Heavy Flavour physics and CP violation

M.Smizanska

Lancaster University, UK

Inroduction

Heavy Flavour (HF) physics is about:

- … learning and testing the phenomenology of the Standard Model, quark-mixing physics (CKM)
- … is about *CP* violation:
  - is δ_{CKM} the only source of *CP* violation in nature ?
- … is both, rare *and* precision physics
- … is looking beyond the Standard Model ! Uncovering *new* physics
- … will be probing flavour of new physics if discovered elsewhere
  - high-pT and Flavour precision probes are complementary (Workshop: HF in the era of LHC, CERN, 2006-2007.)

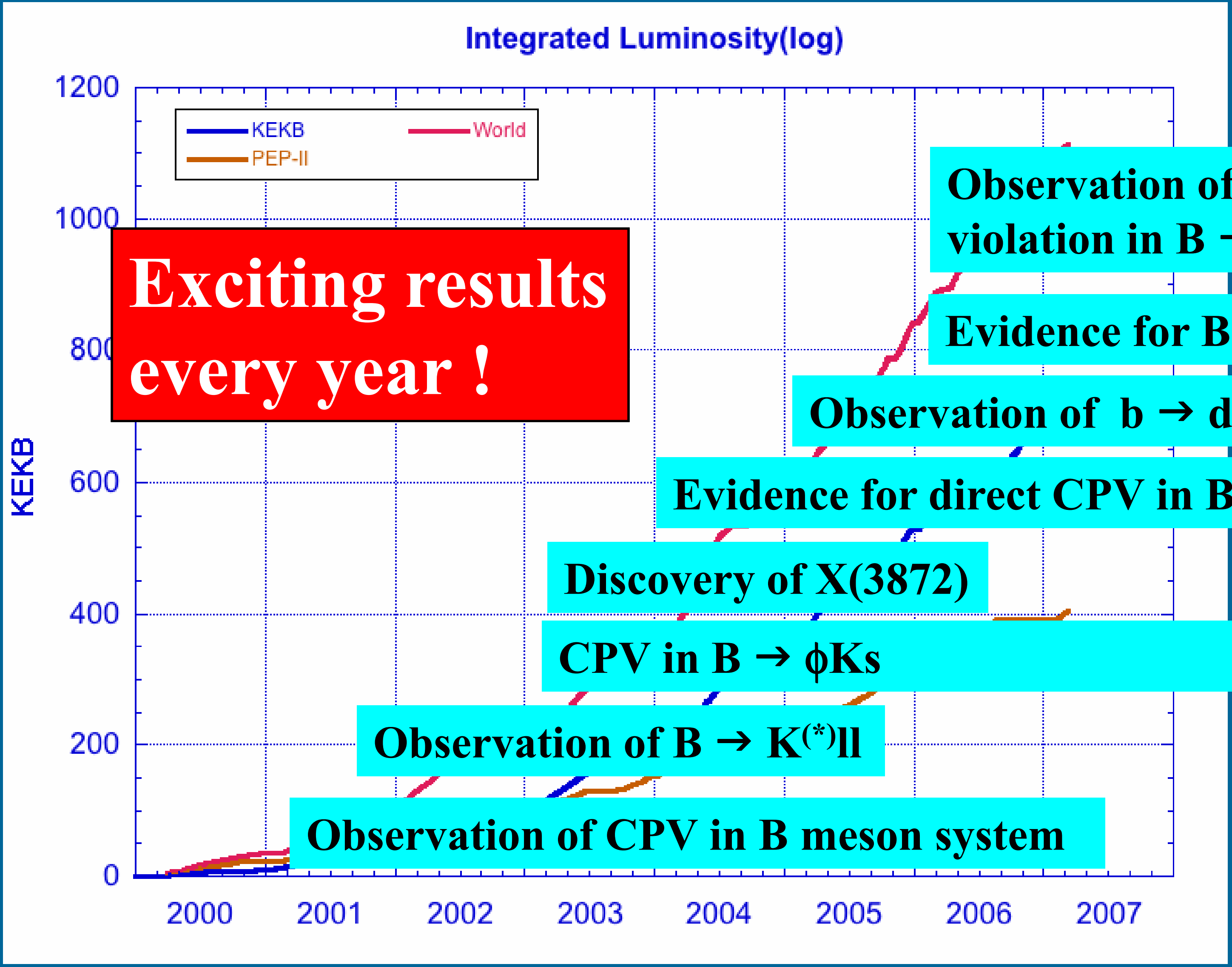
- Current HF lead by B-factories and Tevatron
  - results consistent with SM
  - Recent NP searches – some interesting constraints, however NP evidence need future experiments.
- 2008 LHC takes over and by 2013 inambigously confirm or reject NP in HF sector and start to map.
- Once NP found need detailed map NP in Flavor sector:
  - SuperB, KekB 2016 and upgraded LHCb (ATLAS/CMS) - 2016

Layout

- Overview of most recent measurements of current experiments, combined with expected measurements with existing LHC detectors. Stress is given on rare decays and very precise measurements searching for effects of NP.
    - Very rare leptonic B decays B → $\mu\mu$
    - CPV in Bs mixing
    - Radiative penquin B-decays: inclusive and exclusive b →sγ , dγ; BF and CPV
    - Electro weak penquinB-decays exclusive b→ s***ll*** and angular analysis of B →K****ll***
    - B-decay B → τ ν
    - Perspectives for measurement of γ
- Future facilities and upgrades

Worldwide Experimental facilities current and future measuring B-physics

Achievements at B factories



Exciting results every year !

Observation of direct CP violation in B → $\pi^+\pi^-$

Evidence for B → $\tau\nu$

Observation of b → dγ

Evidence for direct CPV in B → $K^+\pi^-$

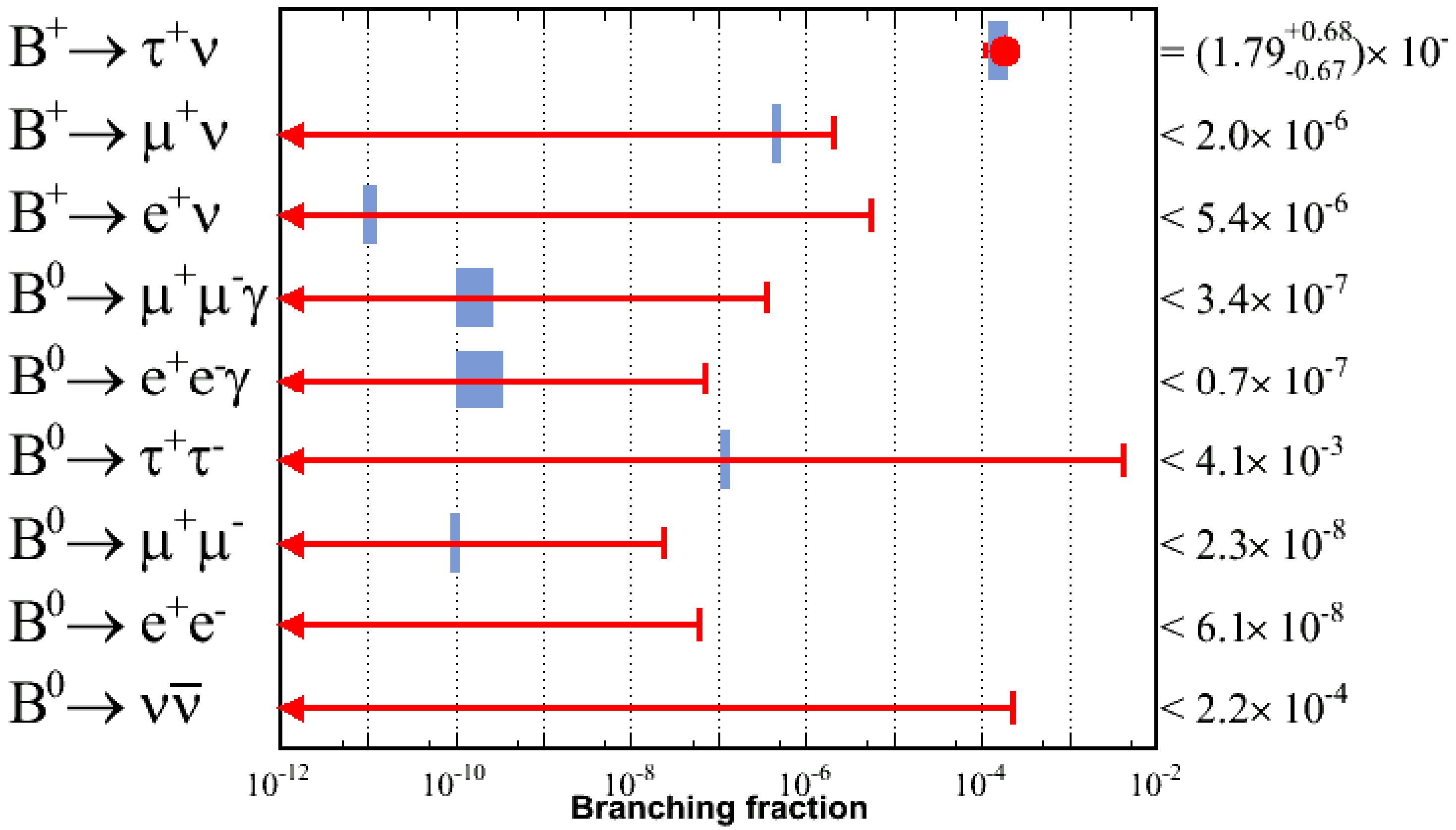
Discovery of X(3872)

CPV in B → ϕKs

Observation of B → $K^{(*)}ll$

Observation of CPV in B meson system

Rare decay searches in B-factories comparison of current results and SM



Extracted from J.Berryhill report on Rare decays WG at Flavor in the Era of the LHC

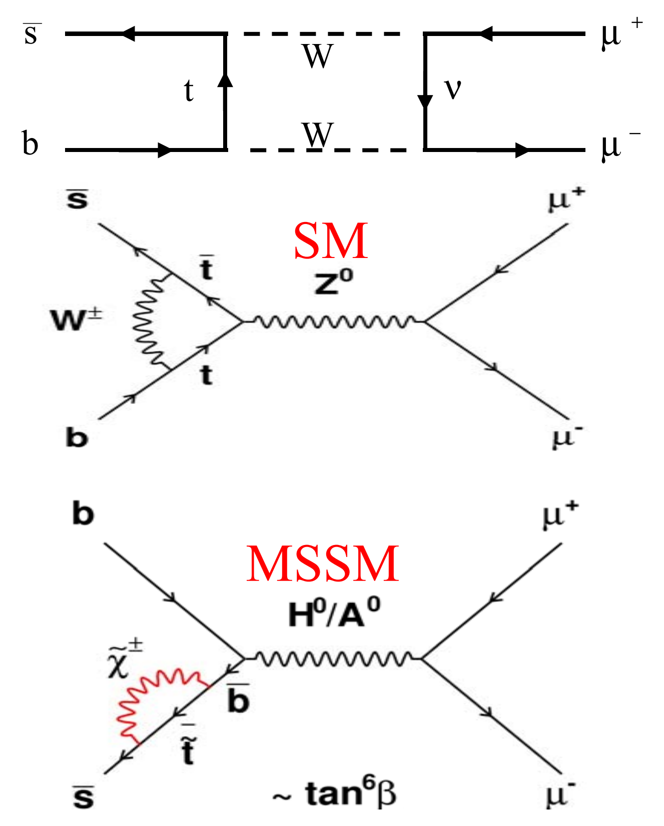
Achievements in Tevatron B phys

- The Tevatron has access to B_s, B_c and baryons
  - physics program complementary to the e^+e^- B-factories
- Very fast turn around of results at the Tevatron RUN-II
  - already showing 2.4 fb^{-1} results
- Competitive and complementary program to B-factories
- B_s mixing measured
  - $\Delta m_s = 17.77 \pm 0.10\ (\mathrm{stat.}) \pm 0.07\ (\mathrm{syst.})\ \mathrm{ps}^{-1}$
- CPV B_s mixing phase ϕ_s and $\Delta\Gamma_s$ limits sharpened
- $\Lambda_b \to J/\psi\, \Lambda$ Lifetime
- First measurement of direct CPV in B_s ($B_s \to K^-\pi^+$)
- $B \to \mu\mu$ limits $\sim 10^{-8}$
- Observation of Σ_b, $B_s \to K^-\pi^+$ $\Lambda_b \to pK^-$ $\Lambda_b \to p\pi^-$

From Jónatan Piedra, Mar 2007 in CERN, updated

$B_s \rightarrow \mu\mu$

- Very rare loop decay $B_s \rightarrow \mu\mu$, sensitive to new physics:
  - BR =$(3.4 \pm 0.4) \times 10^{-9}$ in SM
  - Current 90% CL limit:
    - CDF note 8956 (2 fb^{-1}): 47×10^{-9} = 14*BR_{SM}
    - D0 note 5344-CONF (2 fb^{-1}): 75×10^{-9} = 20*BR_{SM}
  - BR can be strongly enhanced in SUSY:
    - e.g. current measurement of anomalous magnetic moment of muon suggests $BR(B_s \rightarrow \mu^+\mu^-)$ up to 100×10^{-9} within the CMSSM for high tanβ → see next slide

