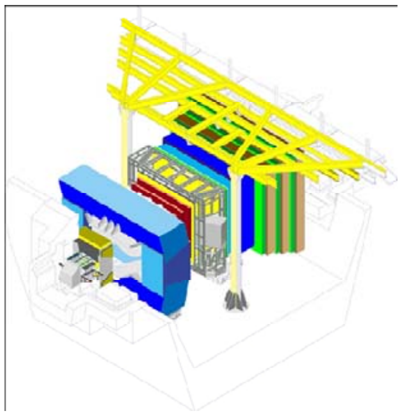
LHCb Physics Program

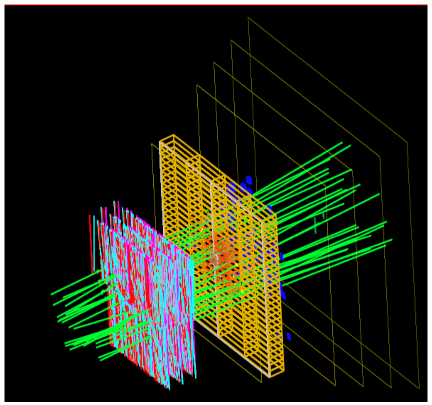
On behalf of LHCb collaboration
M.N Minard (LAPP)



Status LHCb (R.Jacobson)

Single arm spectrometer

B- physics dedicated

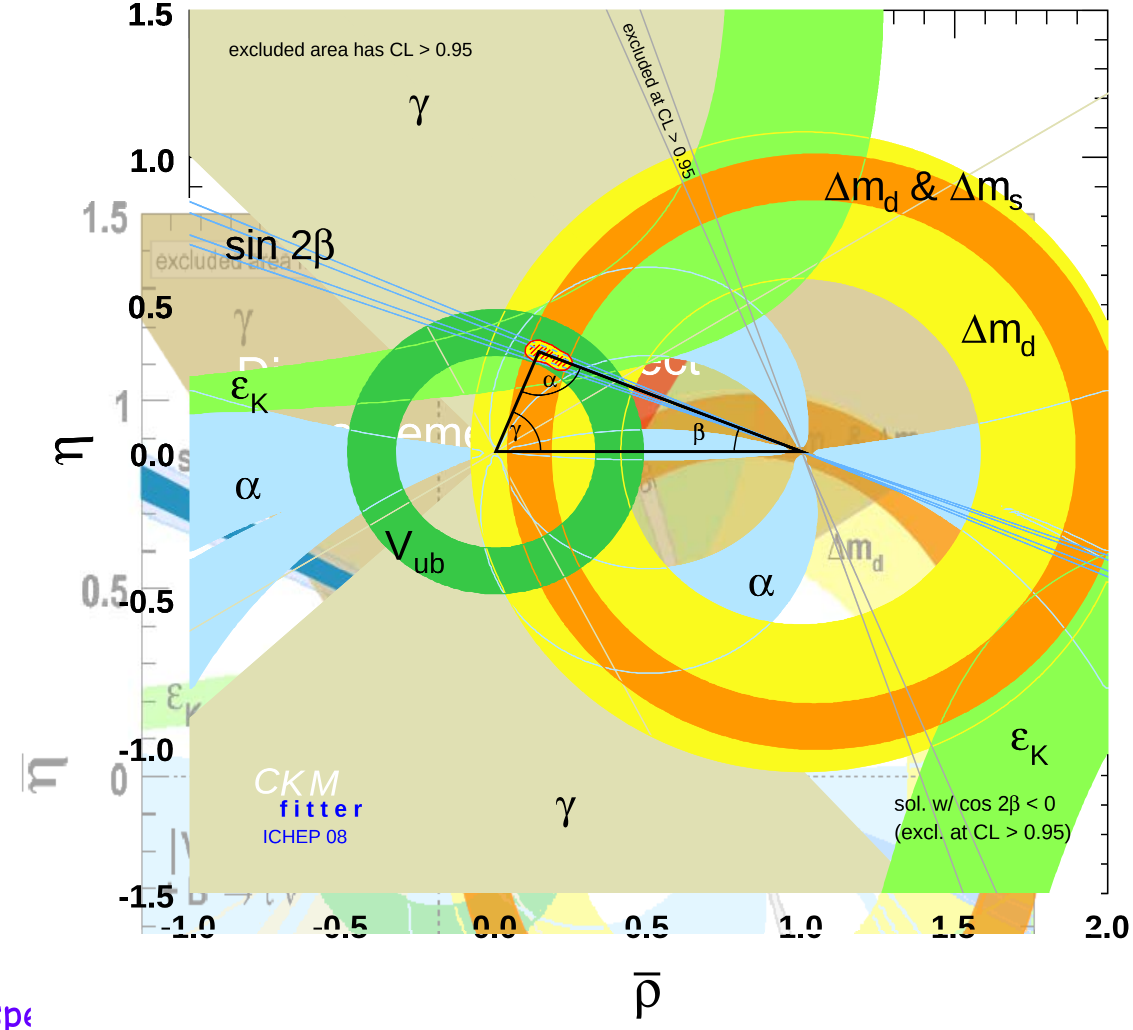


Improve precision on CKM parameters

- Impressive results from B factories & K sector
- Good agreement with SM

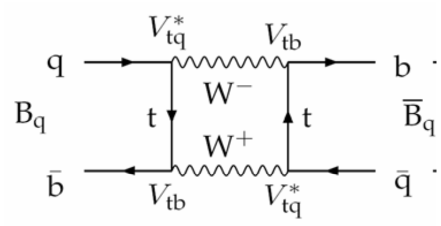
- b->s transitions emerging
  - Tevatron results
  - Belle
- LHCb domain

- Strong constraints from SM on KM sector
- Direct γ measurement :LHCb

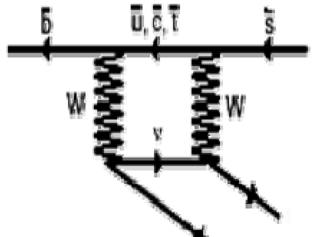


LHCb hints for NP

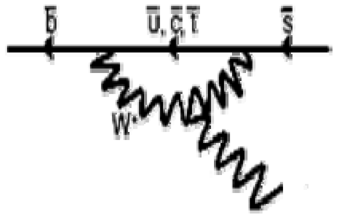
- Hints for NP contribution in loop processes as tree and box / penguin diagrams.



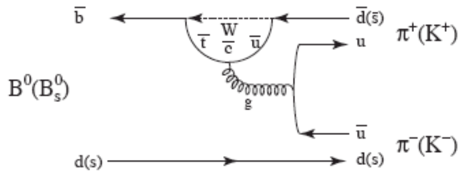
Oscillation box



EW penguin



Radiative penguin



Strong penguin

- **NP from CPV domain precision measurements :**

  Observe deviations from SM expectations

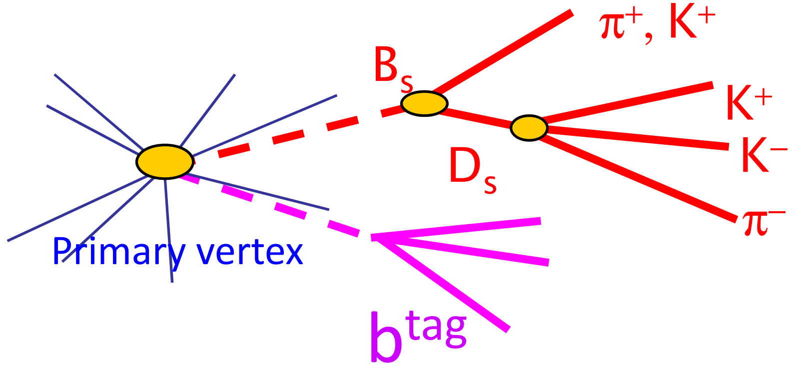
  Confront measurements between channels expecting different NP interference

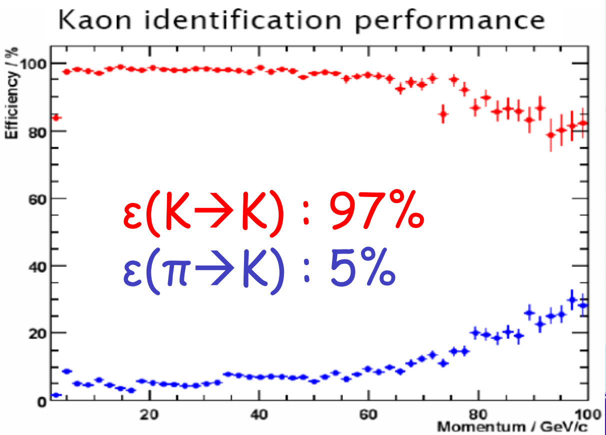
  – Φ_s , mixing phase of the Bs system
  – γ measurements

