with primary vertex with minimal impact parameter (significance)

Selection of $B_d \to K^{*0}\gamma$ and $B_s \to \phi\gamma$

- $\pi^{\pm}, K^{\pm}$:
  - charged tracks consistent with PID
  - Inconsistent with any PV
    - $\chi^2_{IP} > 16(4)$
- Two prong vertex
  - $\chi^2_{VX} < 49$
- K^{*0} :
  - $|\Delta M| < 60\ \mathrm{MeV}/c^2$
- ϕ :
  - $|\Delta M| < 10\ \mathrm{MeV}/c^2$
- γ :
  - clusters in Ecal not associated with any reconstructed track
  - $E_T > 2.8$ GeV
  - $2.2(2.0) < E_T^* < 2.7$ GeV

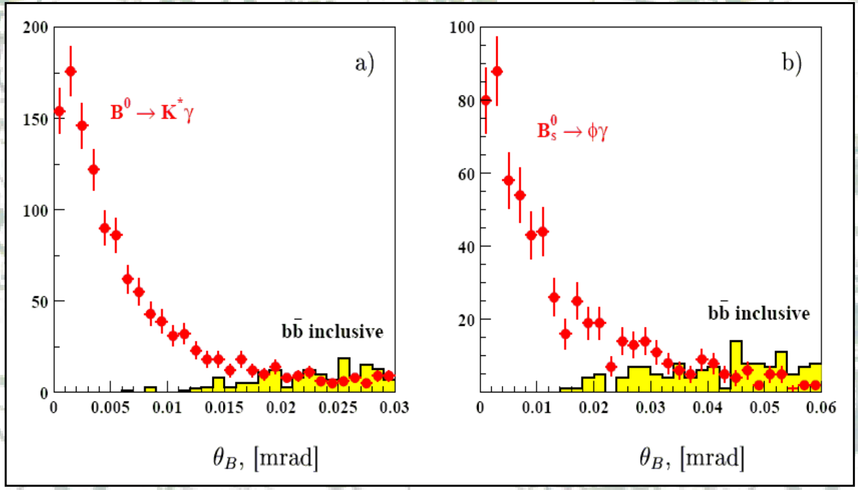


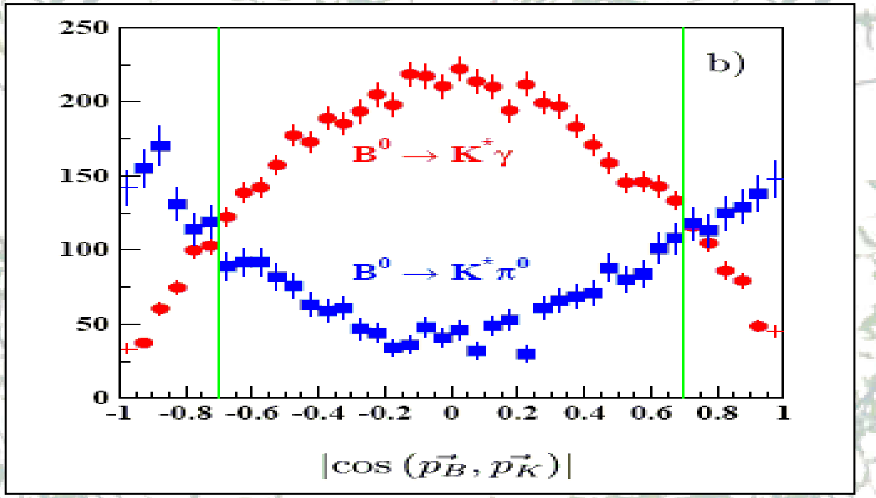


Selection of $B_d \to K^{*0}\gamma$ and $B_s \to \phi\gamma$ (II)

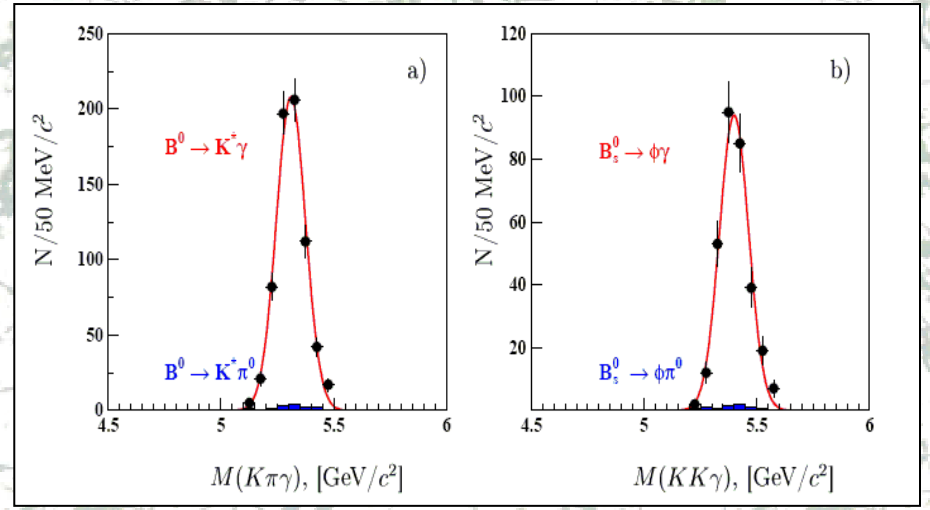
- **B :**
  - $|\theta_B| < 6$ (15) mrad
- **Correlated feeddown with merged π^0, wrongly reconstructed as single photon**