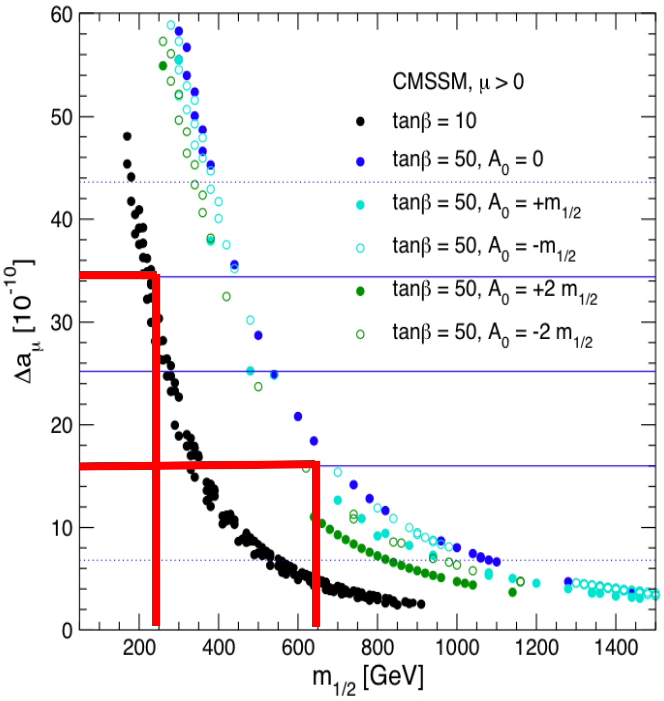


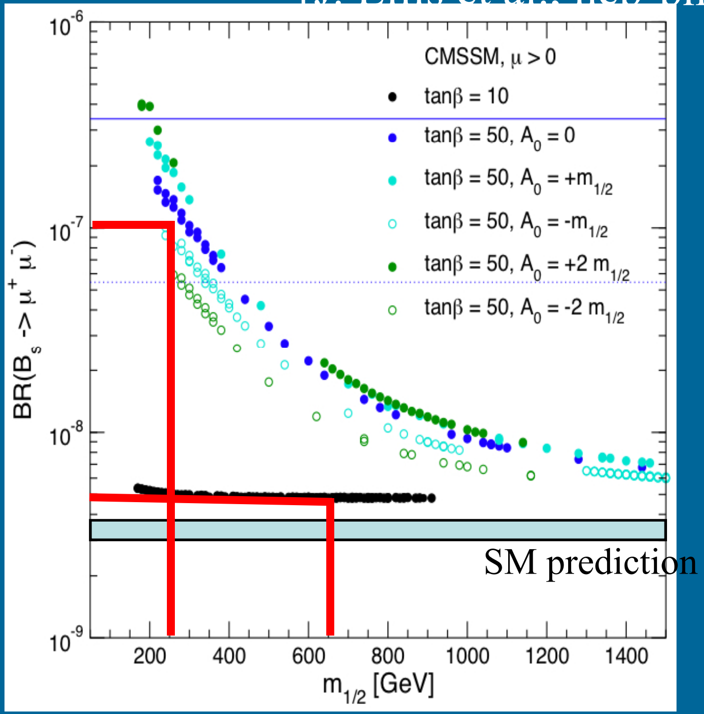
$B_s \to \mu^+\mu^-$

- Anomalous magnetic moment of the muon
  - Muon g–2 collab. measurement deviates by 2.7σ from SM: $\Delta a_\mu = (25.2 \pm 9.2)\times 10^{-10}$
- Implications on $B_s \to \mu^+\mu^-$ within constrained MSSM:

  $250 < m_{1/2}$(gaugino mass) < 650 GeV $\Rightarrow BR(B_s \to \mu^+\mu^-) = 5\times10^{-9}$–$10^{-7}$

[J. Ellis et al., hep-ph/0411216]





$B_s \rightarrow \mu\mu$

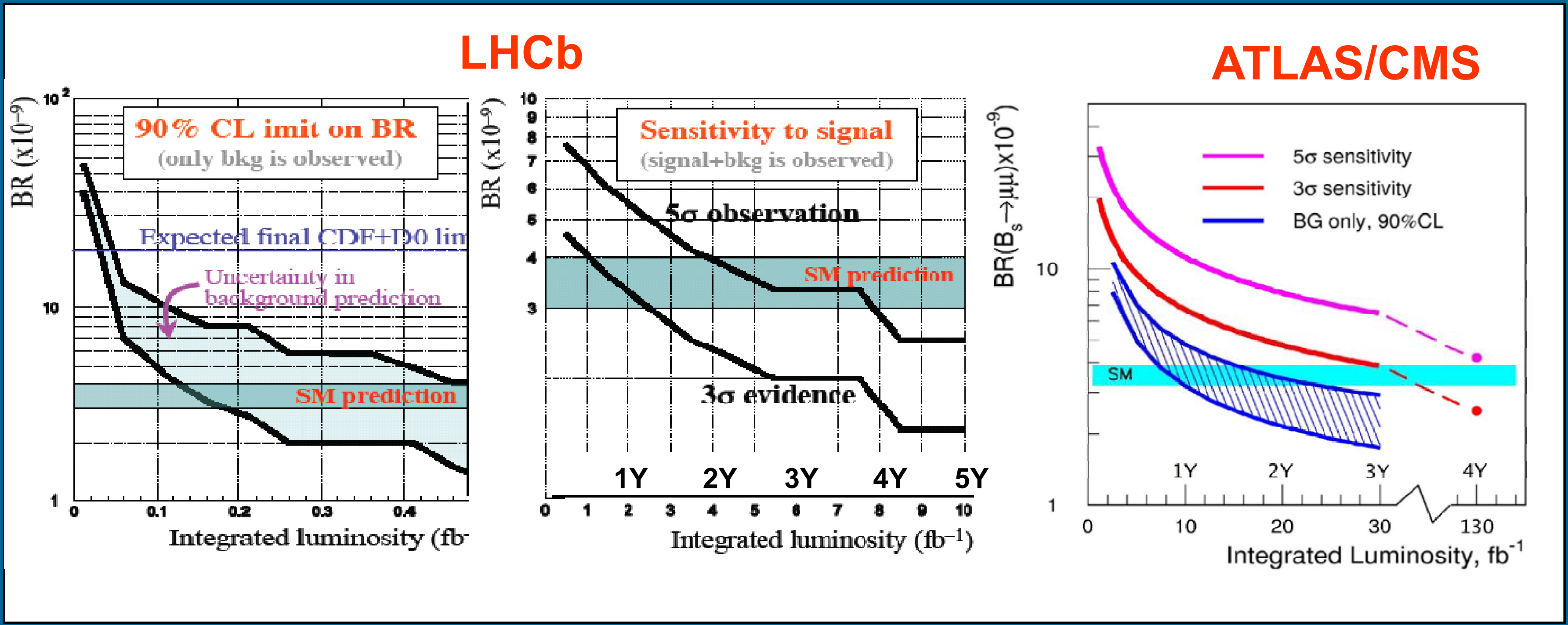
- Easy for LHCb ATLAS, CMS to trigger and select
- Main issue is background rejection
  - with limited MC statistics, indication that largest background is b b $\rightarrow \mu\mu$

Specific BG	**Br**
$B^+ \rightarrow \mu^+\mu^- \ell^+\nu_\ell$	$< 5 \cdot 10^{-6}$
$B^+ \rightarrow J/\psi\ (\mu^+\mu^-)\ \mu^+ \nu$	$\sim 6 \cdot 10^{-5}$
$B_c \rightarrow J/\psi\ (\mu^+\mu^-)\ell^+\nu_\ell$	$< 10^{-4}$
$B^0 \rightarrow \pi^- \mu^+ \nu_\mu$	$\sim 10^{-4}$
$B_d \rightarrow K\pi \quad B_s \rightarrow KK$	$2 \cdot 10^{-5}$
$B^0_d \rightarrow \pi^0 \mu^+\mu^-$	$\sim 2 \cdot 10^{-8}$
$B^0_s \rightarrow \mu^+ \mu^- \gamma$	$\sim 2 \cdot 10^{-8}$

- specific background (table) were simulated – contribute 1-5% of signal
  - largest one from $B_c \rightarrow J/\psi(\mu\mu)\mu\nu$
  - $B_d \rightarrow K\pi$ $B_s \rightarrow KK$, $B^0 \rightarrow \pi^- \mu^+ \nu_\mu$ are detector dependent
  - $B_s \rightarrow \mu^+ \mu^- \gamma$ $B^0_d \rightarrow \mu^+ \mu^- \pi$ are rare channels – of specific interest themselves

arXic:0801.1833v1[hep-ph], 11 Jan 2008

$B_s \rightarrow \mu\mu$



- 0.05 fb-1 LHCb overtakes CDF+D0
- 0.5 fb-1 (~3 months @ 2 x 10^{32}) LHCb excludes BR down to SM

- 3σ evidence LHCb 1 year@ 2 x 10^{32}; ATLAS, CMS 3 years @10^{33}
- 5σ observation LHCb 3 years@ 2 x 10^{32}; ATLAS, CMS 1 year @10^{34}

arXic:0801.1833v1[hep-ph], 11 Jan 2008

New physics in B_s mixing

- After succesful measurement of Δm_s (mass difference of the two B_s mass eigenstates B_H, B_L) by CDF and D0

$$\Delta m_s = 17.77 \pm 0.10\ (\text{stat.}) \pm 0.07\ (\text{syst.})\ \text{ps}^{-1}$$

- Tevatron started to approach even more difficult measurement of weak phase of Bs mixing, $\phi_s = \arg(-M_{12}/\Gamma_{12})$, ($M_{12}$, Γ_{12} elements of mass and decay matrix describing mixing of Bs –anti Bs system).
- ϕ_s is very small in SM and precisely predicted
  - $\phi_s^{SM} = -\arg(V_{ts}^2) = -2\lambda^2\eta = -0.0368 \pm 0.0018$ [Utfitter, summer 2007]
- ϕ_s very sensitive to New Physics contributions:
  - Some models can predict large ϕ_s, while satisfying all existing constraints:
    - e.g. Little Higgs model with T-parity provides significant enhancement of both ϕ_s and B_s semi-leptonic asymmetry A_{SL} while Δm_s is found to be smaller than SM value
- Measurement of ϕ_s is challenging.
- Recent Tevatron results as well as Utfitter – combining CDF, D0 and indirect measurements – attracted attention of flavour community…

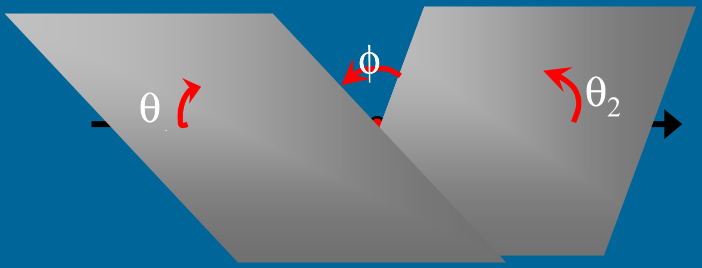
Experimental approach to B_s mixing phase ϕ_s

- ❑ Measurement of ϕ_s is challenging not only because CPV may be small.
    - Experimentally most feasible channel is **$B_s \to J/\psi\phi$** (other decays can give only negligible improvement $B_s \to J/\psi\eta$, $\eta_c\phi$, D_sD_s)
- ❑ $B_s \to J/\psi(\mu\mu)\ \phi\ (KK)$
    - easy to trigger and suppress background. At LHC huge statistics (~100k per Y in each LHCb, ATLAS, or CMS).
    - determined by 8 parameters **$\phi_s\ \Gamma_s\ \Delta\Gamma_s\ \Delta m_s\ A_\perp\ A_\parallel\ \delta_1\ \delta_2$** which need to be determined simultaneously from fit to data.
    - Tevatron statistics are limited - simplified analysis was unavoidable.
        - results extracted in form of 2-dimensional **(ϕ_s, $\Delta\Gamma_s$)** plane with Confidence regions..

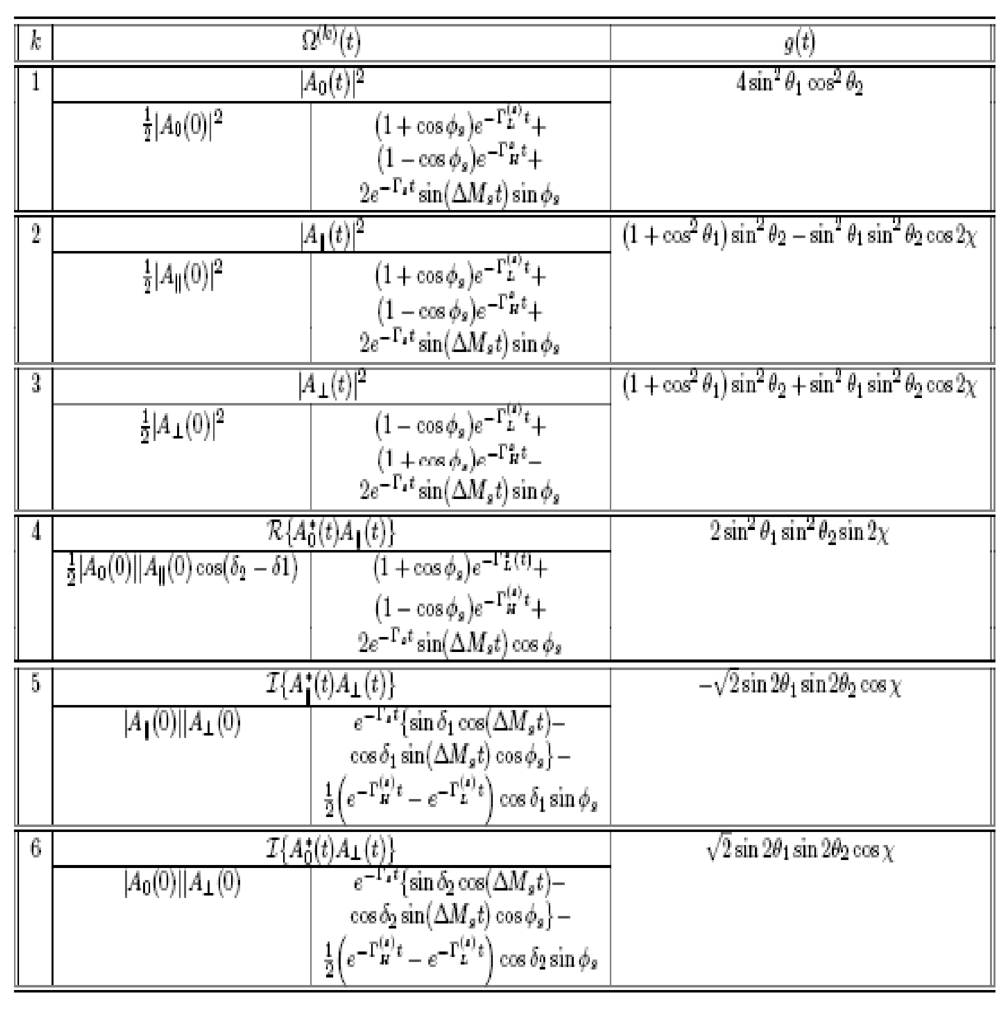
Experimental approach to Bs mixing phase ϕ_s, cont