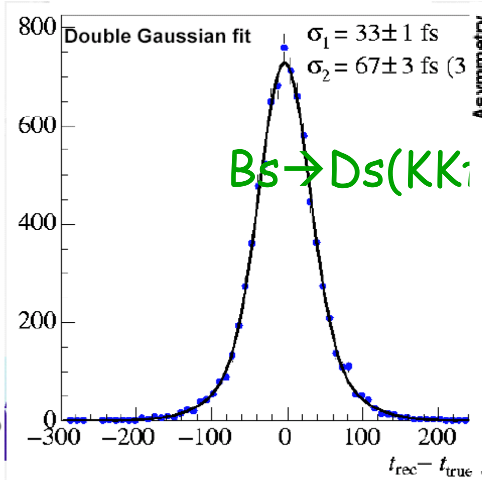
- **NP from rare decays high precision measurements :**
  - Branching ratio
  - Time asymmetry measurements

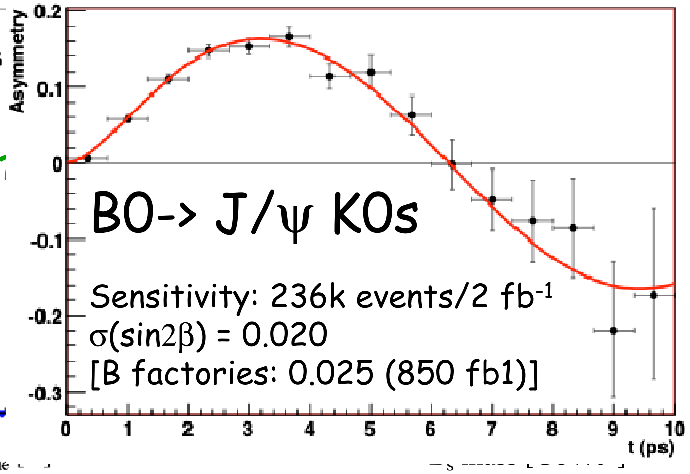
LHCb apparatus caracteristics

- High statistics on all b and c species :
  - 2fb^{-1}: 10^{12} $b\bar{b}$ pairs
  - Heavy flavor precision experiment
    - Lepton and hadron trigger
    - Efficient particle ID
    - Decay time resolution
    - Flavour tagging





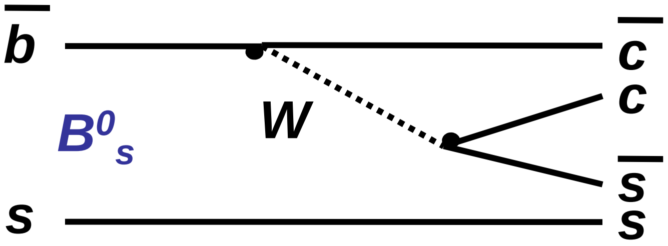


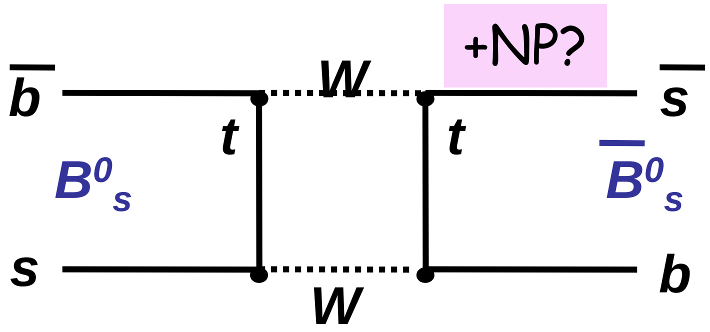


proper time resolution ~ 40 fs

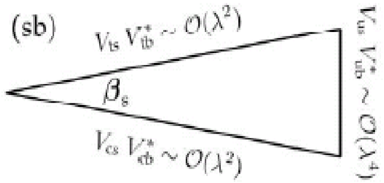
B_s mixing phase ϕ_s

B_s phase Φ_s





Lifetime B^0_s, B^0_s distributions give oscillation pattern of frequency Δms and amplitude ~ $\sin\phi_s$ trough the phase in the mixing box diagram. $\phi_s = -2\beta_s$



$$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

$\surd_s$ can be extracted from CP time-dependent asymmetry decay rates :

$$A_{CP} = \frac{n_f \sin(\Phi_s)\sin(\Delta m_s t)}{\cos(\Delta\Gamma_s t/2) - n_f \cos(\Phi_s)\sinh(\Delta\Gamma_s t/2)}$$

with $n_f = \pm 1$ CP eigenstate

Bs → J/Ψ η, Bs → J/Ψ η', Bs → ηc Φ Bd → Ds+ Ds- CP eigenstate

Bs -> J/Ψ φ , mixing +-1 CP eigenstate

NP may modify the mixing phase $\quad \Phi(B^0_s \to J/\psi\phi) = -2\beta_s + \Phi_M^{NP}$

B_s phase Φ_s (2)

Current results from Tevatron:

D0 $\beta_s = -0.57^{+0.24}_{-0.30}$ with 2.8 fb^{-1}
CDF $-\beta_s = [0.28, 1.28]$ @ 68%CL with 2.8 fb^{-1}

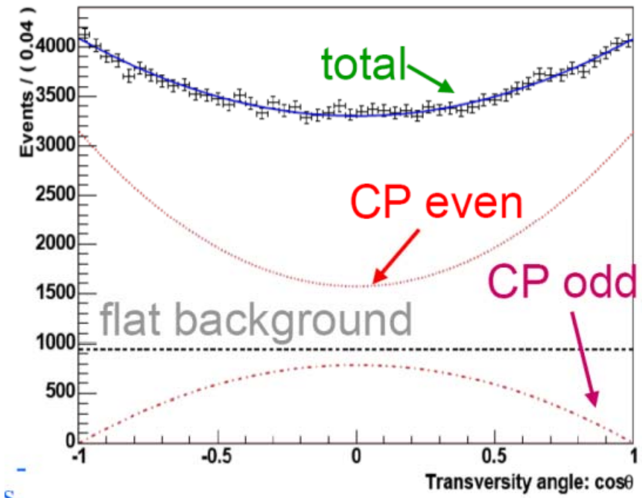
Use of pure CP eigenstates statistic limited →

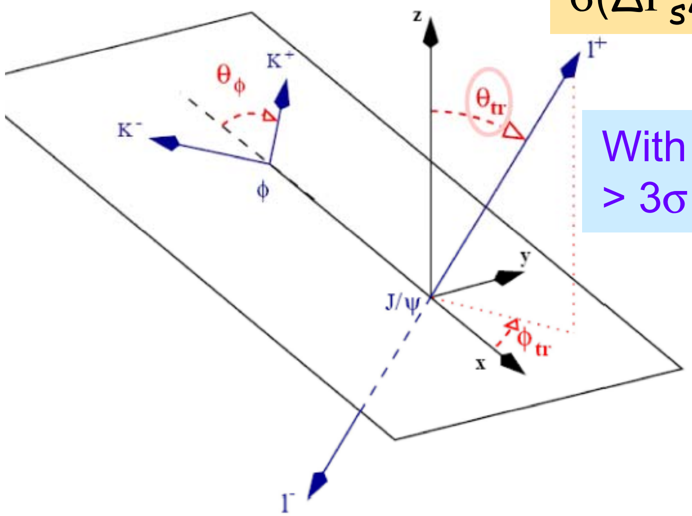
Decay	Yield (2 fb^{-1})	$\sigma(\phi_s)$
$J/\psi\ \eta_{\gamma\gamma}$	8.5 k	0.109
$J/\psi\eta_{\pi\pi\pi}$	3 k	0.142
$J/\psi\ \eta'_{\pi\pi\eta}$	2.2 k	0.154
$J/\psi\ \eta'_{\rho\gamma}$	4.2 k	0.08
$\eta_c\ \phi$	3 k	0.108
$D_s^+ D_s^-$	4k	0.133
All CP eig	-	0.046
$J/\psi\ \phi$	130 k	0.023

$\sigma(\Delta\Gamma_s/\Gamma_s) = 0.0092$

B_s -> J/Ψ φ large yield, low background
mixture of CP = +1 and CP = -1 states
angular analysis to disentangle the two states