  $B \to K^{*0}\pi^0$, $B_s \to \phi\pi^0$
  - opposite $K^{*0}(\phi)$ polarization
    - $|\cos\theta| < 0.75$





$B_d \rightarrow K^{*0}\gamma$ $B_s \rightarrow \phi\gamma$ (III)



	$B_d \rightarrow K^{*0}\gamma$	$B_s \rightarrow \phi\gamma$
ε_{REC} [%]	4.5	4.3
$\varepsilon_{TRIG/REC}$ [%]	19	19
$\varepsilon_{SEL/TRIG}$ [%]	18	27
ε_{TOT} [%]	0.16	0.22

- B-mass window is defined as ± 200 MeV/c^2
  - $\sigma(M_B) = 65$ MeV/c^2
- The correlated feeddown is well under the control

Annual yield (using 10^{12} $b\bar{b}$ events/10^7 second)

	$B_d \rightarrow K^{*0}\gamma$	$B_s \rightarrow \phi\gamma$
N/year	35k	9.3k

Background

Background estimation is limited by the size of available sample of 10^7 forward $b\bar{b}$ events and $3x10^7$ minimum bias events

No background events are found in "wide" mass interval 4.5-6.0 GeV/c^2

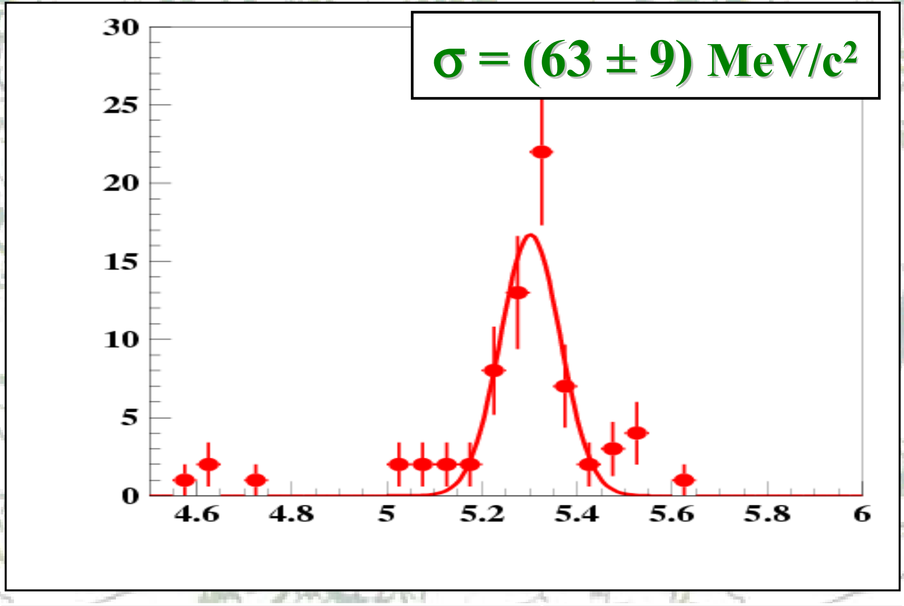
only 90%CL upper limits can be set now from $b\bar{b}$-background

- We consider now forward $b\bar{b}$ production as a major source of background
  - large p_T, large impact parameters, secondary verticies, …
  - (This assumption need to be properly validated and proved)

	$B_d \to K^{*0}\gamma$	$B_s \to \phi\gamma$
B/S	<0.7	<2.4

First look at $B_d \to \omega\gamma$

- $b \to d\gamma$ transition
- $|V_{td}|$ can be extracted without large theoretical uncertainty
    - also for large Δm_s
- $Br(B \to K^*\gamma) / Br(B \to \omega\gamma) \sim 65$
- reconstruction efficiency is low:
    - π^0 need to be reconstructed
- Background condition is difficult
    - 3 neutral particles in final state