Experimental information:

- 3 angles, proper decay time, flavour tag; background fraction and composition
- Independent measurement of Δms in flavour explicit channel
- Independent determination of uncertaintes of all the above measurements (detector resolutions, wrong tag fractions, systematic errors)

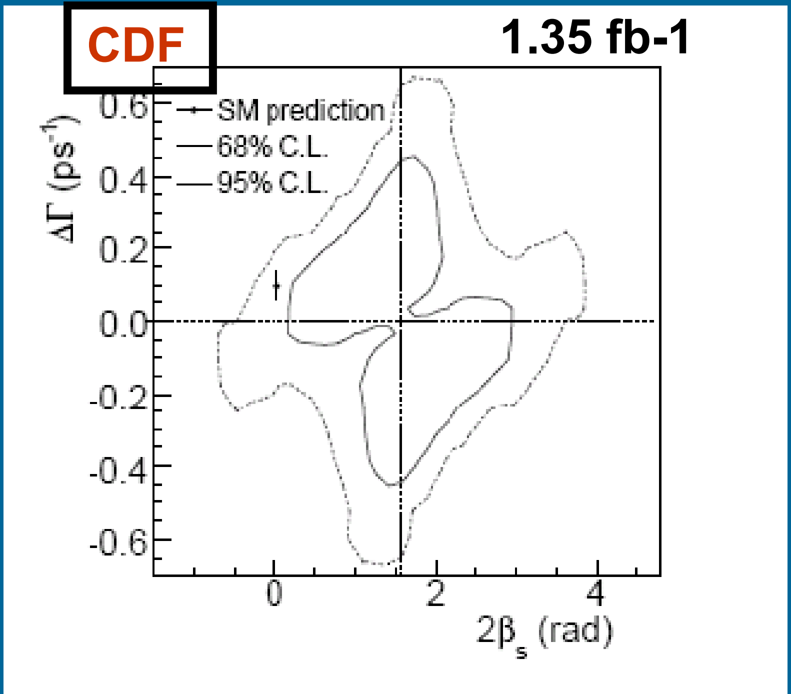


pdf ($\phi_{s,}$ Γ_s, $\Delta\Gamma_s$, Δm_s $A_\perp$,$A_\parallel$, δ_1,δ_2)

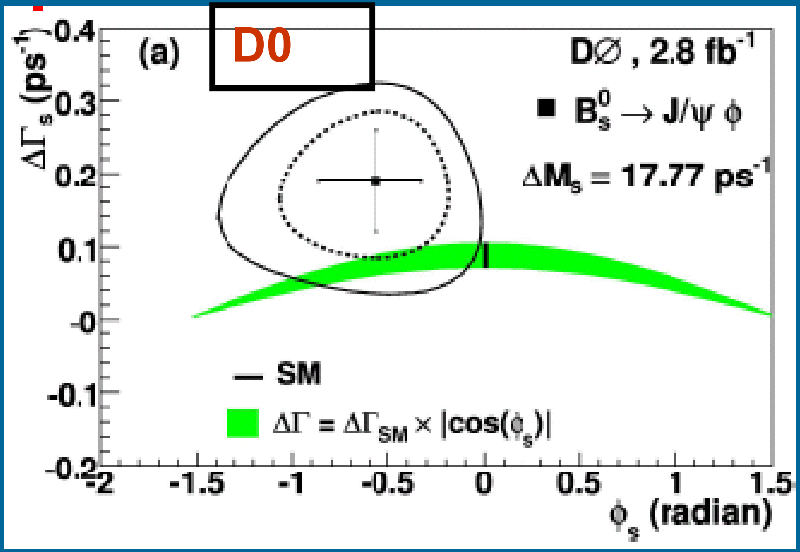


k	$\Omega^{(k)}(t)$		$g(t)$
1	$\lvert A_0(t)\rvert^2$		$4\sin^2\theta_1\cos^2\theta_2$
	$\frac{1}{2}\lvert A_0(0)\rvert^2$	$(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{s}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
2	$\lvert A_\parallel(t)\rvert^2$		$(1+\cos^2\theta_1)\sin^2\theta_2-\sin^2\theta_1\sin^2\theta_2\cos 2\chi$
	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2$	$(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{s}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
3	$\lvert A_\perp(t)\rvert^2$		$(1+\cos^2\theta_1)\sin^2\theta_2+\sin^2\theta_1\sin^2\theta_2\cos 2\chi$
	$\frac{1}{2}\lvert A_\perp(0)\rvert^2$	$(1-\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1+\cos\phi_s)e^{-\Gamma_H^{s}t}-$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
4	$\mathcal{R}\{A_0^*(t)A_\parallel(t)\}$		$2\sin^2\theta_1\sin^2\theta_2\sin 2\chi$
	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos(\delta_2-\delta 1)$	$(1+\cos\phi_s)e^{-\Gamma_L^{s}(t)}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{(s)}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\cos\phi_s$	
5	$\mathcal{I}\{A_\parallel^*(t)A_\perp(t)\}$		$-\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\chi$
	$\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert$	$e^{-\Gamma_s t}\{\sin\delta_1\cos(\Delta M_s t)-$ $\cos\delta_1\sin(\Delta M_s t)\cos\phi_s\}-$ $\frac{1}{2}\left(e^{-\Gamma_H^{(s)}t}-e^{-\Gamma_L^{(s)}t}\right)\cos\delta_1\sin\phi_s$	
6	$\mathcal{I}\{A_0^*(t)A_\perp(t)\}$		$\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\chi$
	$\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert$	$e^{-\Gamma_s t}\{\sin\delta_2\cos(\Delta M_s t)-$ $\cos\delta_2\sin(\Delta M_s t)\cos\phi_s\}-$ $\frac{1}{2}\left(e^{-\Gamma_H^{(s)}t}-e^{-\Gamma_L^{(s)}t}\right)\cos\delta_2\sin\phi_s$	

CDF and D0 confidence level bounds on $\Delta\Gamma_s$ - ϕ_s



arXiv:0712.2397v1 [hep-ex] 14 Dec 2007



FERMILAB-PUB-08-033-E
arXiv:0802.2255v1 [hep-ex] 15 Feb 2008

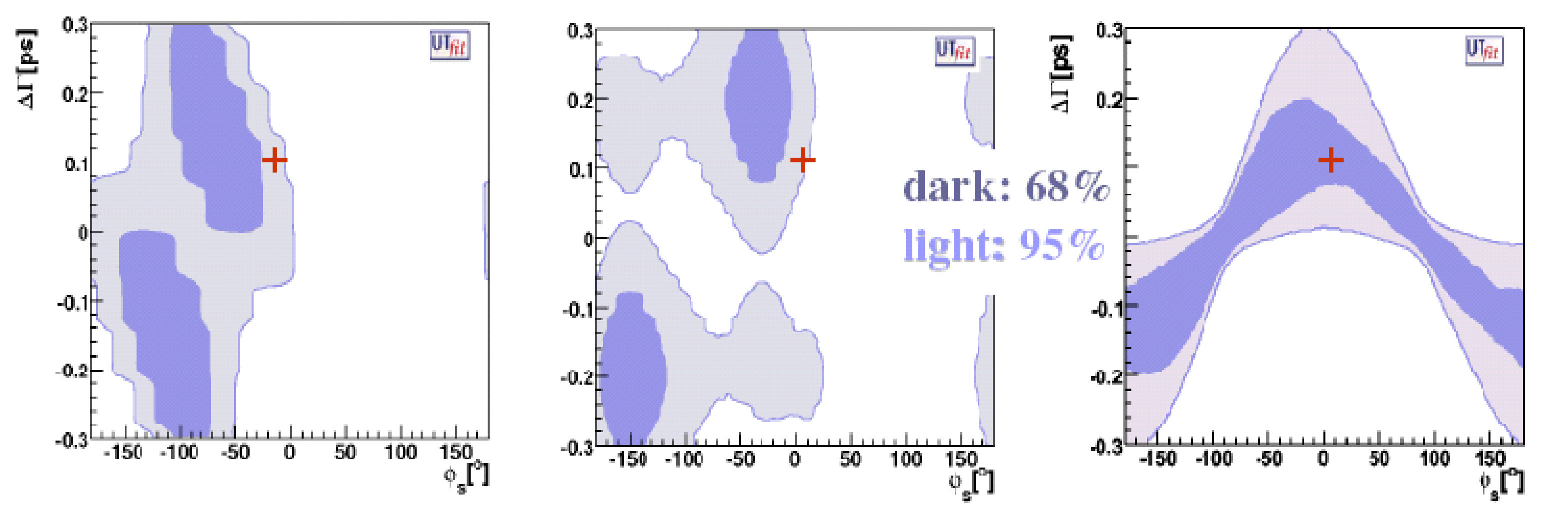
Conclusions from experiments:
assuming SM values $\Delta\Gamma_s$ =0.096 ps-1 and ϕ_s =0.04
the probability of deviation of these values of as large as the observed data is 15 % (CDF) and 6.6% (D0)

UtFit analysis constraints on $\Delta\Gamma_s$ - ϕ_s

CDF measurement

D0 measurement

UTFit analysis using other B-physics measurements: A_{SL}, A_{CH}, τ_{Bs} $\Delta\Gamma s$ / Γs



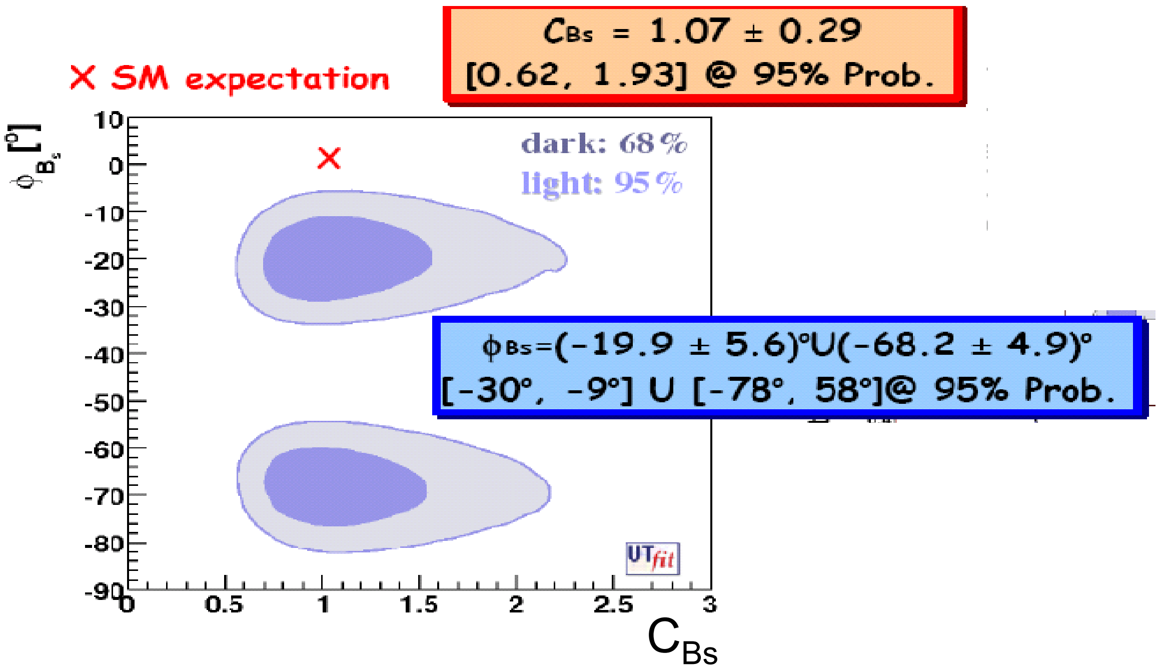
arXiv:0803.0659v1 [hep-ph] 5 Mar 2008

UTFIT working group combined

- CDF, D0 measurements of the 2-dimensional probability $\Delta\Gamma_s$ vs ϕ_s
- and the result of UTfit analysis using other B-physics measurements: A_{SL}(semileptonic asymmetry Bs), A_{CH} (dilepton charge asymmetry), Bs lifetime from flavor specific modes, $\Delta\Gamma s/\Gamma s$.

Recent UTfit group contrains on ϕ_s, cont

Combining the three inputs (previous slide) – UTfit claims
more than 3 σ deviation from SM prediction of CPV Bs mixing phase



C_{Bs} = 1.07 ± 0.29
[0.62, 1.93] @ 95% Prob.

ϕ_{Bs}=(-19.9 ± 5.6)°U(-68.2 ± 4.9)°
[-30°, -9°] U [-78°, 58°]@ 95% Prob.

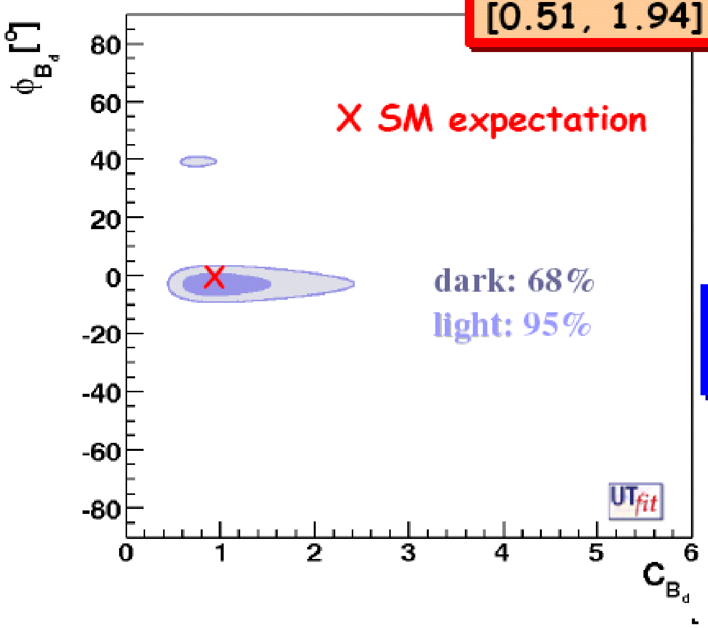
UTfit defined variables
$\phi_{Bs} \equiv \phi s - \phi s(SM)$;

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \bar{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \bar{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

arXiv:0803.0659v1 [hep-ph] 5 Mar 2008

Analogical UTfit analysis for B_d phase ϕ_d

Analogical UTfit analysis in B_d find CPV consistent with SM



$C_{Bd} = 1.00 \pm 0.32$

[0.51, 1.94] @ 95% Prob.