SM $\Phi_S(B_s \to J/\Psi\ \phi) = -2\beta_s = -0.0368 \pm 0.0017$





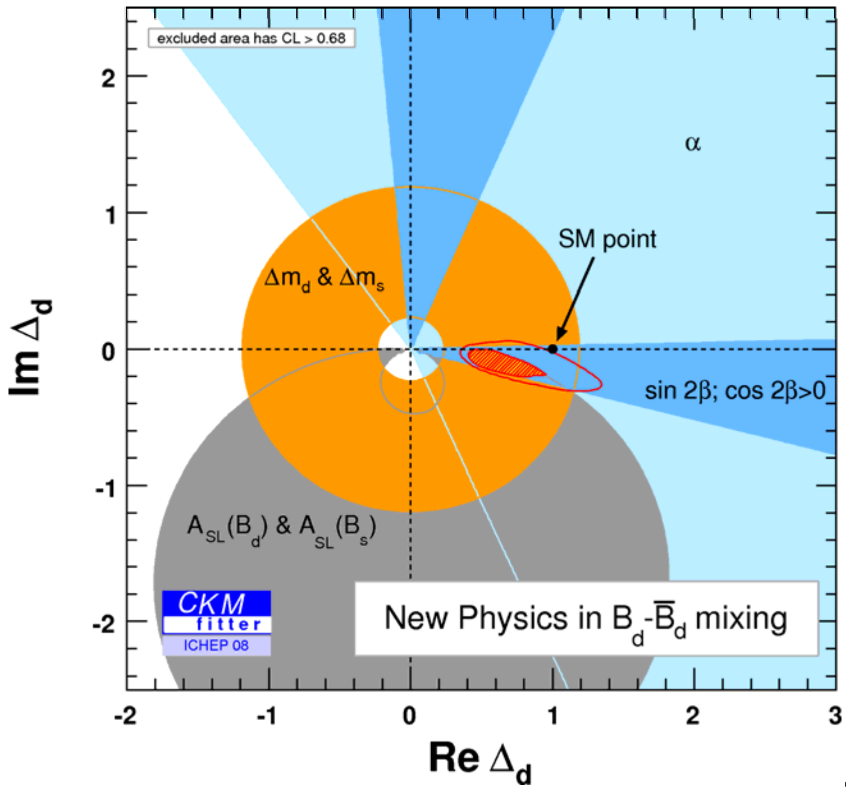
With 10 fb-1 $\sigma_{stat}(\Phi_s)$~ 0.009
> 3σ for non-zero Φ_s of SM

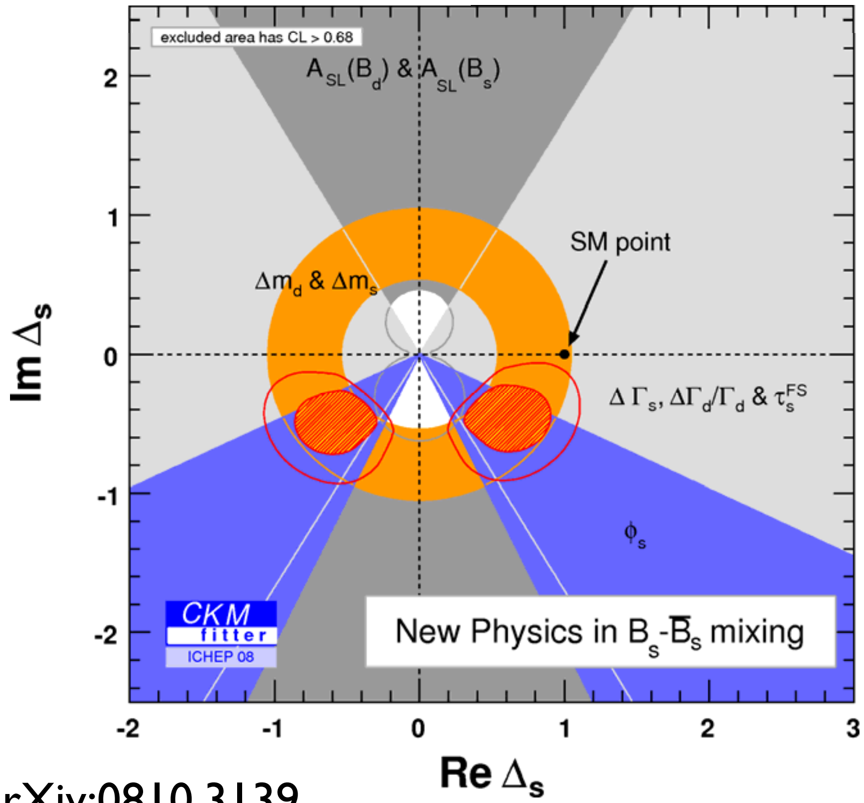
Room for NP in B_s mixing

- The effects of New Physics in the oscillation can be parameterized as:

$$\left\langle B_q^0 \middle| M_{12}^{SM+NP} \middle| \overline{B}_q^0 \right\rangle \equiv \Delta_q^{NP} . \left\langle B_q^0 \middle| M_{12}^{SM} \middle| \overline{B}_q^0 \right\rangle$$

$$\Delta_q^{NP} = \mathrm{Re}(\Delta_q) + i\ \mathrm{Im}(\Delta_q) = |\Delta_q| e^{i\phi^{\Delta_q}} = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$$





arXiv:0810.3139

$b \to \bar{s}ss$ hadronic penguin decays

$B_s \to \phi\phi$

In SM CP violation < 1% due to cancellation of the mixing and penguin phase:

$\phi_{Bs \to \phi\phi}^{SM} \approx 2\arg(V_{ts}^{*}V_{tb}) - \arg(V_{ts}V_{tb}^{*}) = 0$

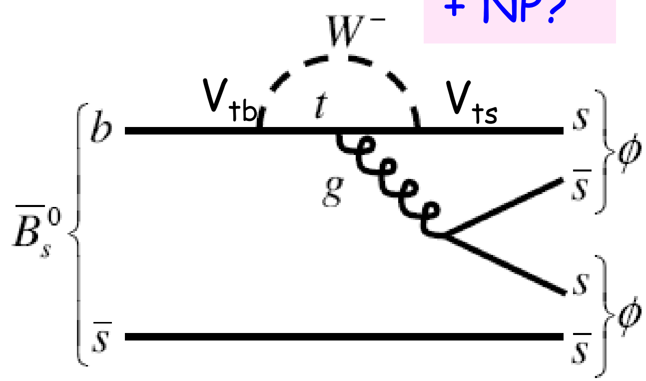
In presence of NP expect different contributions in boxes and in penguins:

$\phi_{Bs \to \phi\phi}^{NP} = \phi_{Mixing}^{NP} - \phi_{Decay}^{NP}$

Mixing box

\+ NP?

\+ NP?



Mixing CP asymmetry angular analysis & time dependance of flavour tagged events

For 2 fb^{-1} $\sigma_{stat}(\phi^{SM}) = 0.11$

B_d related quark penguin

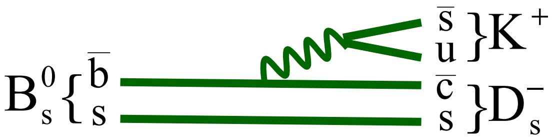
$B_d \to \phi K_S$ & $B_d \to J/\psi K_S$

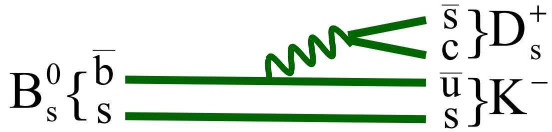
expected precision: $\sigma(\sin(2\beta_{eff})) \approx 0.23$

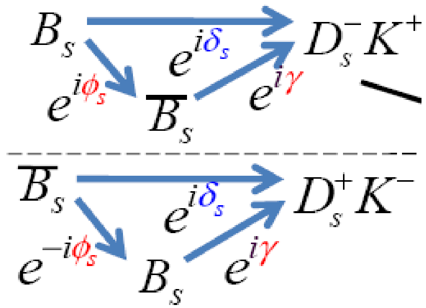
Channel	Yield (2 fb^{-1})	B/S (90%CL)
$B_s \to \phi\,\phi$	3100	< 0.8
$B_d \to \phi\,K_S$	920	< 1.1

γ related measurements

$\Phi_s + \gamma$ from $B_s \rightarrow D_sK$

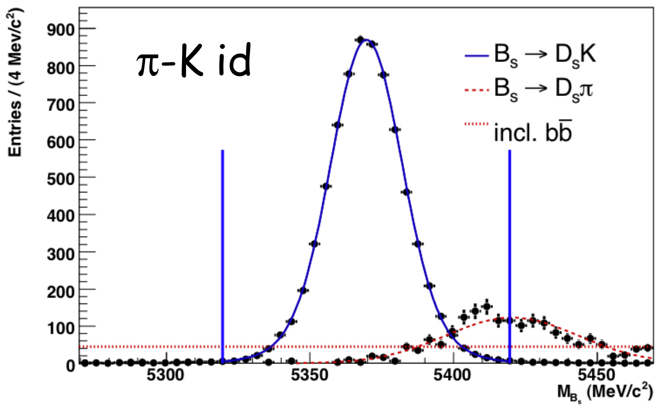






2 Trees : b->c & b->u interfere through B_s mixing

Measure Φ_s+γ . Ratio extracted from data



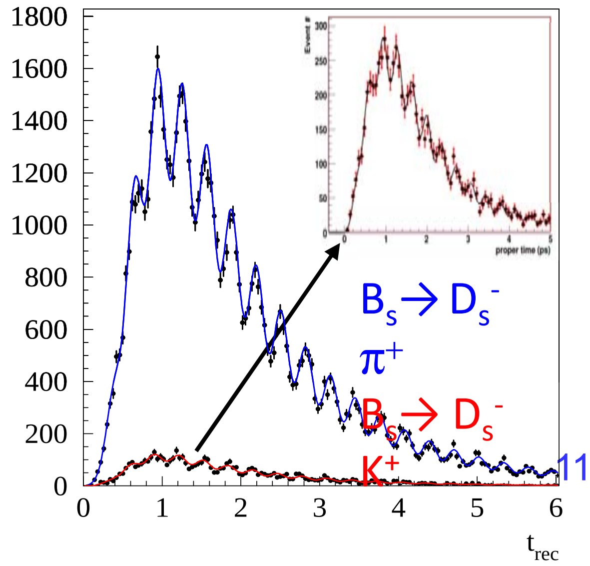
Channel	Yield (2 fb^{-1})	B/S (90%CL)
$B_s \rightarrow D_sK$	6200	< 0.2
$B_s \rightarrow D_s \pi$	140 k	0.4