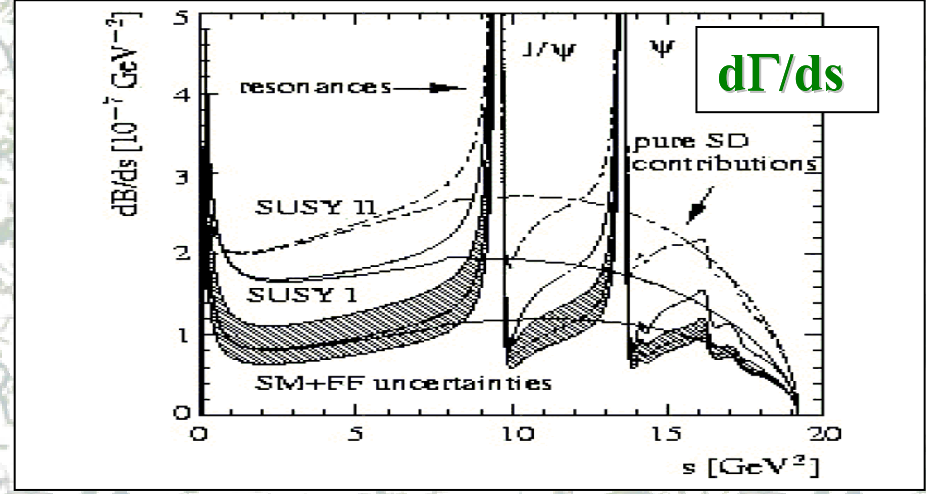
ε_{TOT} [%]	N/year
0.012	40
B / S < 3.5 @ 90 % CL	
$Br(B^0 \to \omega\gamma) = 0.5 \times 10^{-6}$	

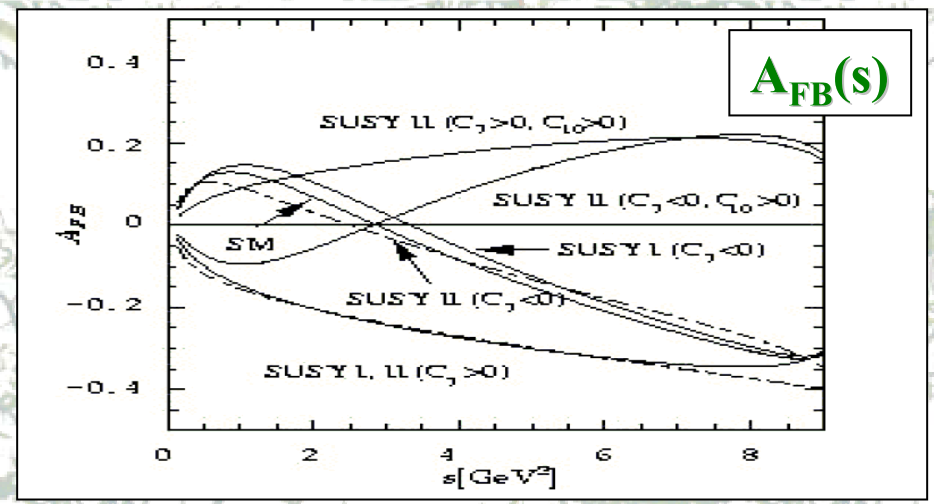
EW penguins: $B_d \to K^{*0}\mu^+\mu^-$

- Combination of $b \to sZ$, $b \to s\gamma$ penguins with the box diagram
- Both Γ and $d\Gamma/ds$ is very sensitive to New Physics as well as the forward-Backward $A_{FB}(s)$ asymmetry

$$A_{FB}(s) = \left(\int_0^1 d\cos\theta - \int_{-1}^0 d\cos\theta\right) \frac{d^2\Gamma}{ds\,d\cos\theta}$$