$\phi_{Bd} = (-3.0 \pm 2.2)°$

[-7.8°, 1.7°] @ 95% Prob.

UTfit defined variables

$\phi_{Bd} \equiv \phi d - \phi d(SM)$;

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \overline{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

LHC potential on new physics in B_s mixing

Large statistics allow complete analysis: likelihood fit for 7 parameters ($\phi_{s,}$ Γ_s, $\Delta\Gamma_s$, $A_\perp$,$A_\parallel$, δ_1,δ_2)

ATLAS fit using full 3-angular-time PDF

	ATLAS
Years / Luminosity	**3Y/ 30 fb-1**
ϕ_s	0.067
ΔΓs	13%
Γs	1%
$A_\parallel$	0.9%
$A_\perp$	3%
δ1	B_d-J/y K*
δ2	B_d-J/y K*
Δm_s (ps-1)	17.77 +- 0.12

*ATLAS CSC NOTE to be published in April 08.

* Same method of Fit done by LHCb. Numbers not public yet.

LHCb sensitivity after 10 fb^{-1}

(5 years) $\delta(\phi_s) = 0.006$

- Includes also pure CP modes such as $B_s \rightarrow J/\psi\eta^{(')}$, $\eta_c\phi$, D_sD_s, but dominated by $B_s \rightarrow J/\psi\phi$
- > 3σ evidence of non-zero ϕ_s, even if only SM

LHC after 2 fb-1

B_s decay mode	**σ(ϕ_s)**
$J/\psi\eta(\gamma\gamma)$	0.109
$J/\psi\eta(\pi^+\pi^-\pi^0)$	0.142
$J/\psi\eta'(\rho^0\gamma)$	0.080
$J/\psi\eta'(\eta\pi^+\pi^-)$	0.154
$\eta_c(4h)\phi$	0.108
$D_s^+D_s^-$	0.133
pure CP modes	**0.046**
$J/\psi(\mu\mu)\phi$	**0.023**
All modes	**0.021**

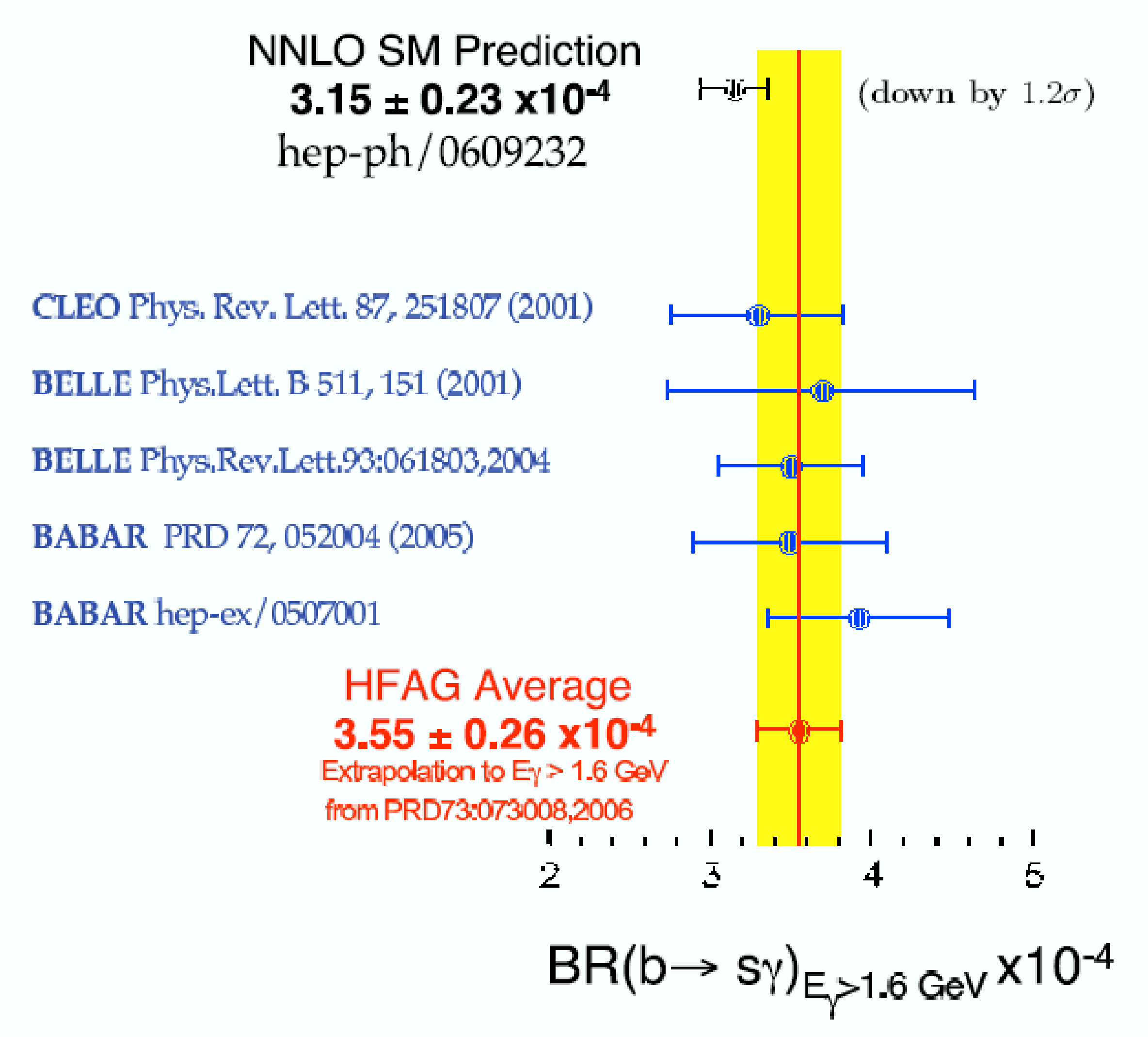
CERN-LHCb-2006-047
CERN-LHCb-2007-027

Inclusive b →s γ

Experiment – NNLO Theory
= +1.2σ

B factories
are likely to improve
precision to 5%

Super B can measure
incl. b →dγ rate to
25% with 5 ab^{-1}



Exclusive b →s,d γ at LHCb

Decay	2 fb^{-1} yield	B_{bb}/S
$B_d \to K^*\gamma$	68k	0.60
$B_s \to \phi\gamma$	11.5k	< 0.55
$\Lambda_b \to \Lambda(1115)\gamma$	0.75k	< 42
$\Lambda_b \to \Lambda(1670)\gamma$	2.5k	< 18

In 1 Y (2 fb-1)

- A_{CP} < 1% in SM, up to 40% in SUSY; can measure at <% level
- Right-handed component of photon polarization O(10%) in SM; can get 3σ evidence down to 21% (10 fb^{-1})

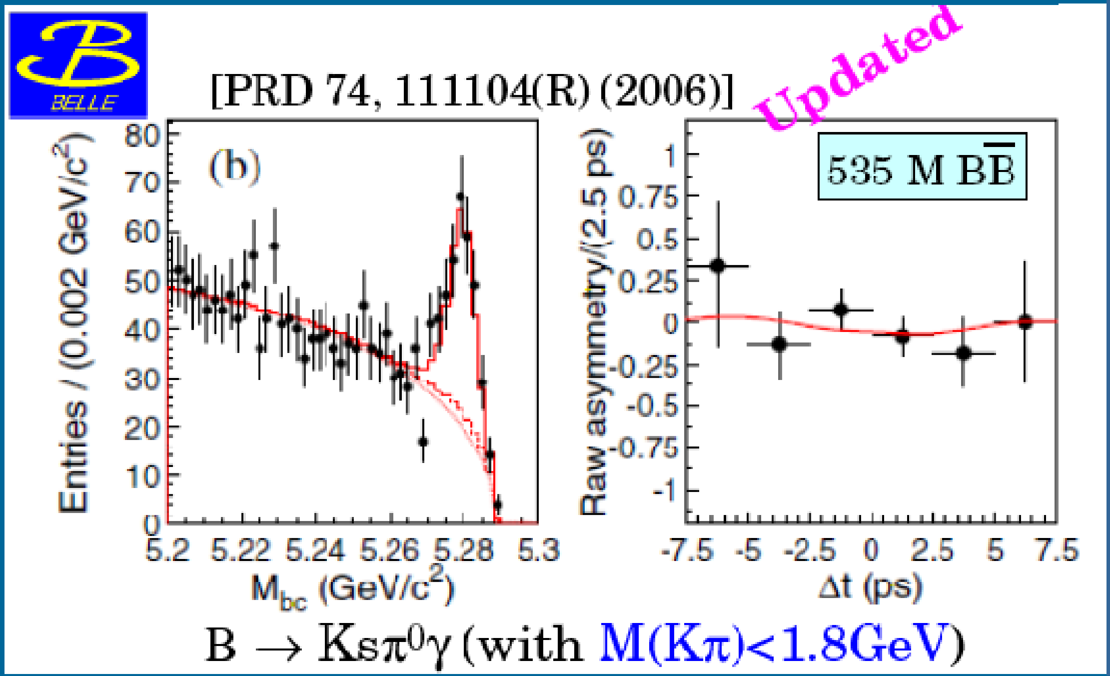
$$A_{CP}(t) = \frac{\Gamma(B^0(t) \to K^{*0}\gamma) - \Gamma(B^0(t) \to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t) \to \bar{K}^{*0}\gamma) + \Gamma(B^0(t) \to K^{*0}\gamma)}$$

CERN-LHCb-2006-012
CERN-LHCb-2006-013

ATLAS also developing radiative trigger for these measurements. Expected statistics - factor 10 smaller than LHCb due to combination with muon L1 signature.

Exclusive b →s,d γ: B-factories

B factories CPV B → $K_s \pi^0 \gamma$



$B \to K_s\pi^0\gamma$ (with $M(K\pi)<1.8\,\mathrm{GeV}$)

SM predicts time dependent CPV S=-0.022 ± 0.012

Belle: current time dependent CPV S=-0.10 ± 0.31 ± 0.07

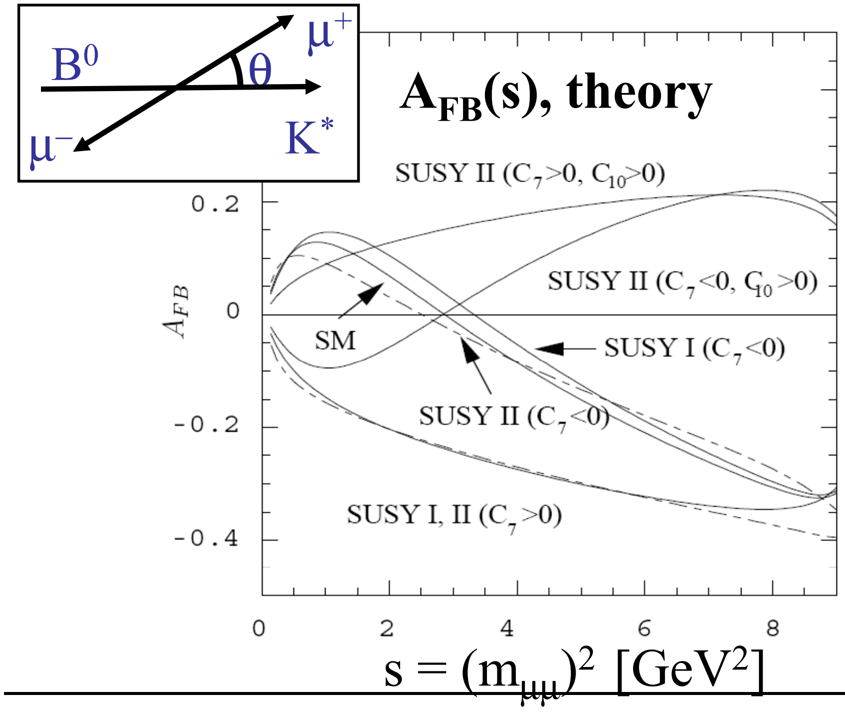
Sensitivity can be improved to 10% @5 ab^{-1} and 3% @50 ab^{-1} Super factory

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

CERN-LHCb-2007-038
CERN-LHCb-2007-039

☐ Suppressed loop decay

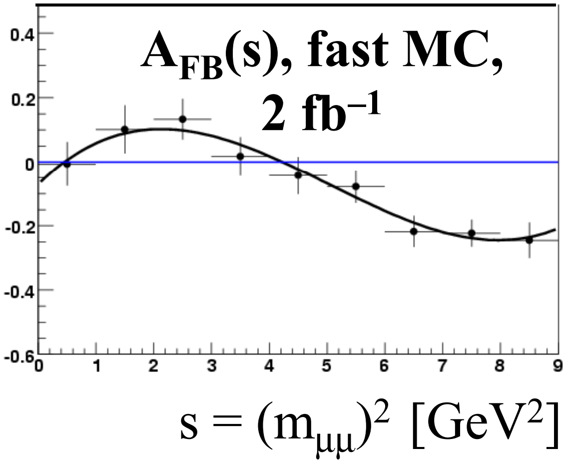
- Forward-backward asymmetry $A_{FB}(s)$ in the μμ rest-frame
  - sensitive probe of New Physics
  - zero of A_{FB} gives access to ratio of Wilson coefficients C_7^{eff}/C_9^{eff}



☐ Sensitivity

(ignoring non-resonant Kπμμ evts for the time being)