Include $B_s \rightarrow D_s\pi$ to constrain Δm_s

Fit time-dependent rates of $B_s \rightarrow D_sK$ and $B_s \rightarrow D_s\pi$

Sensitivity with 2fb^{-1}:

$\Phi_s + \gamma$	9°-12°
Δm_s	0.007 ps^{-1}



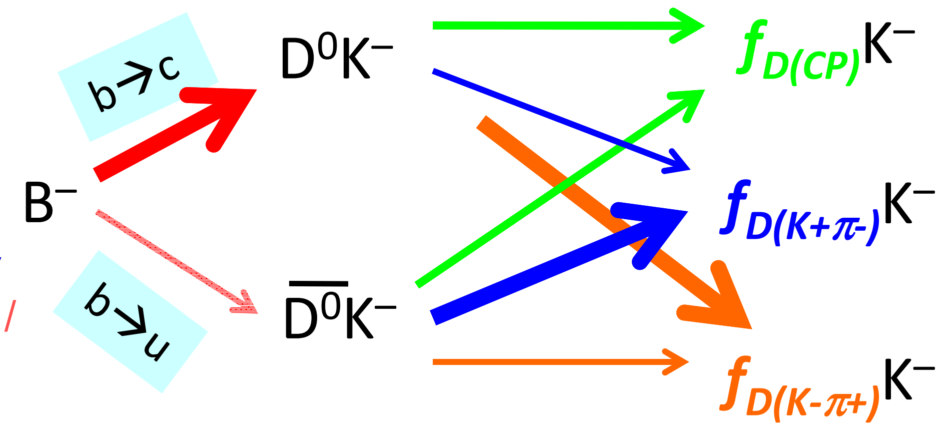
γ from trees: B→DK

- Two tree amplitudes (b→c & b→u) interfere in decays to a common D^0 and $\overline{D}^0$ state f_D

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

For each mode parameters $\gamma,(r_b,\delta_b)$

- Exploit interference according the decay mode (analysis from B-factories).
  - GLW : CP eigenstate of D $^{(*)0}$
    D0-> $K^+K^-/\pi+\pi-$, $K_s\pi0$
  - ADS : Use common flavor state
    - doubly cabbibo supressed D^0-> K+π-
    Lower event rate / large asymmetry
    - Favoured mode: Large event rate / tiny asymmetry
  - Dalitz for 3 body decays



γ from loops: $B^0_{d/s} \to h^+h^-$

- Interference of b→u tree & b→d(s) penguin diagrams leads to CP violation depending on γ (Sensitive to NP)

$$A_f^{CP}(t) = \frac{A_f^{dir}\cos\Delta mt + A_f^{mix}\sin\Delta mt}{\cosh\left(\frac{\Delta\Gamma t}{2}\right) - A_f^{\Delta}\sinh\left(\frac{\Delta\Gamma t}{2}\right)}$$

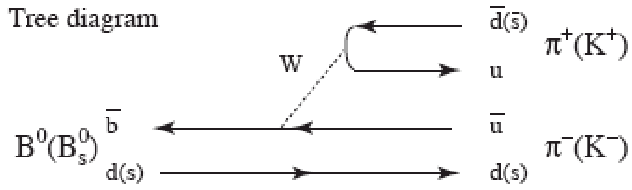
- A^{dir} & A^{mix} depend on mixing phase 2β, γ, and ratio of penguin to tree amplitudes = $d\,e^{i\theta}$

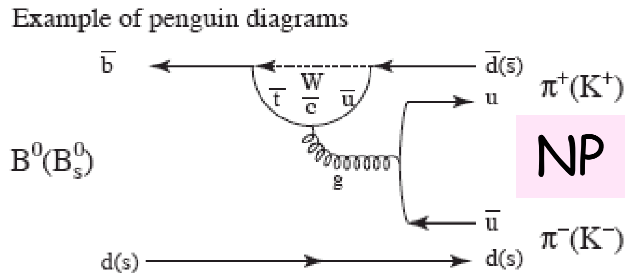
- $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ (d->s) diagrams
- U-spin symmetry.
  4observables: $(A^{dir}$ & $A^{mix})_{\pi\pi,}$ $(A^{dir}$ & $A^{mix})_{kk}$
  - Parameters : γ, penguin to tree amplitudes $(d\,e^{i\theta})_{\pi\pi,\,,\,kk}$

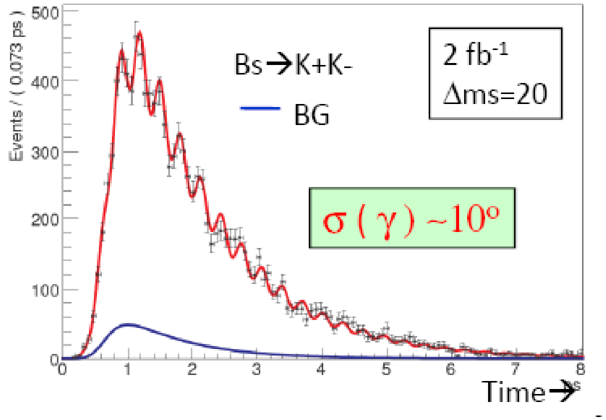
decay	Yield (2fb^{-1})	B/S
$B^0 \to \pi^+\pi^-$	36k	0.5
$B_s^0 \to K^+K^-$	36k	1.5

σ(γ) In 2fb^{-1}
10°

Compare to γ from trees to get hints of NP in penguins







γ from trees: B→DK

tree

B mode	D mode	Method	Yield (2fb-1)	sensitivity	Parameter
$B_s \to D_s K$	$KK\pi$	tagged, $A^{CP}(t)$	6.2K		$\gamma+2\beta_s$
$B^+ \to D\ K^+$ favo	$K\pi$	ADS	56K	8.2 9.6 ° Strong phases	γ
$B^+ \to D\ K^+$ suppr	$K\pi$	ADS	*		γ
$B^+ \to D\ K^+$	$KK/\pi\pi$	counting, GLW	8.6k		γ
$B^\pm \to D^0\ K^\pm$	$K3\pi$	ADS	61K		γ
$B^\pm \to D^{0*} K^\pm$	$D^0\pi^0/D^0\gamma$	GLW +ADS	42K		γ
$B^\pm \to D^0\ K^\pm$	$K^+K^-\pi^+\pi$	GLW Dalitz	1.7	18°	γ
$B^0 \to D^0 K^{*0}$	$K\pi, KK, \pi\pi$	ADS+GLW	5K	6-25	γ
$B \to \pi\pi, KK$	–	tagged, $A^{CP}(t)$	36K	10	$\gamma / \beta_d / \beta_s$