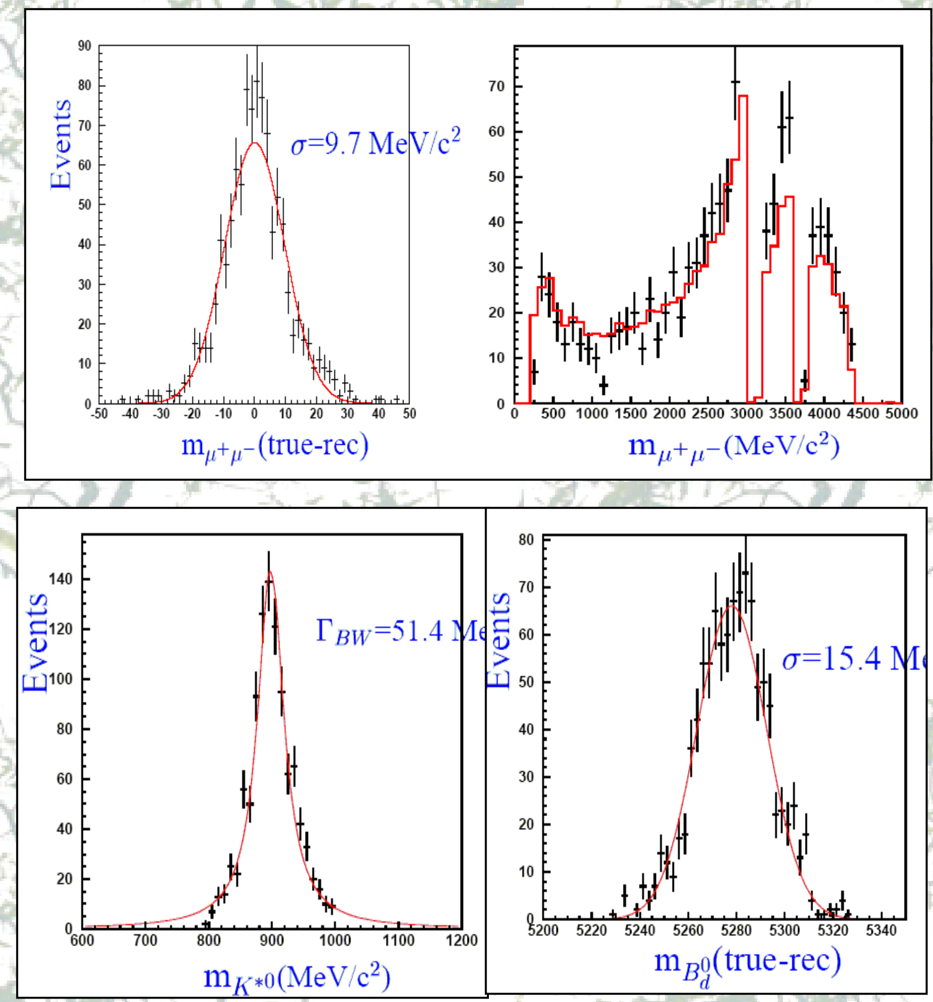
θ is angle between μ^+ and K^{*0} in dimuon restframe





Selection of $B_d \rightarrow K^{*0}\mu\mu$

- $\mu^{\pm}$:
  - charged tracks consistent with PID
  - $p_T > 500$ MeV/c2
- Two prong $\mu\mu$-vertex
  - $\chi^2_{VX} < 8$
- $J/\psi,\psi(2S)$ veto:
  - 2.9-3.2, 3.65-3.75 GeV/c^2
- K,π
  - charged tracks consistent with PID
  - $p_T(\pi) > 200$ MeV/c^2
- K^{*0}
  - $\chi^2_{VX} < 8$
  - $p_T > 900$ MeV/c2
  - $|\Delta M| < 100$ MeV/c2



Efficiencies, Event yields and B/S

- $\varepsilon_{TOT} = 0.7\%$, $\varepsilon_{TRIG} = 74\%$
- Annual yield : 4400 events
- B/S for forward $b\bar{b}$ events
  - [0.2-2.0] at 90% CL
- Various $b\to\mu X$, $\mu\mu X$, $J/\psi X$ channels were studied as sources of potential feeddown

	B/S at90%CL
forward $b\bar{b}$	[0.2, 2.0]
$b\to\mu(c\to\mu X)X$	<1.1
$b\to\mu X$ + c.c	0.5 ± 0.2
$B\to J/\psi K^*$	<0.04
$B\to J/\psi K_S$	<0.04
$B_s\to J/\psi\phi$	<0.05

Gluonic penguins: $B_d \to \phi K_S$ $B_s \to \phi\phi$

- SM: Channels with domination of 1-gluonic penguin amplitude
  - The contributions from EW-penguin amplitudes $O(10\%)$
- CP-violation for $B_d \to \phi K_S$