- **7.2k signal events/2fb^{-1}**, $B_{bb}/S = 0.2 \pm 0.1$
  - NB: expect 0.3k/1ab^{-1} at B factories



- With 10 fb^{-1}, the zero of $A_{FB}(s)$ can be measured to ±0.27 GeV^2 (~7% of SM value)

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

CERN-LHCb-2007-05

- ☐ Other observables based on transversity amplitudes ($A_\perp$, $A_{//}$, A_0) extracted from a 3-angle analysis:
  - — small theoretical errors in the SM,
  - — sensitive to right-handed FCNC

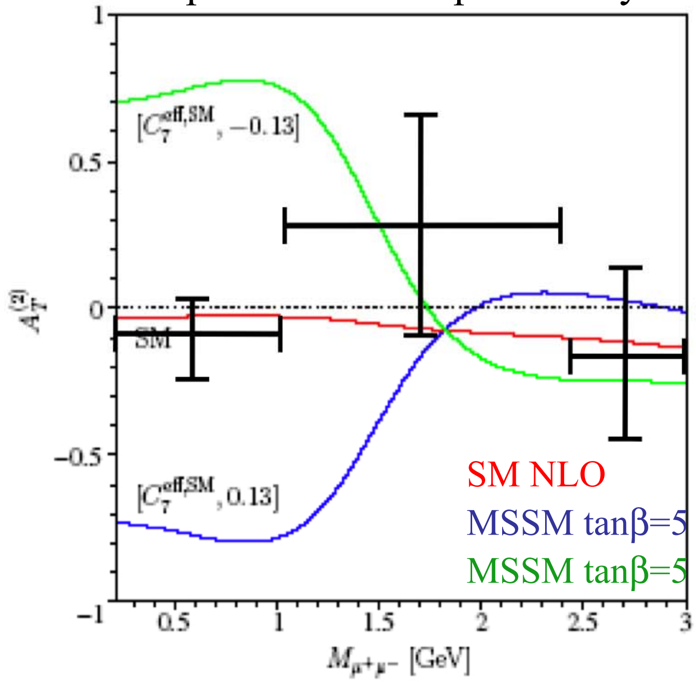
Stat. precisions in the region $s = (m_{\mu\mu})^2 \in [1, 6]\ (\mathrm{GeV}/c^2)^2$ where theory calculations are most reliable

	2 fb^{-1}	10 fb^{-1}
$A_T^{(2)}$	±0.42	±0.16
F_L	±0.016	±0.007
A_{FB}	±0.020	±0.008

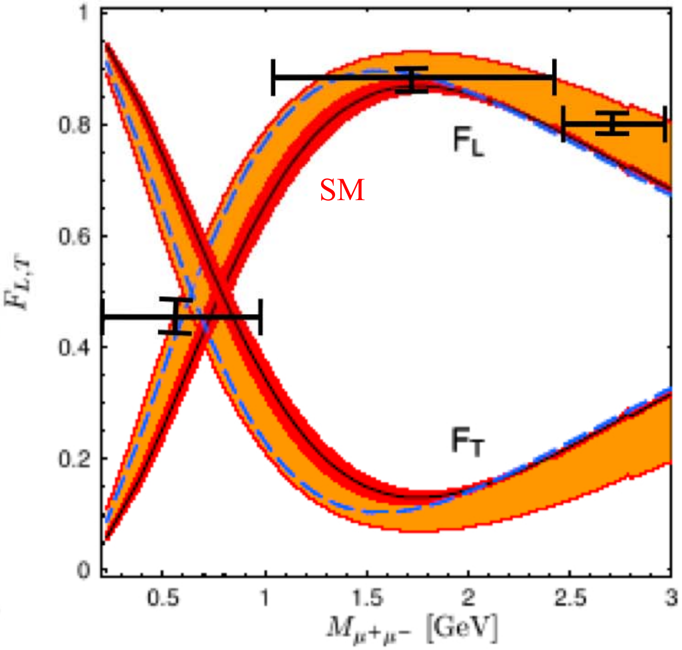
$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_{//}|^2}{|A_\perp|^2 + |A_{//}|^2}$$

$$F_L(s) = \frac{|A_0|^2}{|A_0|^2 + |A_{//}|^2 + |A_\perp|^2}$$

2nd polarization amplitude asymmetry



K* longitudinal polarization fraction



Error bars:
LHCb 2 fb^{-1}

Curves:
theory

[Lunghi & Matias, hep-ph/0612166]

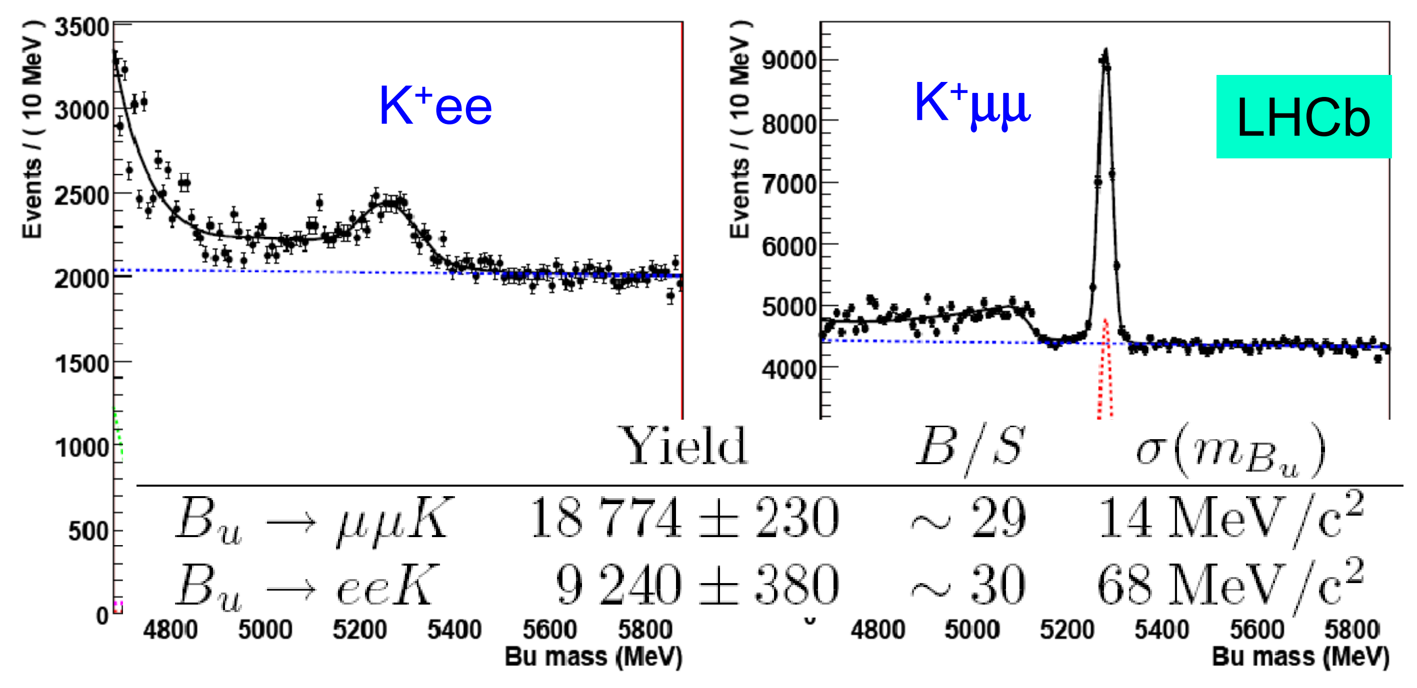
$B^+ \to K^+ l\, l$: LHCb

Higgs-like scalar/pseudoscalar operators can enhance $K^+\mu\mu$ over K^+ee
Interesting cross-check on an anomalous $B_S \to \mu\mu$ signal

Super B precision in RK = BF($B \to K\, \mu\mu$)/BF($B \to Kee$) is 4% @ 50 ab^{-1}
(electrons and muons have roughly equal sensitivity)

LHCb has unequal sensitivity but still a significant K^+ee signal:

LHCb RK precision is 4.3% @ 10 fb^{-1}



	Yield	B/S	$\sigma(m_{B_u})$
$B_u \to \mu\mu K$	$18\,774 \pm 230$	~ 29	$14\ \mathrm{MeV}/c^2$
$B_u \to eeK$	$9\,240 \pm 380$	~ 30	$68\ \mathrm{MeV}/c^2$

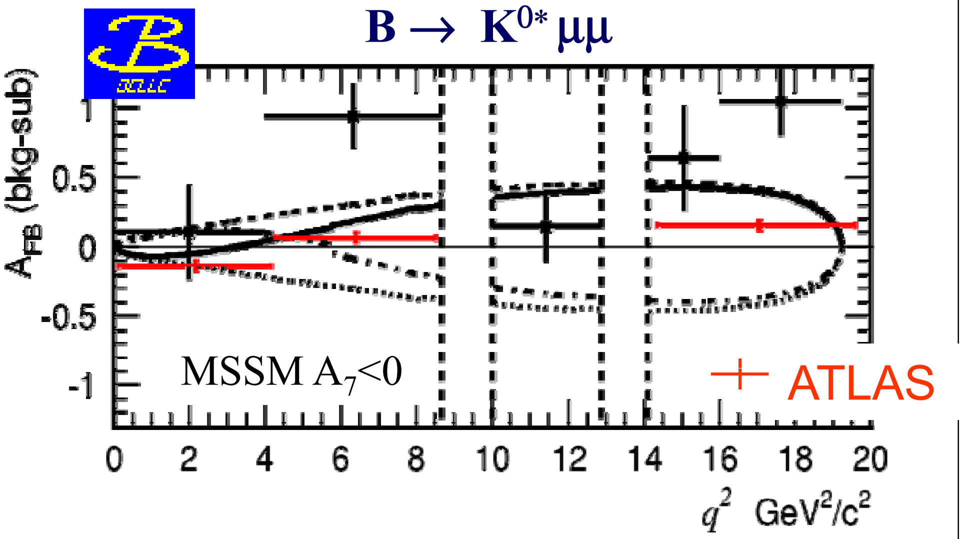
P. Koppenburg, et al LHCb Note 2007-034

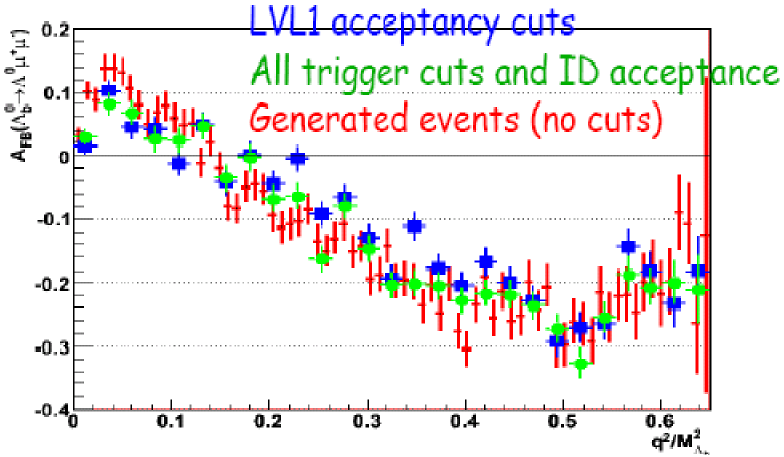
Exclusive b →d,s $\mu\mu$ in ATLAS

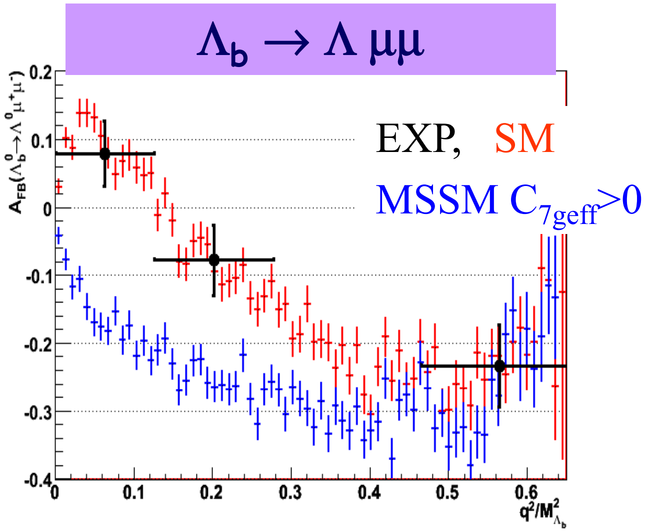
Variety of exclusive channels

Key points: di-muon trigger acceptance calibrations; vertexing.