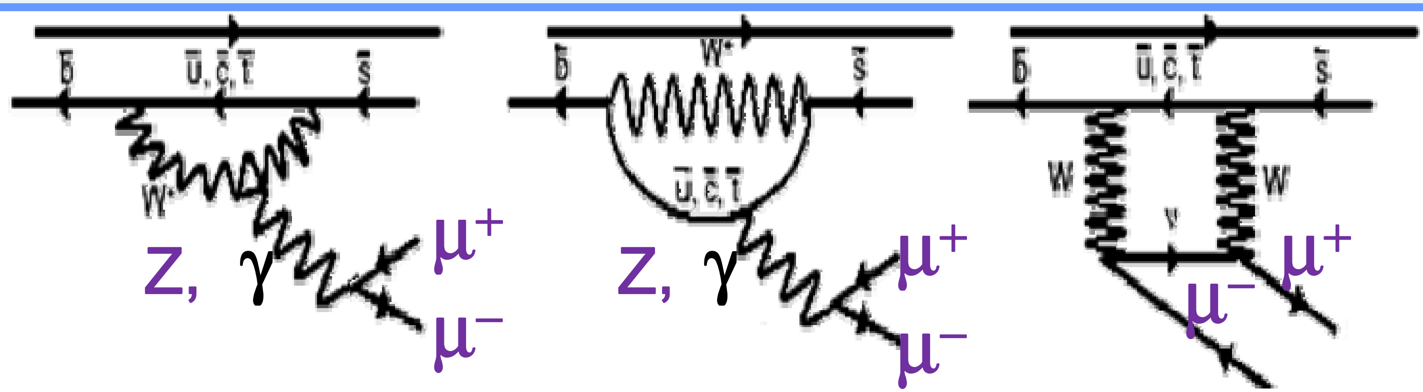
HLT trigger
K-π PID
Mass resolution

Global fit from ADS/GLW under δ_B°assumption =35°
R_b

Combine tree – $2fb^{-1}$
$\sigma(\gamma)$: 4°

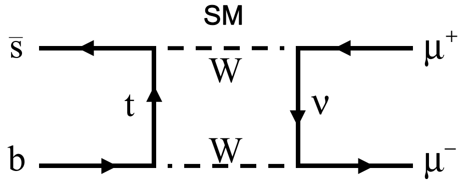
Rare decays

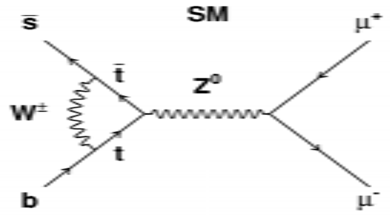
Rare decays seeking for NP

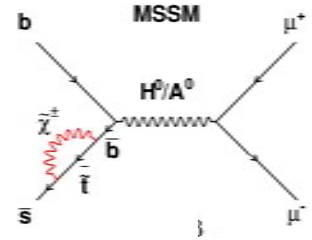


	NP? in	*BR*(SM)	*BR* exp	@ LHCb
$B_s \to \phi\gamma$	$\delta C7$	Large Theory Error On br	$(57^{+18}_{-12}{}^{+12}_{-11})\ 10^{-6}$ Belle'08	γ polarization
$B^0 \to K^* \mu^+ \mu^-$	$\delta C7$, $\delta C9$	«	$(1.22^{+0.38}_{-0.32}) \cdot 10^{-6}$ B factories	angular distributions
$B_s \to \mu^+ \mu^-$	S-P coupling	$(3.35 \pm 0.32) \cdot 10^{-9}$ helicity suppressed	TeVatron @ 90% CL (2 fb^{-1}) **$< 45 \times 10^{-9}$**	**BR**

$B_s \to \mu\mu$







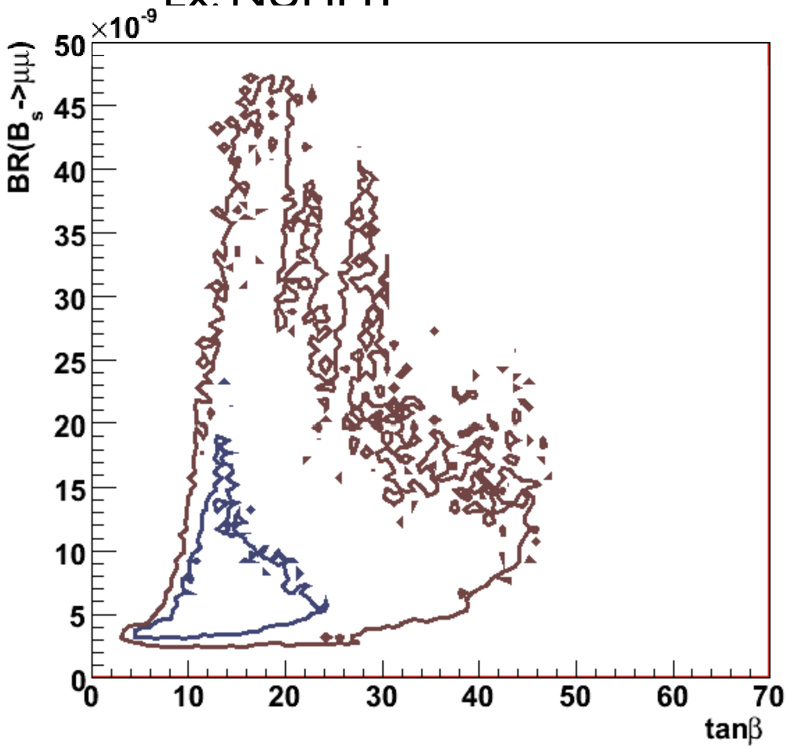
- Helicity suppressed – NP sensitivity
  in SM: $BR(B_s \to \mu\mu)$ (3.35 ± 0.32) x 10-9

- Enhancement from SUSY model :
  $BR(B_s \to \mu\mu) \propto \tan^6\beta / M_H^2$

  Sensitive to new physics coupling with Scalar & pseudo scalar

Ex :
Possible enhancement
$BR(Bs \to \mu^+\mu^-) \sim 20 \times 10^{-9}$

Ex: NUHM I



J.Ellis et al. arXiv:0709.0098v1 [hep-ph] (2007)

$B_s \to \mu\mu$

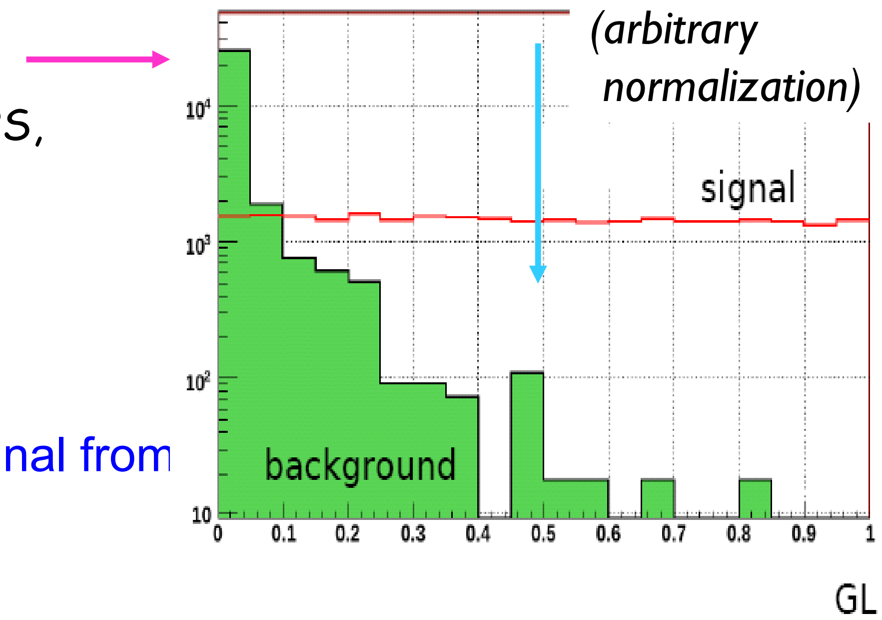
Analysis relies on :

Geometry Likelihood (GL) :

geometrical properties (muon IPS, B lifetime, isolation, IP)

Good mass resolution

Particle ID : DLL $(\mu-\pi)$ & DLL$(\mu$-K)



- Sensitive Region: GL > 0.5
- Statistical method applied to separate signal from background

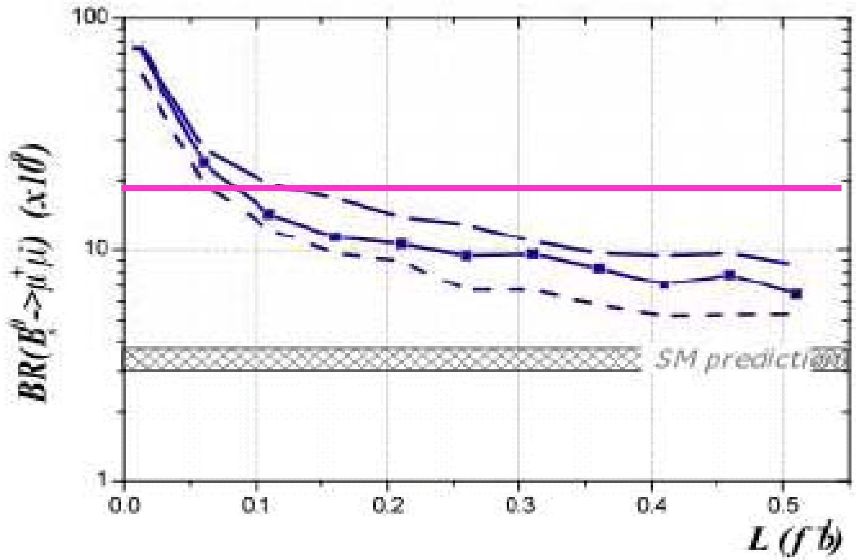
SM BR, in 2fb^{-1} ~21 signal events

~172 background events

Major uncertainty on BR from relative B_s,B^+ hadronization fractions ~14%.