$A_{CP}(B_d \to \phi K_S) = A_{CP}(B_d \to J/\psi K_S)$

The accuracy: $O(5\%) \to 30\%$

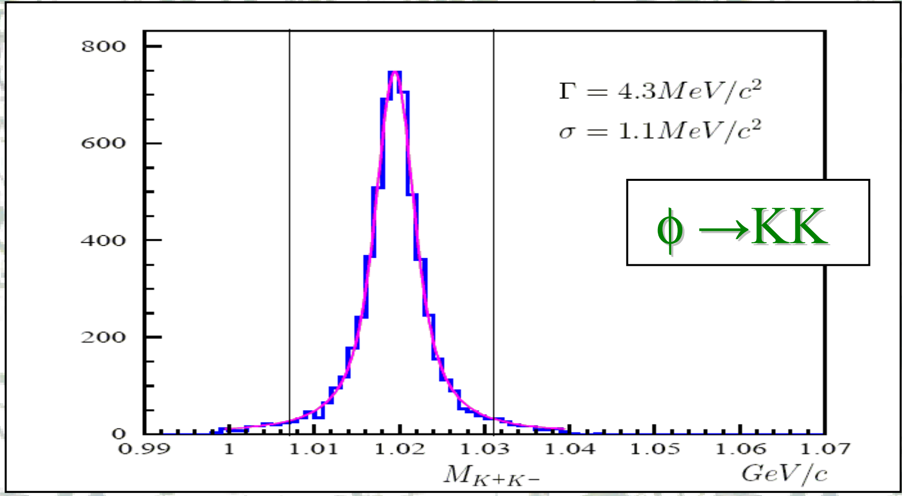
- Last summer Belle reports the value $A_{CP}(B_d \to \phi K_S)$ inconsistent with $A_{CP}(B_d \to J/\psi K_S) = -\sin(2\beta)$
  - Hints for New Physics in $b \to sg$ transitions ?

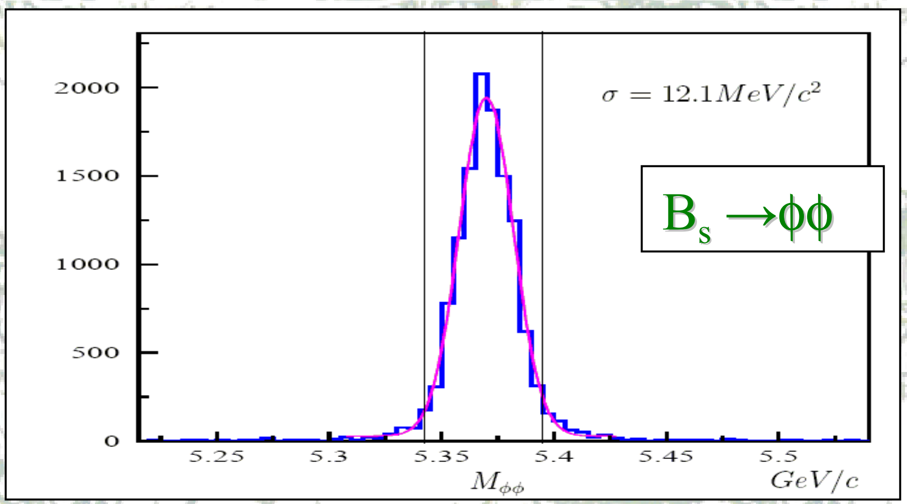
or

  - The probe for FSI ?