30 fb-1	$\delta A_{FB}/A_{FB}$ (1-6)GeV^2
$B \rightarrow K^{0*}\mu\mu$	4.8%
$B_s \rightarrow \phi\ \mu\mu$	6%
$B^+ \rightarrow K^{+*}\mu\mu$	5.2%
$B^+ \rightarrow K^+\mu\mu$	3.%
$\Lambda_b \rightarrow \Lambda\mu\mu$	6%


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



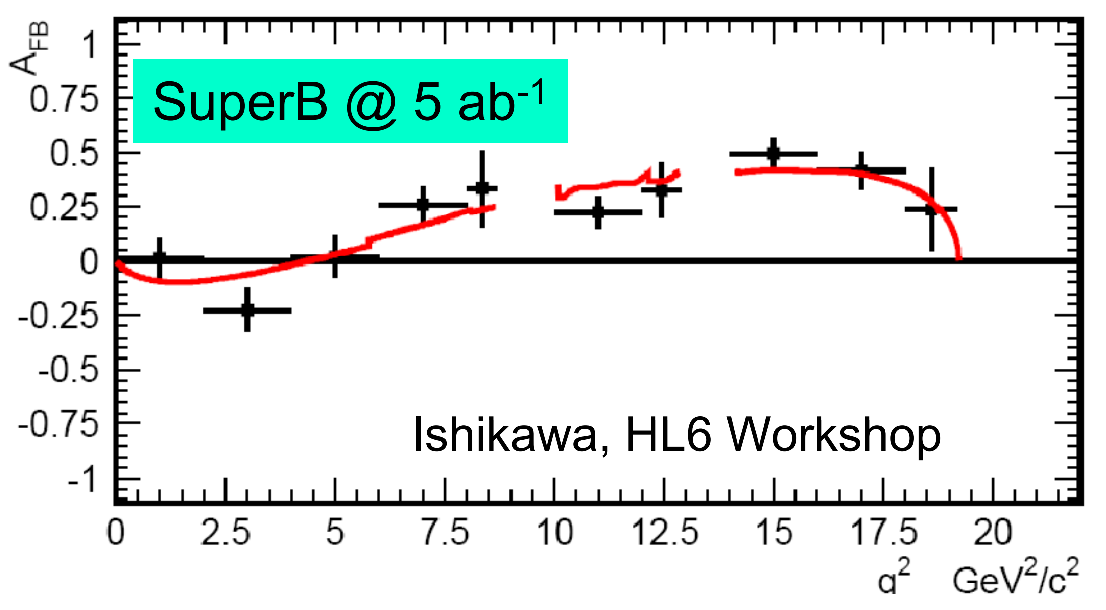

$\Lambda_b \rightarrow \Lambda\mu\mu$

B →K**ll* : Super KEKB

Belle has extracted
Wilson coefficients C9 and C10 directly from the data
by fitting global distribution of

$$d^2\Gamma/d\cos\theta_\ell dq^2$$

$$\begin{aligned} A_9/A_7 &= -15.3^{+3.4}_{-4.8} \pm 1.1 \\ A_{10}/A_7 &= 10.3^{+5.2}_{-3.5} \pm 1.8, \end{aligned}$$



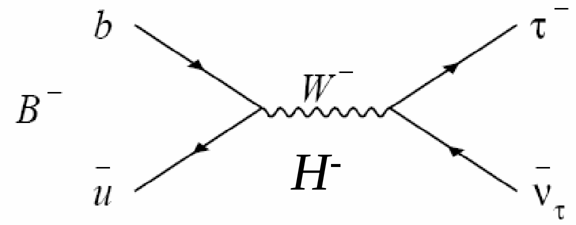
$\int \mathcal{L}$ (ab^{-1})	1	5	10	50
$K^*\ell\ell\ A_{FB}$				
1-6 GeV$^2/c^4$	18	8.2	5.8	2.6
$>$ 10 GeV$^2/c^4$	11	4.7	3.3	1.5
All	7.9	3.5	2.5	1.1

$\int \mathcal{L}$ (ab^{-1})	1	5	10	50
A_9	25	11	7.8	3.5
A_{10}	29	13	9.2	4.1

Extrapolating to SuperB, A9/A7 (equivalent to AFB zero) and A10/A7 can be measured with stat. error of 4%

B+ $\rightarrow \tau^+\nu$

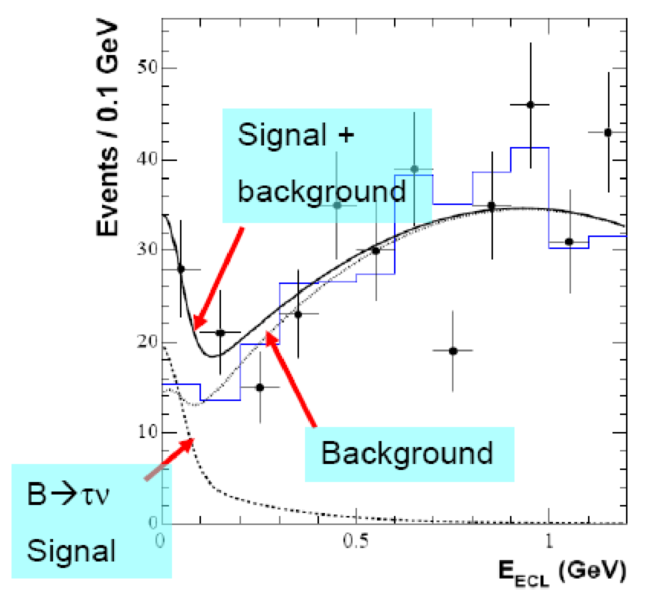
$B_{SM} = 1.59 \mp 0.40 \times 10^{-4}$



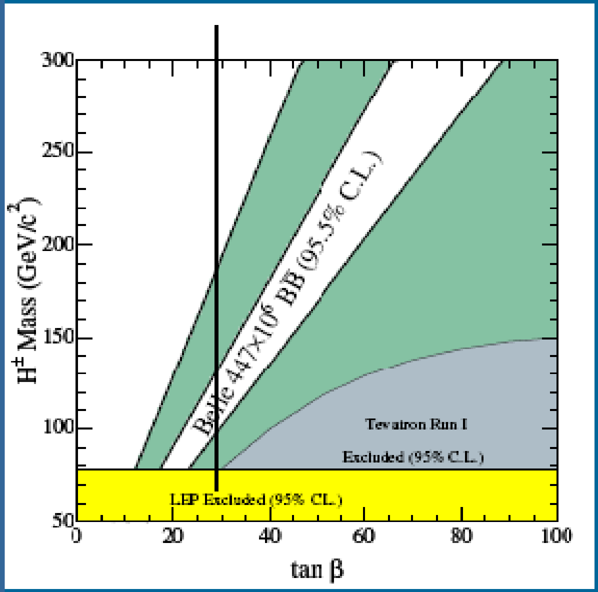
$B_{NP}/B_{SM} \sim \tan^4\beta$

Belle result excludes (at tan β = 30) M(H+) < 100 and 130 < M(H+) < 190 GeV

First evidence: 3.5 σ



Belle PRL 97 (2006) 251802



$BF(B \rightarrow \tau\nu) = 1.79\ (+0.56 - 0.49) \times 10^{-4}$

Consistent with SM

No clear signal in Babar hep-ex/0608019

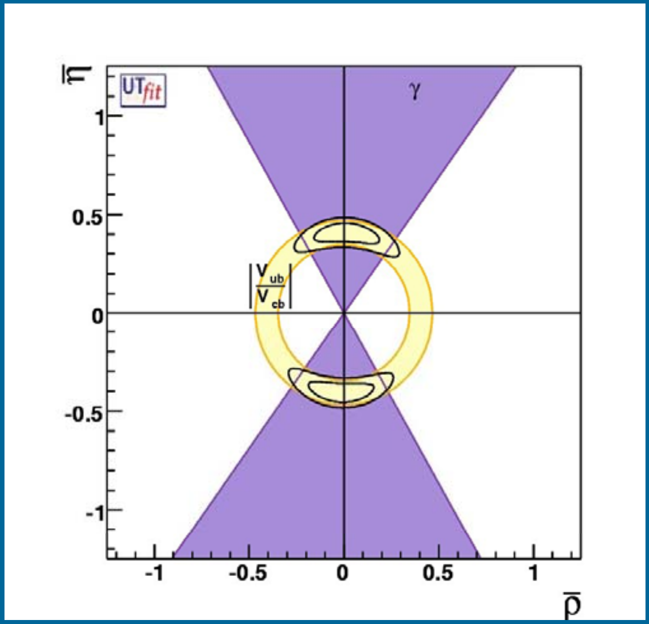
LHCb precision on γ and impact on CKM Fit

- Precise measurement of γ missing in UT evaluation so far
- Combined LHCb sensitivity to γ with :
  - $B_s \rightarrow D_s^{-(+)}K^{+(-)}$
  - $B^- \rightarrow DK^-$ and $B^+ \rightarrow DK^+$
  - $B^0 \rightarrow D^0K^{*0}$

O.Schneider, Euroflavour07

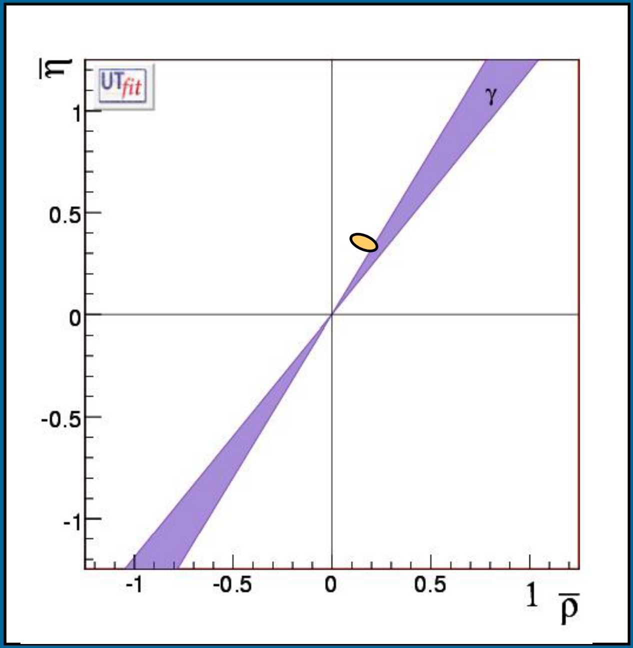
$\sigma(\gamma)$ ~5° with 2 fb^{-1}, ~2.5° with 10 fb^{-1}

Current situation



M.Pierini, CERN seminar 20.3.2008

γ from B→DK at LHCb after 10 fb–1



New projects & upgrades 2014 and further

New projects and upgrades - motivation

- 2008-2014 LHCb (ATLAS,CMS): unambigously confirm or reject NP in HF sector and start to map HF NP.
- So why new projects/upgrades beyond this point? (Super KEKB, SuperB, upgrades of LHCb, ATLAS, CMS)
- Testing flavor structure of SM has taken many years, testing flavor structure in NP – will not be simple task.

- If by 2013 LHCb (ATLAS, CMS) find NP signals in B-sector ($B^0 \to \mu\mu$, $B_s \to \phi\phi$, $B_s \to J\psi/\phi$) or UT inconsistencies at <5° – there will be many further NP effects in flavour to be measured.

- If high p_T searches in ATLAS, CMS find NP, however no big signatures in flavour sector (e.g. Minimal Flavour Violation might give same size CPV as SM and possibly small deviations in $B^0 \to \mu\mu$, and $b \to (d,s)$ penquin– then
  - Need CPV test to high precision and improve $B^0 \to \mu\mu$, and $b \to (d,s)$ penquin

- In both scenarios the LHC upgrade and the SuperB factories – would provide complementary, detailed and very precise measurements allowing to understand NP of HF.

LHCb upgrade: LHCb beyond 10 fb^{-1}

- ➢Aim: increase luminosity by 10: 5 years at $2\times10^{33}\ cm^{-2}s^{-1} = 100\ fb^{-1}$
- ➢Physics goals: several measurements expected to remain statistically limited after 10 fb–1:

- CPV in B_s mixing, in particular in b → sss penguins
  - aim for 0.01 (0.002) precision on $B_s \to \phi\phi$ ($B_s \to J\psi/\phi$) CP asymmetry
- γ with theoretically clean methods, e.g. $B_s \to D_sK$, $B \to D(K_S\pi\pi)K$, $B \to D(hh)K$
  - aim for < 1° precision on angle γ [+ count on improvements in LQCD]

- ($b\to sl^+l^-$)
  - more detailed and precise analysis of exclusive modes, e.g. $A_T^{(2)}$ in $B^0 \to K^*\mu\mu$
- Hunt for more rare and difficult modes:
  - $B^0 \to \mu\mu$, exclusive $b \to d\gamma$, …

Extracted from: G. Wilkinson@BNM08 Jan 2008, and O.Schnieder,@EuroFlavour07.

LHCb upgrade timescale

- LHCb has set up an upgrade WG in early 2007:
  - Examine physics case and required detector R&D
    - 1st LHCb upgrade workshop in Jan 2007
  - Ramp up R&D, feasibility studies, …

- Possible timescale:
  - Decision after having seen some significant results from first phase of LHC
  - Start data-taking with upgraded detector ~4 years later
  - Accumulate 100 fb^{-1} by ~2020

- Note:
  - LHCb upgrade independent of LHC machine luminosity upgrade (SLHC)
    - SLHC not needed for LHCb upgrade & LHCb upgrade compatible with SLHC

Extracted from: G. Wilkinson@BNM08 Jan 2008, and O.Schnieder,@EuroFlavour07.