Bs branching ratio determination useful

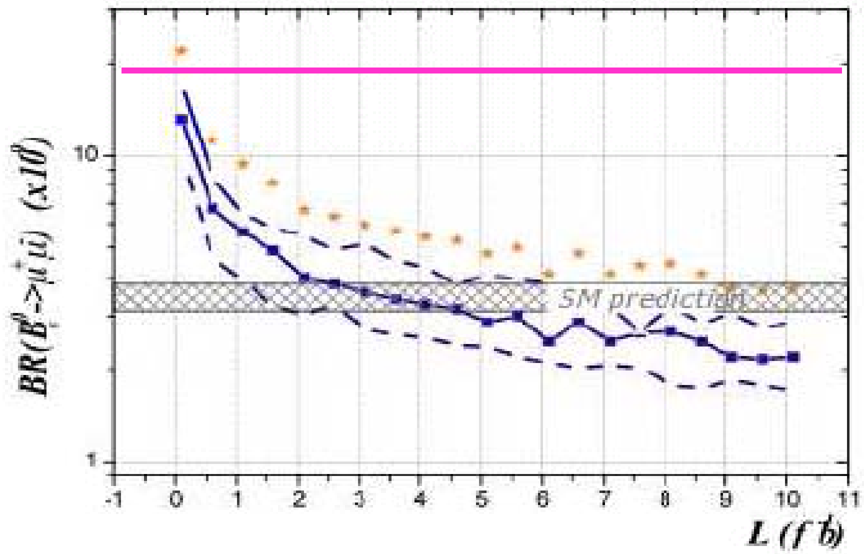
$B_s \rightarrow \mu\mu$



Expected CDF+D0 limit 8fb-1

90% exclusion

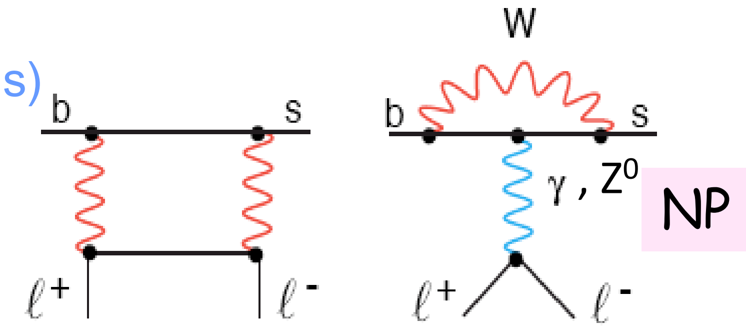
Main uncertainty
hadronization fraction



Within SM BR:
2 $fb^{-1} \Rightarrow$ 3σ evidence
10 $fb^{-1} \Rightarrow$ 5σ observation

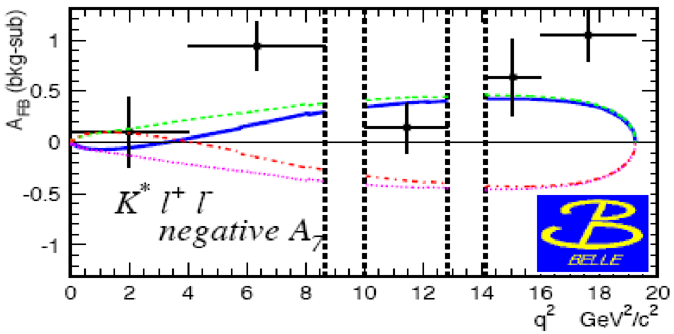
$B^0 \rightarrow K^{0*}\mu^+\mu^-$

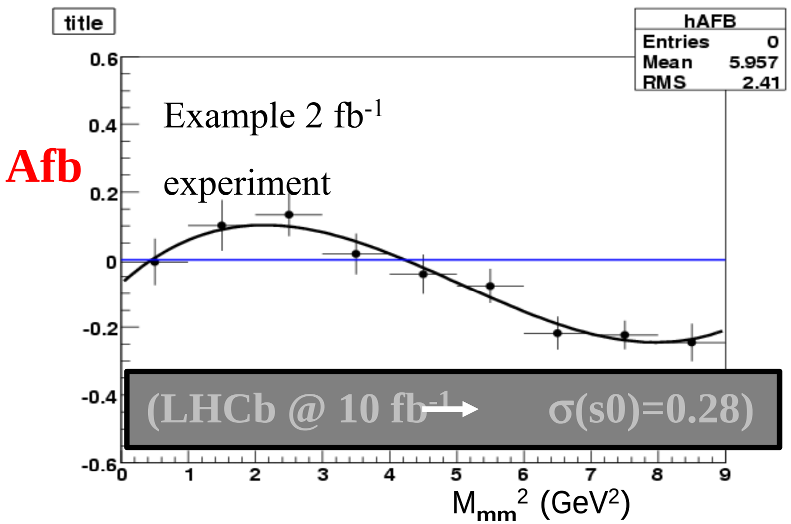
- Suppressed Loop FCNC process (EW penguins)
- Several observables to test the dynamics
  - Afb (s=mll2)
  - Angular distributions: θ_l, ϕ, θ_{K^*}
  - Invariant mass $\mu^+\mu^-$ $s = (m_{\mu\mu})^2 = q^2$
- NP can affect:
  - Forward-backward asymmetry $A_{FB}(s)$ in θ_l distribution
  - Dependence on s (predicted by several models)



Zero of $A_{FB}(s)$

SM $s_0 = 4.36^{+0.33}_{-0.31}$ GeV^2/c^4

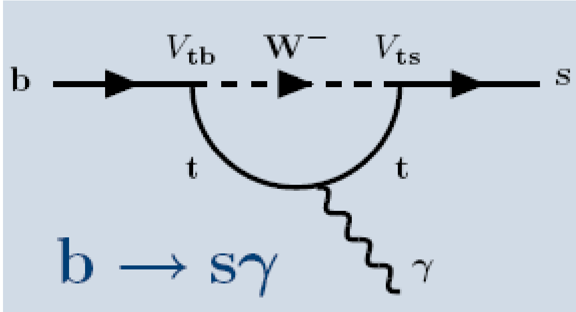




γ polarization in $B_s \rightarrow \phi\gamma$

- $B_s \rightarrow \phi\gamma$ FCNC radiative penguin
- Time dependent CP asymmetry

probe SM/NP



$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

– $A^{dir} \approx 0$, $A^{mix} \approx \sin 2\psi \sin 2\phi$,

$A^{\Delta} \approx \cos 2\psi \cos\phi$

$\tan\psi = |b \rightarrow s\,\gamma_R| / |b \rightarrow s\,\gamma_L| \sim 0$ $\cos\phi \approx 1$

- In SM : C =0 , S= $\sin 2\psi \sin\phi$, $A\delta = \sin 2\psi \cos\phi$

- Sensitivity ; σ(C) , σ(S) = 0.11 *2fb-1*
- SM extensions (left-right-symmetric, unconstrained MSSM) predict large $\tan\psi$ while no change on inclusive *BR* ($b \rightarrow s\gamma$)

Conclusions

- LHCb is looking forward for the 1st collisions

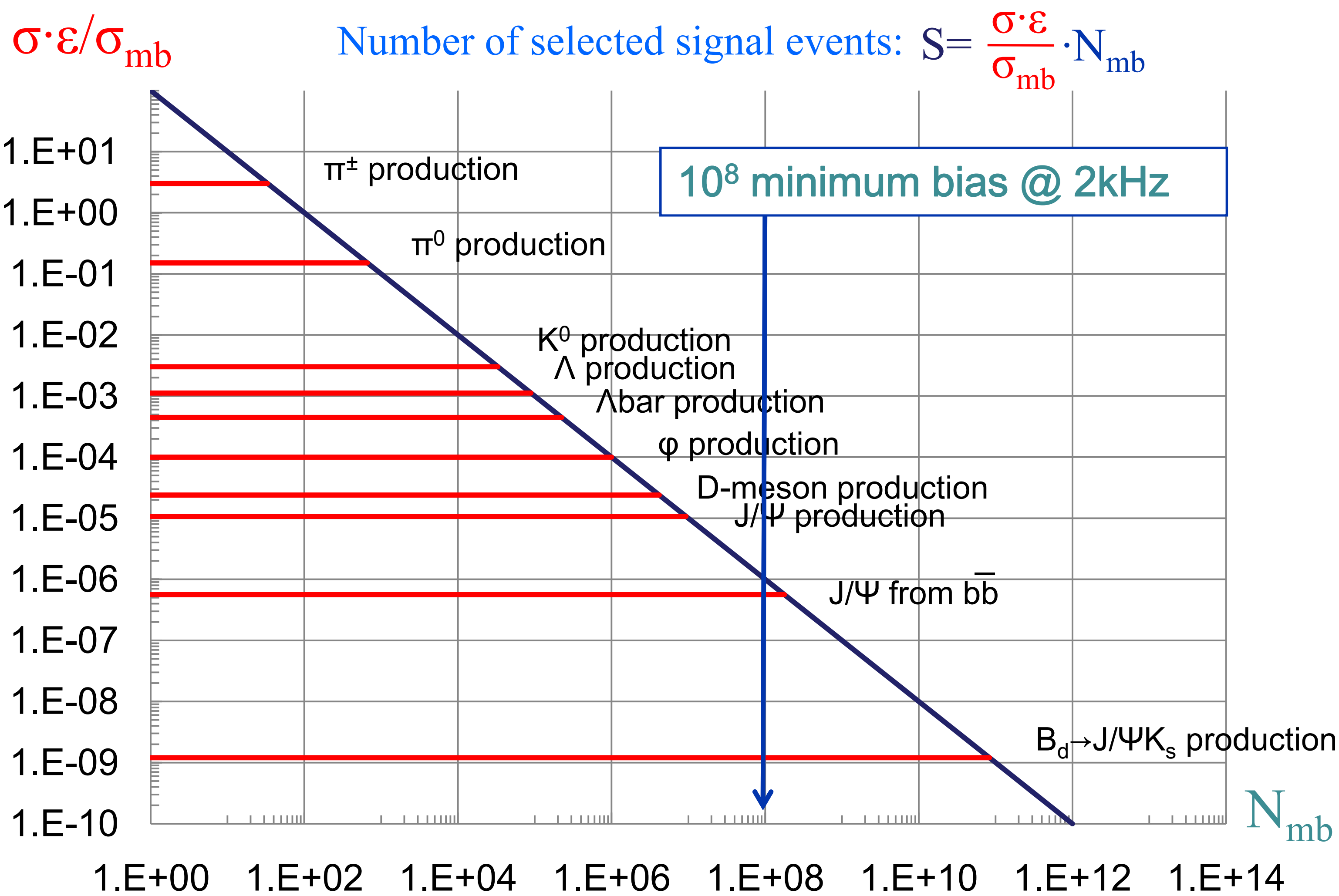
- Interesting results can comme early (0.5 fb^{-1})
  - $Bs \rightarrow J/\varphi\ \phi$ Φs measurement with 0.05 precision
  - Bs -> $\mu\mu$ BR limit close SM value
  - Direct γ measurement $\sigma(\gamma)$ 10°