Selection of $B_d \to \phi K_S$ and $B_s \to \phi\phi$

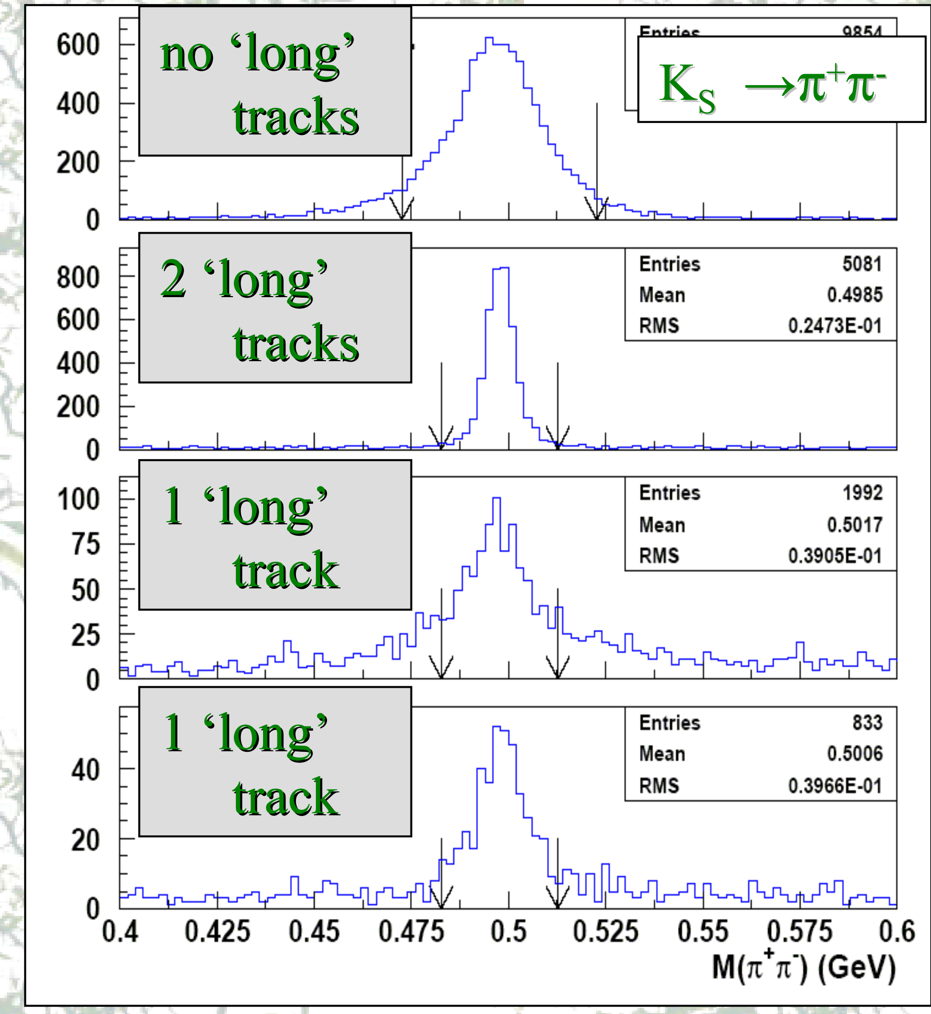
- **$K^{\pm}$:**
  - charged tracks consistent with PID
  - Inconsistent with any PV
    - $\chi^2_{IP} > 4$
- Two prong vertex
  - $\chi^2_{VX} < 10(100)$
- **ϕ :**
  - $|\Delta M| < 17(12)$ MeV/c²
- **$B_s \to \phi\phi$**
  - $\chi^2_{VX} < 100$
  - $\theta_B < 10$ mrad
  - Decay angle: $|\cos\theta| < 0.75$
  - $|\Delta M| < 24$ MeV/c²