B → μμ with possible scenario of ATLAS upgraded detector

➲The aim is to benefit from @10^{35} while preserving the physics performance
➲Inner detector performance for $B_s \rightarrow \mu\mu$
➲with scenario B-layer 3.7 cm X0=2.6% vertex resolution remains same

		Bs vertex resol. $\sigma\ R_{xy}(\mu m)$	Mass resol. $\sigma\ M\ (MeV)$
ATLAS Detector now B-layer 5 cm	$\lvert\eta\rvert<2.5$	***26.0***	***89***
Upgrade – possible scenario B-layer 3.7 cm X0=2.6%	$\lvert\eta\rvert=0$ $\lvert\eta\rvert=1.5$	***20.5*** ***24.0***	***63*** ***92***

**** from V.Kostiuchin @Tracker Upgrade workshop, Dec.2007.***

➲Critical point @10^{35} output rate of the First level trigger should be kept low enough to allow HLT processing. Possible strategies: to reduce rate while reducing background more strongly than signal:

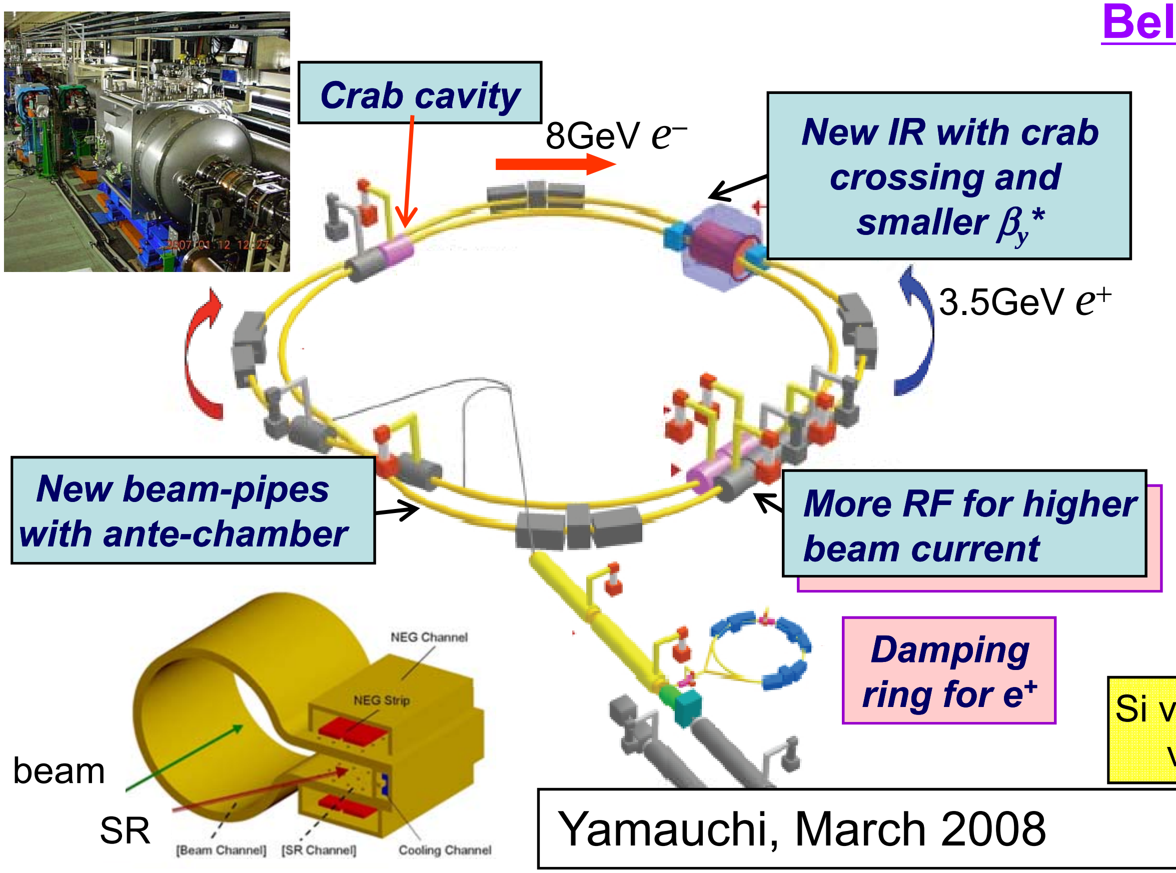
- ➲Increase di-muon trigger thresholds μ6μ6 → μ15μ15
- ➲ three muon signatures at First level trigger μ6μ6μ6

➲Most important ATLAS upgrade milestones: 2010 TDR, MoU 2011, 2014 LHC stop data, upgrade Install 2015

KEKB Upgrade Plan : Super-B Factory at KEK

- ***Asymmetric energy e^+e^- collider at E_{CM}=m(Υ(4S)) to be realized by upgrading the existing KEKB collider.***
- ***Initial target:*** ***10× higher luminosity*** ≅ **2×10^{35}/cm²/sec** **after 3 year shutdown**

  → **2×10^{9} $B\bar{B}$ *and* $\tau^+\tau^-$ *per yr.***
- ***Final goal:*** **$L=8\times10^{35}$/cm²/sec *and* $\int L\, dt = 50\ ab^{-1}$**



Crab cavity

8GeV e^-

New IR with crab crossing and smaller β_y*

3.5GeV e^+

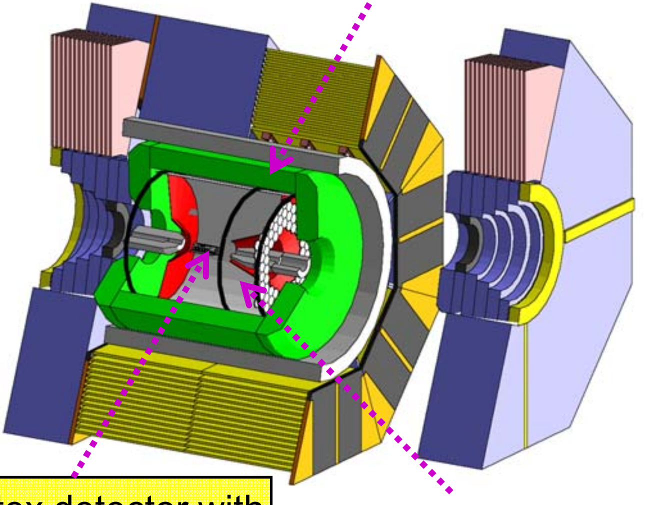
New beam-pipes with ante-chamber

More RF for higher beam current

Damping ring for e⁺

Yamauchi, March 2008

Belle with improved rate immunity

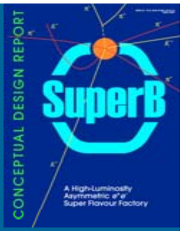


Faster calorimeter with wave form sampling and pure CsI

Si vertex detector with very short strips

Background tolerant small cell drift chamber

The SuperB Experiment

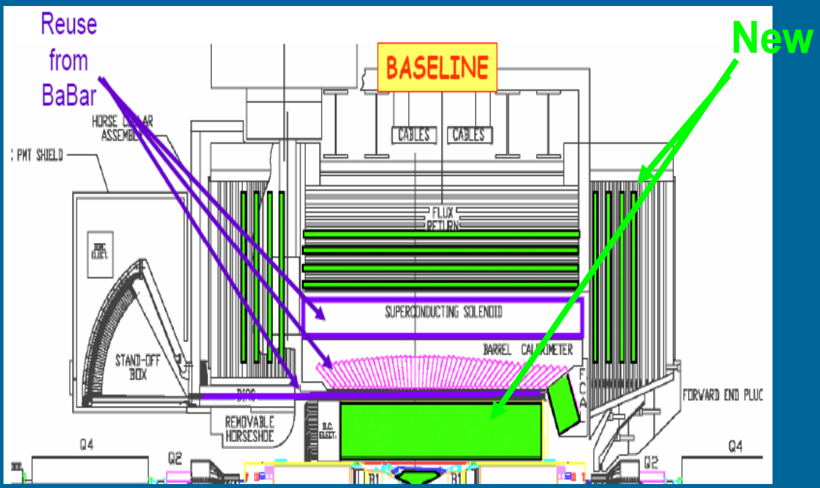


- *Aim:* To constrain new physics through virtual effects in the LHC era.
- 75ab^{-1} in 5 years of operation at the $\Upsilon(4S)$, i.e. ~75 Billion B, D and τ leptons.
  - Also run at different $\sqrt{s}$, and with polarised beams.

- Reuse parts of BaBar/PEP-II without compromising performance (reduces overall cost). Baseline detector design similar to BaBar
- Proposed site at Tor Vergata, University of Rome campus in Frascati.

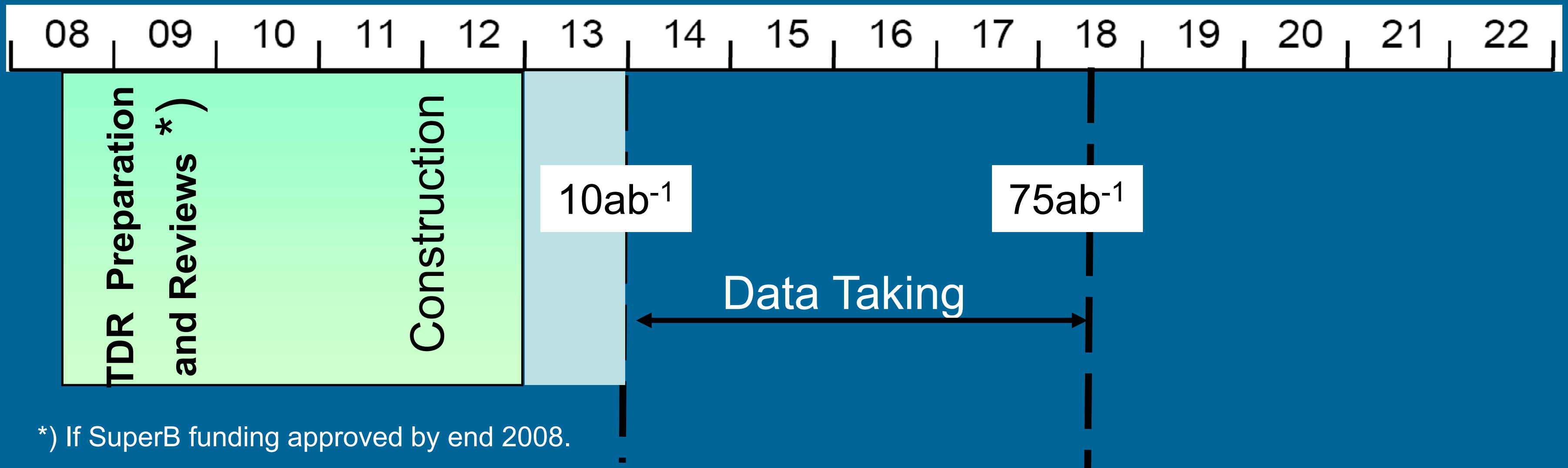
- Interest from HEP community
  - Australia, Canada, France, Germany, Israel, Italy, Norway, Russia, Slovenia, Spain, Switzerland, Taiwan, UK, USA.
  - Signatories from 13 UK institutes.

- Conceptual Design Report under review by INFN.



SuperB CDR: arXiv:0709.045
http://www.pi.infn.it/SuperB/

SuperB and KEKB upgrade Timelines



TDR Preparation and Reviews *)

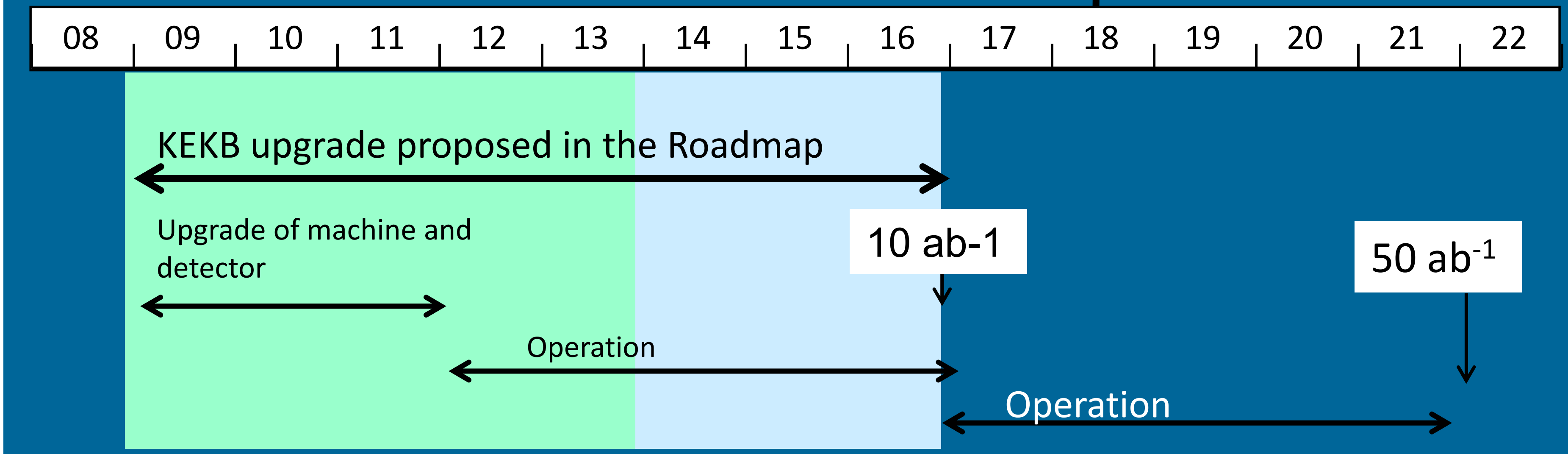
Construction

$10ab^{-1}$

$75ab^{-1}$

Data Taking

*) If SuperB funding approved by end 2008.



KEKB upgrade proposed in the Roadmap

Upgrade of machine and detector

10 ab-1

$50 ab^{-1}$

Operation

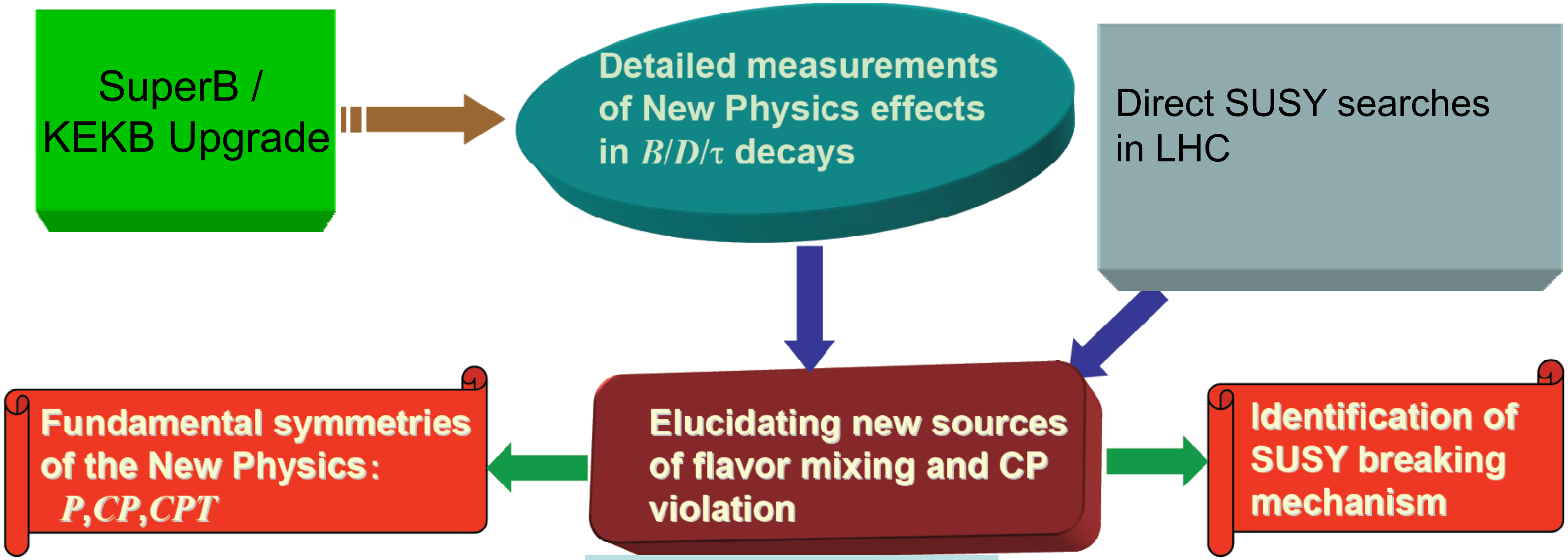
Operation

Summary, perspectives

- Current Heavy Flavours (HF) lead by B-factories, Tevatron after Run-II very fast turn around – complementary to B-factories.
- Precisions dominated by tree level decays, consistent with SM
  - Current NP searches in FCNC b-d(s) and in CPV of Bs mixing – some interesting constraints, however NP evidence need future experiments.
- 2008 LHC takes over –
  - in 5 months LHCb stands where Tevatron now; ATLAS, CMS contribute to HF since 10^{33}
- By 2013-14 inambigously confirm or reject NP in HF sector and start to map.
  - LHC - synergy between high pT direct SUSY and HF searches
- Once NP found need detailed map NP in Flavor sector:
  - SuperB, KekB 2016 and upgraded LHCb (ATLAS/CMS) - 2016