- LHCb able to provide strong improvement in B_s sector
- Potential and channels variety allows field for indirect NP discovery

Backup

Physics from (very) first data

Exploit minimum bias data (almost no trigger)



Sensitivities for 100 fb^{-1}

Observable	Sensitivity
$S(B_s \to \phi\phi)$	$0.01 - 0.02$
$S(B_d \to \phi K^0_S)$	$0.025 - 0.035$
$\phi_s\ (J/\psi\phi)$	0.003
$\sin(2\beta)\ (J/\psi K^0_S)$	$0.003 - 0.010$
$\gamma\ (B \to D^{(*)}K^{(*)})$	$< 1^\circ$
$\gamma\ (B_s \to D_s K)$	$1 - 2^\circ$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$5 - 10\%$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	$0.05 - 0.06$
$A_{\rm FB}(B \to K^{*0}\mu^+\mu^-)\ s_0$	$0.07\ \mathrm{GeV}^2$
$S(B_s \to \phi\gamma)$	$0.016 - 0.025$
$A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	$0.030 - 0.050$
charm x'^2	2×10^{-5}
mixing y'	2.8×10^{-4}
CP y_{CP}	1.5×10^{-4}

Also studying Lepton Flavour Violation in $\tau \to \mu\mu\mu$

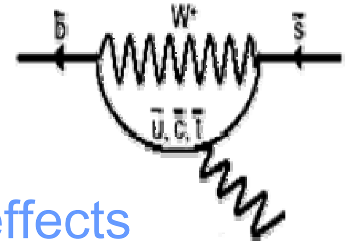
Upgrade

- Increase L0 hadron bandwidth
- Manage a factor 110 in luminosity
  - Go from 1Mhz to 40 Mhz data flow

- Implications :
  - Electronics and detector upgrade is being investigated
  - Change Vertex Locator to pixels 3D device

Rare decays

- In the SM, $b \to s$ only through loops (FCNC) implies:
  - Processes are rare
  - Powerful to find/constraint NP!

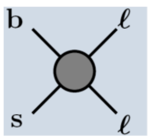


- Operator Product Expansion parametrize new physics effects through # $b \to s$ observables :

$$H_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left\{ \sum_{i=1}^{10} c_i(\mu) \mathcal{O}_i(\mu) + c_S(\mu)\mathcal{O}_S(\mu) + c_P(\mu)\mathcal{O}_P(\mu) + c'_S(\mu)\mathcal{O}'_S(\mu) + c'_P(\mu)\mathcal{O}'_P(\mu) \right\}$$

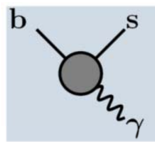
- Observables are functions of *C*'s.
  - Branching ratios (*BR*) Cs
  - Polarizations (C9)
  - Angular distributions (C7/C9)

- Three examples for LHCb:



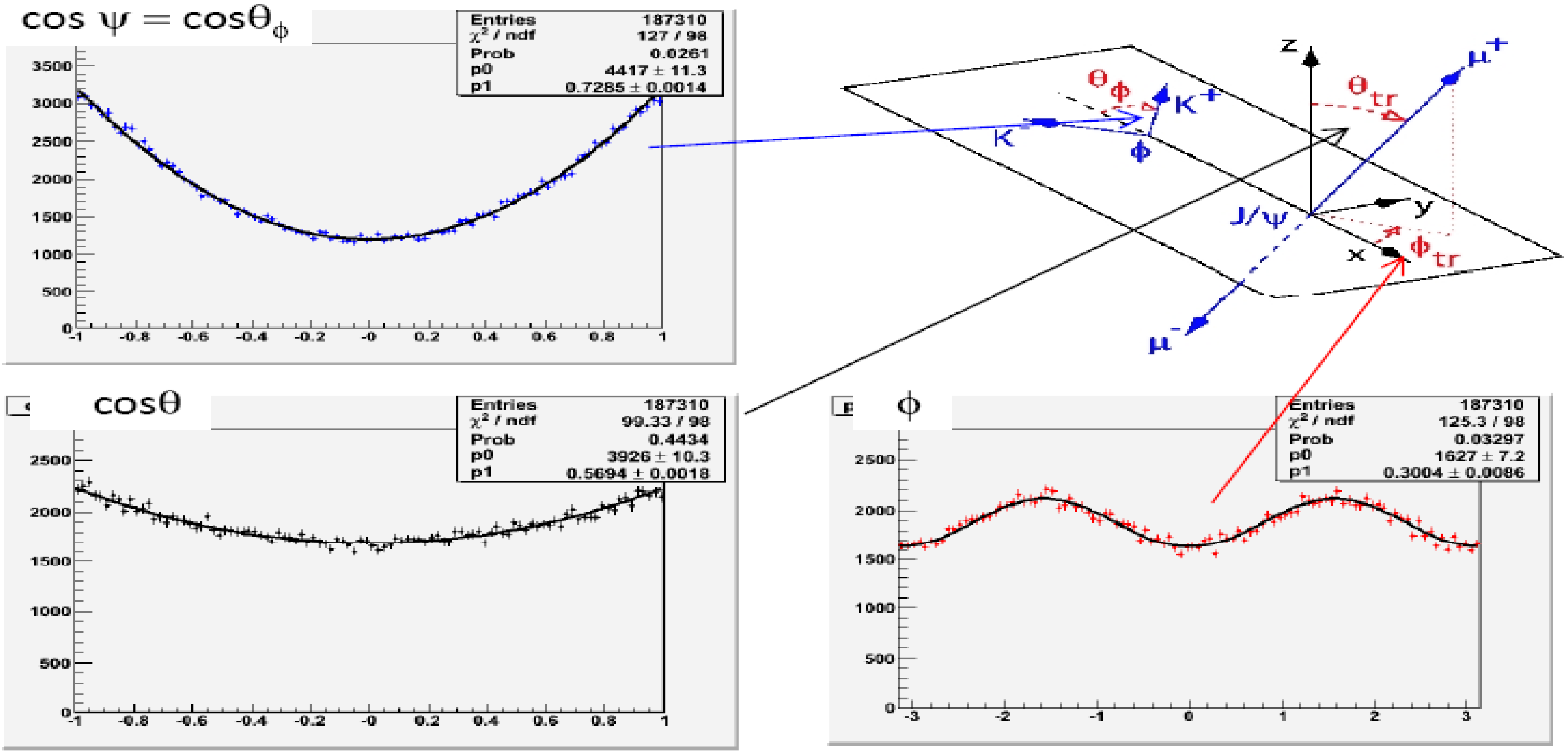
$B^0 \to K^*(K^+\pi^-)\mu^+\mu^-$

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

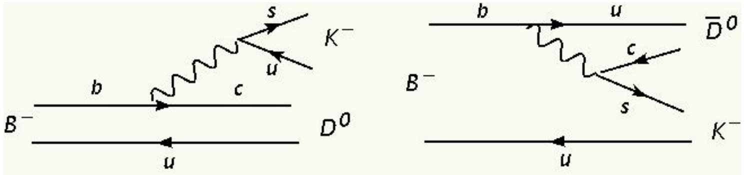


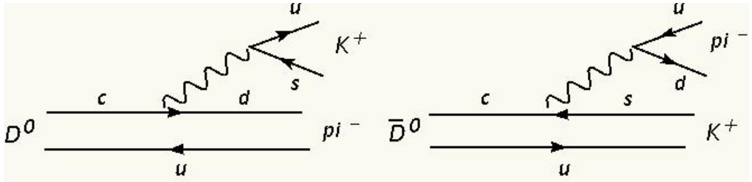
$B_s \to \phi(K^+K^-)\gamma$

Full 3D Angular Analysis



Study possible systematics of LHCb acceptance and reconstruction on distributions.