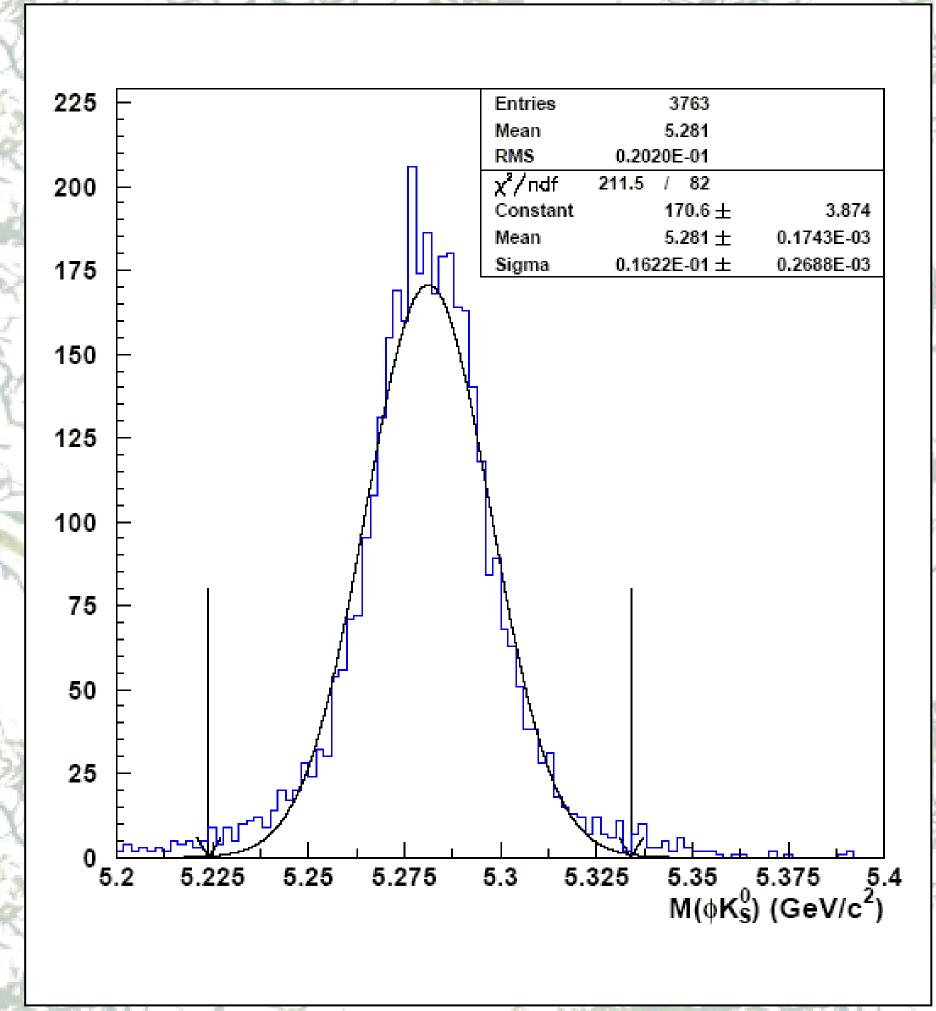
Selection of K_S for $B_d \to \phi K_S$

- **K_S :**
  - Secondary vertex from $\pi^+\pi^-$ pair consistent with PID
    - $\chi^2_{VX} < 20$
  - Different track categories:
    - With and without track fragments measured in precise silicon vertex detector
  - $|\Delta M| < 15(25)$ MeV/c^2



Selection of $B_d \to \phi K_S$

- **B :**
  - Impact parameter to the primary vertex
    - IP < (250,200,100)μm
  - $p_T(K_S)$ > 1100(500) MeV/c²
  - $p_T(\phi)$ > 1350 MeV/c²
  - θ_B < 10 mrad
  - |ΔM| < 55 MeV/c²
    - $\sigma(M_B)$ = 16 MeV/c²



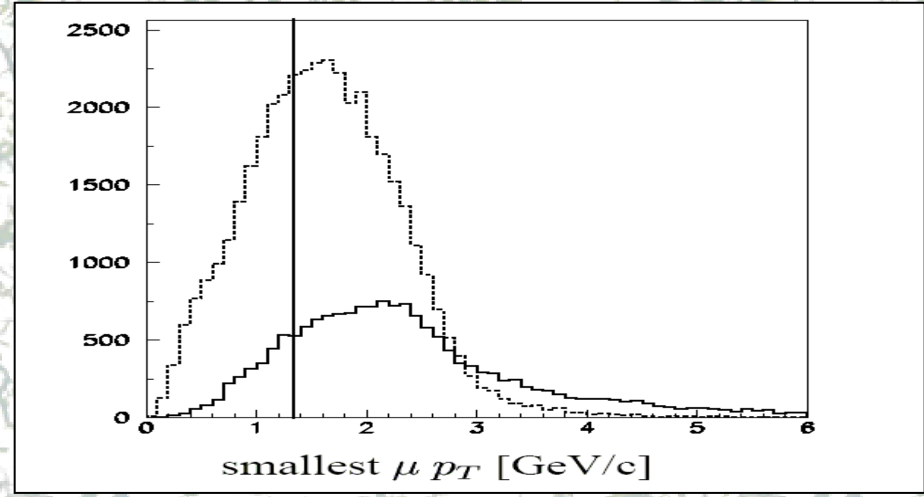
Efficiencies, Event Yields and B/S

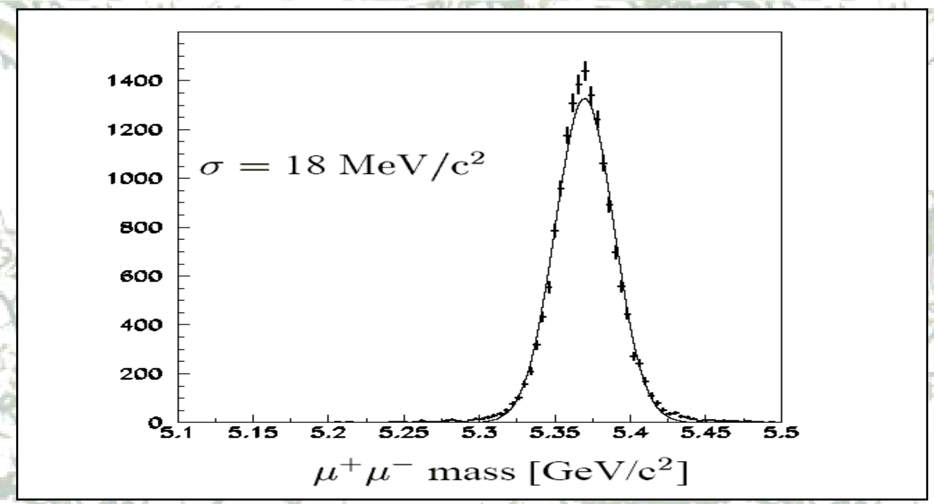
- Enlarged mass window
- $B_s \to \phi\phi$
  - 4-7 GeV/c^2
- $B_d \to \phi K_S$
  - 4-6.6 GeV/c^2
- No background events from 10^7 forward $b\bar{b}$ events
- 1 event from 10^6 $b \to \phi X$ sample (for $B_d \to \phi K_S$)
  - effectively x3.5 statistics as forward $b\bar{b}$