BACKUPS

Physics programme of KEKB upgrade and SuperB



SuperB / KEKB Upgrade

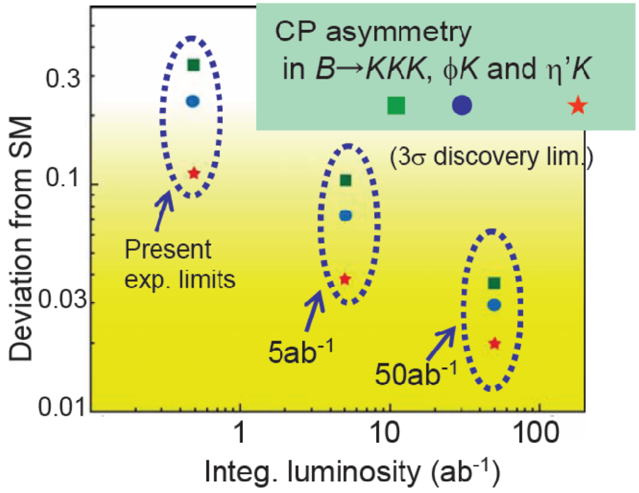
Detailed measurements of New Physics effects in $B/D/\tau$ decays

Direct SUSY searches in LHC

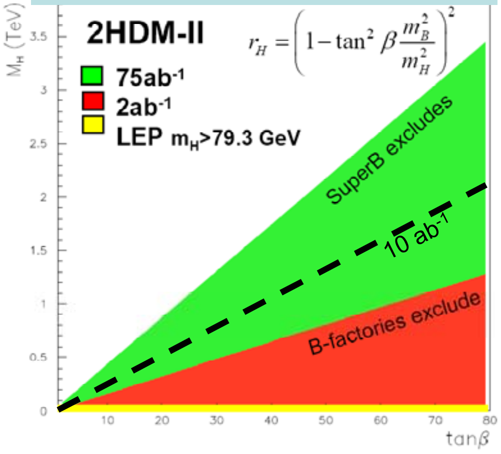
Elucidating new sources of flavor mixing and CP violation

Fundamental symmetries of the New Physics: *P,CP,CPT*

Identification of SUSY breaking mechanism



Search for $H^\pm$ in $B^+\to l^+\nu$



Y.Okada *et al.*

SUSY Model \ Obs.	Unitarity triangle	$B\to\phi K_S$	*Time dep. CPV in* $b\to s\gamma$	*Direct CPV in* $b\to s\gamma$	$\tau\to\mu\ \gamma$
mSUGRA	–	–	–	–	–
SU(5) SUSY GUT + ν_R (degenerate)	–	–	+	–	–
SU(5) SUSY GUT + ν_R (non-degen.)	+	+	+ +	–	+ +
U(2) Flavor symmetry	+	+	+ +	+	/

+ +: large +: sizable –: small

Selected topics on charm physics

"Charm" Data Samples

- Reach of Current experiments
  - CLEO-c
    - 0.75 fb^{-1} @3.77 GeV - 2.7×10^6 D^0D^0 pairs & 2.1×10^6 D+D-
    - 0.75 fb^{-1} @4.17 GeV - 7×10^5 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$
  - BABAR, Belle (combined 2 ab^{-1}) - 10^{10} charm mesons
  - CDF, D0 (combined 16 fb^{-1})
- Reach of approved experiments
  - BESIII
    - 20 fb^{-1} @3.77 GeV - 72×10^6 D^0D^0 pairs & 56×10^6 D+D-
    - 12 fb^{-1} @4.17 GeV - 11×10^6 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$
  - LHCb (10 fb^{-1})
  - PANDA
- Reach of proposed experiments
  - LHCb upgrade(100 fb^{-1}),
  - Super B-factory (50 ab^{-1} @10 GeV) - 2.5×10^{11} charm mesons
    - 150 fb^{-1} @3.77 GeV - 5.4×10^8 D^0D^0 pairs & 4.2×10^8 D+D-
    - 200 fb^{-1} @4.17 GeV - 1.9×10^8 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$

“Evidence” for D Mixing: Only 2 results > 3σ

- Babar (384 fb^{-1}) $D^0 \to K\pi$
  - c.w. Belle (400 fb^{-1})

    $x'^2 = (0.18^{+0.21}_{-0.23}) \times 10^{-3} \quad y' = (0.6^{+4.0}_{-3.9}) \times 10^{-3}$

$$x'^2 = (-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$$
$$y' = (9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$$

- Belle (540 fb^{-1}) $D^0 \to KK,\pi\pi$
  - c.w. W.A. (includes Belle '03)

    $y_{CP} = (0.90 \pm 0.42)\%$

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

- Belle (540 fb^{-1}) $D^0 \to K_S\pi\pi$
  - c.w. CLEO (9 fb-1)

$x = (1.8 \pm 3.4 \pm 0.6)\% \quad y = (-1.4 \pm 2.5 \pm 0.9)\%$

$$x = (0.80 \pm 0.29 \pm 0.17)\%$$
$$y = (0.33 \pm 0.24 \pm 0.15)\%$$

- CLEO-c (281 pb^{-1}) - new results expected soon
  - y, x^2 and cosδ

Before Moriond '07

NO MIXING (x,y)=(0,0) excluded:
- ✓ ~2.1 σ Belle $D^0 \to K\pi$ (no CPV)
- ✓ ~2.3 σ BaBar $D^0 \to K2\pi/K3\pi$
- ✓ ~2.2 σ Average y_{CP}

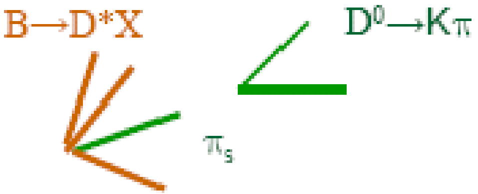
After Moriond '07

NO MIXING (x,y)=(0,0) excluded:
- ✓ 3.9 σ BABAR $D^0 \to K\pi$ (no CPV)
- ✓ ~2.4 σ Belle $D^0 \to K_S\pi\pi$
- ✓ ~3.5 σ New Average $y_{CP}=1.12 \pm 0.32$

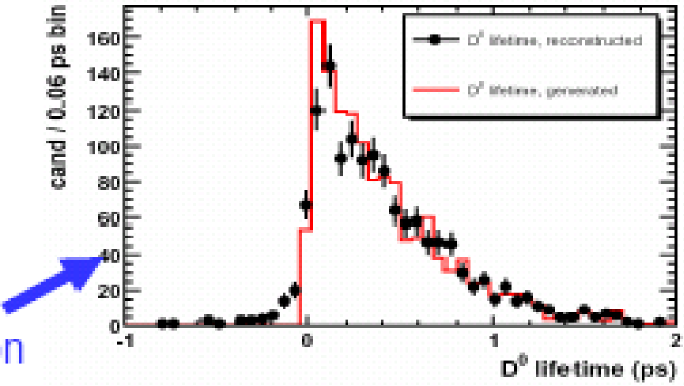
Charm physics – at LHCb

Charm physics is now firmly part of baseline LHCb physics (LHCb-2007-049).

Recently demonstrated potential to perform world-best measurements using charm from D* produced in B decays found in HLT trigger stream.



Partially reconstruct B decay vertex to find birth position of D^0 - gives good proper time resolution



Studies in benchmark analyses – x'^2 and y' from WS $K\pi$; y_{CP} from KK – show great promise: $\sigma_{x'^2} \sim 6 \times 10^{-5}$, $\sigma_{y'} \sim 9 \times 10^{-4}$, $\sigma_{y_{CP}} \sim 5 \times 10^{-4}$

Prompt charm will enhance statistics – but L0 trigger suppresses yield

CPV – the holy grail of charm physics

Charm CPV (in mixing, decay or mix-decay interference) is expected to be tiny in the SM, but can certainly be enhanced by NP. Particularly interesting case: SCS decays, where effects of SM and NP will be largest.

LHCb has statistics to have world best sensitivity in charm CPV; upgrade can push limits much further

eg. upgrade yield in $B \to D^*X$, $D^0 \to KK$ ~2.10^8 (cf. BaBar 130k in 390 fb^{-1})

upgraded trigger will greatly improve yield from primary charm!

Statistics to push sensitivity down to $< 10^{-4}$ – enough to see SM CPV ?

Wealth of other channels will permit systematics to be isolated, and any observed CPV to be characterised.

- $D^0 \to K\pi$, $K\pi\pi\pi$
- Partial width CPV in $D^0 \to KK$, $\pi\pi$
- $D^0 \to KK\pi\pi$ (T-odd moments + Dalitz analysis CPV search)

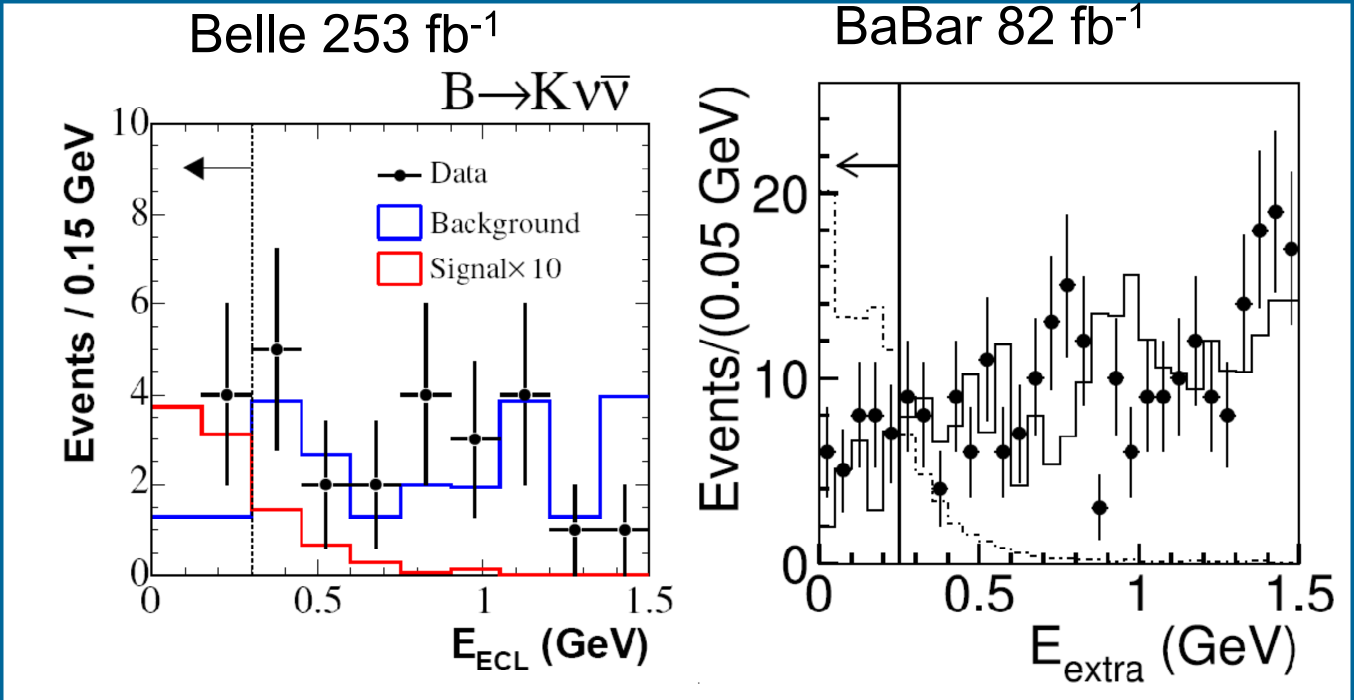
- CPV in $D^+ \to K\pi\pi$ Dalitz
- $D^0 \to K_s\pi\pi$
- Plus rare decays, eg. $D^{(0)}_{(s)} \to l^+l^-$ $[(X_{u,s})]$

B →K(*) $\nu\,\nu$

- Theoretically cleaner mode than K* *ll*

<u>Tag side reco of:</u>
hadronic B decay
(Belle, ε = 0.15%)
or D* *l* ν decay
(BaBar, ε = 0.5%)

& signal side K^+
& no other tracks
& small extra ECAL energy
(ε = 40%)



$$\mathcal{B}(B^- \to K^-\nu\bar{\nu}) < 3.6 \times 10^{-5}$$ (10 X SM)

Belle preliminary hep-ex/0507034

$$\mathcal{B}(B^0 \to K^{*0}\nu\,\bar{\nu}) < 3.4 \times 10^{-4}$$ (20 X SM)

Belle preliminary hep-ex/0608047

For Super B factory, 3σ Kνν SM signal @ 12 ab^{-1}, 5σ @ 33ab^{-1}, 18 % measurement @ 50 ab^{-1}, with hadronic tag alone