$$r_B e^{i(\delta_B \pm \gamma)} \qquad r_D e^{i\delta_D^{K\pi}}$$

$$
\begin{aligned}
\Gamma(B^- \to (K^-\pi^+)_D K^-) &= N^{K\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K\pi} - \gamma)),\\
\Gamma(B^- \to (K^+\pi^-)_D K^-) &= N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K\pi} - \gamma)),\\
\Gamma(B^+ \to (K^+\pi^-)_D K^+) &= N^{K\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K\pi} + \gamma)),\\
\Gamma(B^+ \to (K^-\pi^+)_D K^+) &= N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K\pi} + \gamma)),\\
\Gamma(B^- \to (h^+h^-)_D K^-) &= N^{hh}(1 + r_B^2 + 2r_B \cos(\delta_B - \gamma)),\\
\Gamma(B^+ \to (h^+h^-)_D K^+) &= N^{hh}(1 + r_B^2 + 2r_B \cos(\delta_B + \gamma)).
\end{aligned}
$$

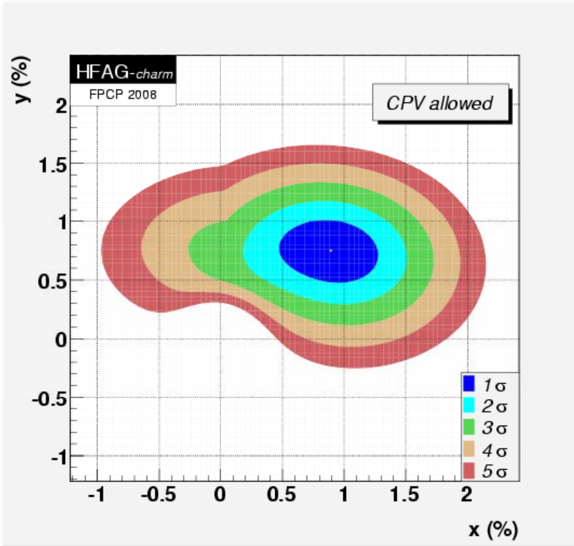
$$
\begin{aligned}
\Gamma(B^- \to (K^-\pi^+\pi^-\pi^+)_D K^-) &= N^{K3\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K3\pi} - \gamma)),\\
\Gamma(B^- \to (K^+\pi^-\pi^+\pi^-)_D K^-) &= N^{K3\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K3\pi} - \gamma)),\\
\Gamma(B^+ \to (K^+\pi^-\pi^-\pi^+)_D K^+) &= N^{K3\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K3\pi} + \gamma)),\\
\Gamma(B^+ \to (K^-\pi^+\pi^+\pi^-)_D K^+) &= N^{K3\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K3\pi} + \gamma)).
\end{aligned}
$$

Charm Physics

- Sensitivity to NP : loop diagrams involves d quarks
- Mixing

$$x = \frac{M_1 - M_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

Mixing observed in Babar & Belle
x = 0.89± 0.26%
y = 0.75± 0.17%



. Time-dependent D0 mixing with wrong-sign D0→K+π– decays
. Direct CP violation in D0→K+K–

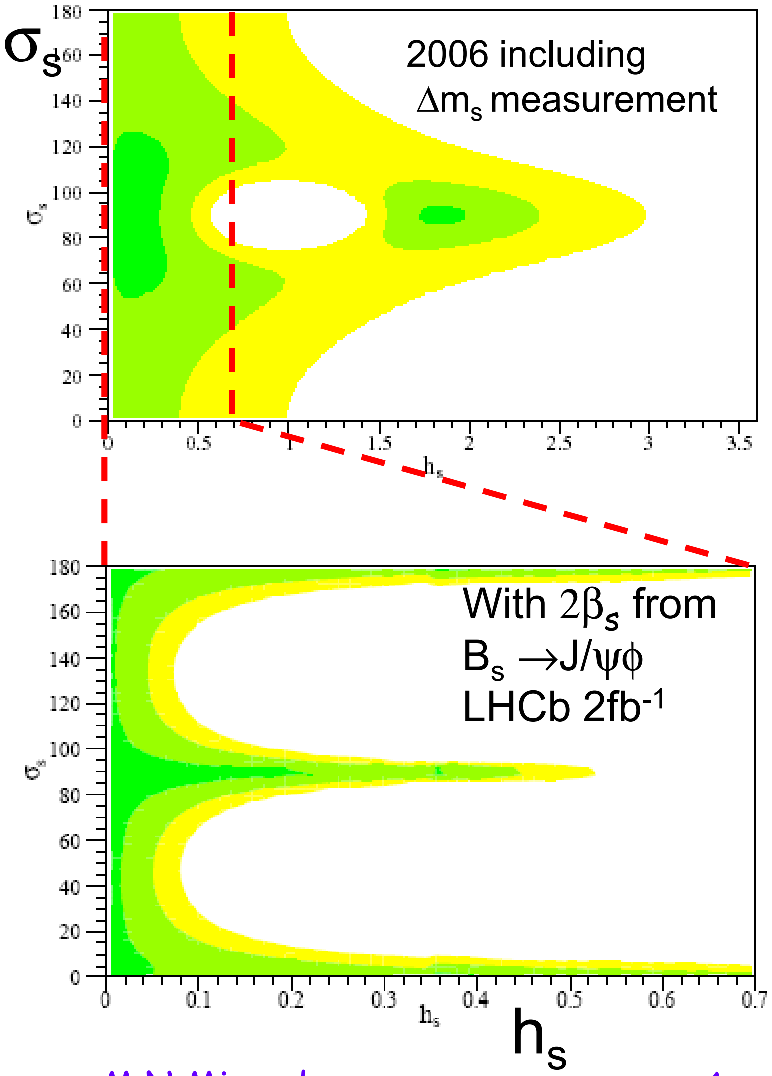
LHCb

- With luminosity increase level of interest emerge:
- 0.5 fb-1
  - Bs→ J/φ φ : 0.05 precision on βs
  - Bs -> μμ : improved limit

2 fb -1 (1year)	10fb-1
CPV	CPV
γ from tree : 5	γ from tree & loop : 4
γ from penguins 10	γ from penguins : 6
Bs mixing phase : 0.023	Bs mixing phase : 0.009 MS level
β_s^{eff} from penguins : 0.11	
Rare decays	Rare decays
s_0 0.5 GeV^2 from B→K^*μμ	s0 0.3 GeV^2 from B→K*μμ
Bs -> μμ 6 10^{-9} at 5 σ	Bs -> μμ SM at 5 σ
	Bs-> φγ σ(A^δ) =0.09

Room for NP in B_s mixing

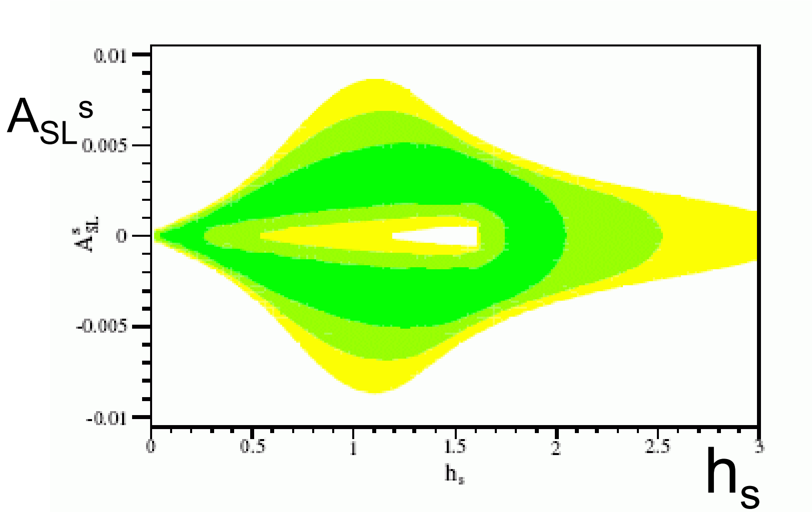
Ligeti, Paucci,Perez, hep-ph/0604112



New Physics in B_s mixing amplitude M_{12} parameterized with h_s and σ_s:

$$M_{12} = \left(1 + h_s \exp(2i\sigma_s)\right) M_{12}^{SM}$$

Additional constraints can come from semileptonic Asymmetry. In SM: $A_{SL}^{s} \sim 10^{-5}$: $B_s \to D_s \mu\nu$



LHCb expects

$\sim 10^9$ events/ 2fb^{-1} → $\delta(A_{SL}^{s})_{stat} \sim 2\times10^{-3}$ in 2fb^{-1}