	$B_d \to \phi K_S$	$B_s \to \phi\phi$
e_{TRIG}[%]	19	23
ε_{TOT}[%]	0.074	0.45
N/year	800	1200
B/S	<1.1 ($b\bar{b}$) <0.3 ($b \to \phi X$)	<0.2

Real rear decay: $B_s \to \mu^+\mu^-$

- SM: Br ~ 3×10^{-9}
- Many New Physics models predict enhancement
  - 10^1-10^3
- $\mu^\pm$
  - Compatible with μ PID
  - $p_T > 1.3$ GeV/c
- μμ
  - $\chi^2_{VX} < 4$
  - $\Delta Z/\sigma Z > 29$
  - $p_T > 3$ GeV/c
  - $|\Delta M| < 600$ MeV/c^2



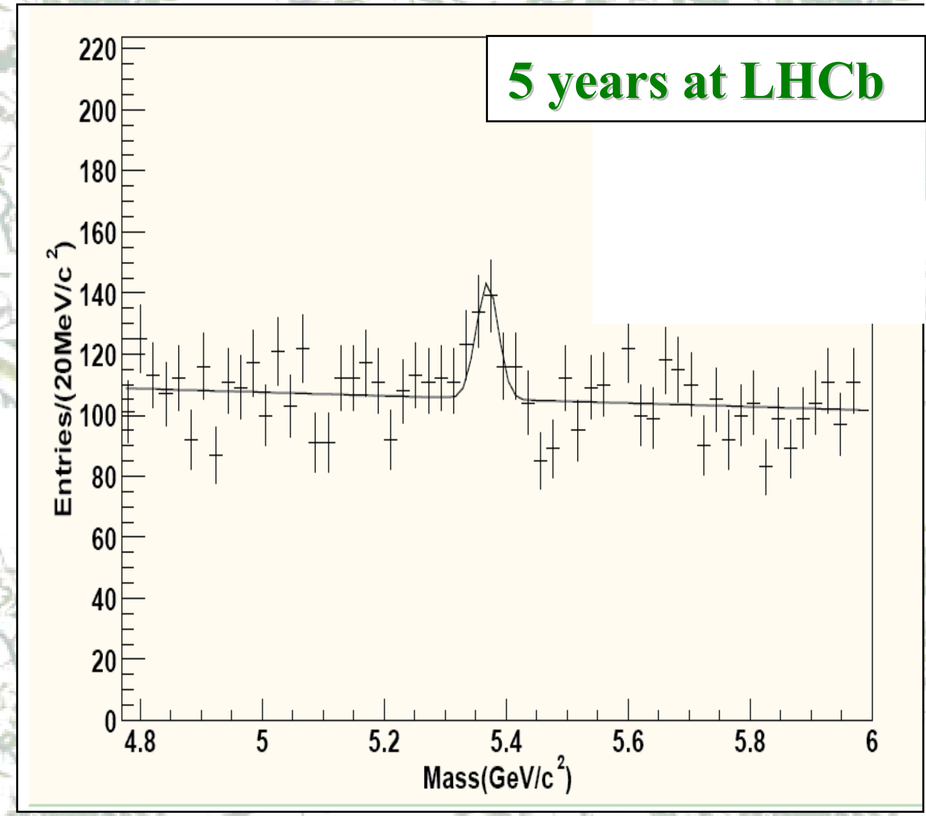


Efficiencies, Event Yield and B/S

- $\varepsilon_{TOT} = 2.5\%$, $\varepsilon_{TRIG} = 80\%$
- N/year = 17 events

No background events neither from 10^7 forward $b\bar{b}$ sample no from 10^7 $b \to \mu X, \bar{b} \to \mu X$ sample

	B/S at 90%
Forward $b\bar{b}$	<440
$b \to \mu X, \bar{b} \to \mu X$	<6



Summary

- LHCb has a good physics potential for study of rare decays

	N/year	B/S @90%CL
$B_d \to K^{*0}\gamma$	35k	<0.7
$B_s \to \phi\gamma$	9.3k	<2.4
$B_d \to K^{*0}\mu^+\mu^-$	4.4k	[0.2, 2.0]
$B_s \to \phi K_S$	800	<1.1 ($b\bar{b}$) <0.3 ($b\to\phi X$)
$B_s \to \phi\phi$	1.2k	<0.2
$B_s \to \mu\mu$	17	<440 ($b\bar{b}$) <6 ($b\to\mu X$)