Flavour Physics at LHC version 2.0

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Since the last Ringberg (2006)

Many interesting theoretical ideas being presented…

Since the last Ringberg (2006) -what happened with experiments?

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☹☹☹☹LHC is still not yet running

No really significant result before the end of 2010.

Start beam injection, circulation and first collisions at the injection energy $\sqrt{s}$ = 900 GeV: September to October 2009

Then, increasing the energy to $\sqrt{s}$ = 10 TeV,

increasing the number of bunches

Physics run at $\sqrt{s}$ = 10 TeV to collect 200~300 pb^{-1}

(first 100 days 50 pb^{-1}, the next 100 days 200 pb^{-1})

for ATLAS, CMS and LHCb by ~October 2010

LHCb hopes..

~1 fb^{-1} in 2011, then >2f b^{-1}/year, 10 fb^{-1} by ~2015

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☹☹KEKB will stop by the end of 2009

No further increase of $\Upsilon(4S)$ data since summer 2008, i.e. not reaching 1 ab^{-1}

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☹No decision on the real funding of any of the SuperB projects yet

B-factory statistics

- BBABR 433 fb^{-1} $\Upsilon(4S)$ = ~500 M BB
- Belle: 720 fb^{-1} $\Upsilon(4S)$ = ~800 M BB

Final statistics for $\Upsilon(4S)$

53 fb^{-1} $\Upsilon(5S)$ = >5M B_s's

$\Upsilon(5S)$ statistics will be still doubled

(BABAR 3 fb^{-1} above 4S)

But also some good news…

☺Some R&D funding for the SuperB studies

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INFN: regional funding for Technical Design Report over a period of ~2 years

KEK: R&D money for 2009

Baseline scheme is still high-current. But recently a change of its priority to the study of low-emittance option a la INFN concept.

A half solution (LER low + HER normal) made and further study on going.

Decision on the scheme in September. Plan is to start upgrade from April 2010. Waiting for the approval of the ministry.

But also some good news…

☺Some R&D funding for the SuperB studies

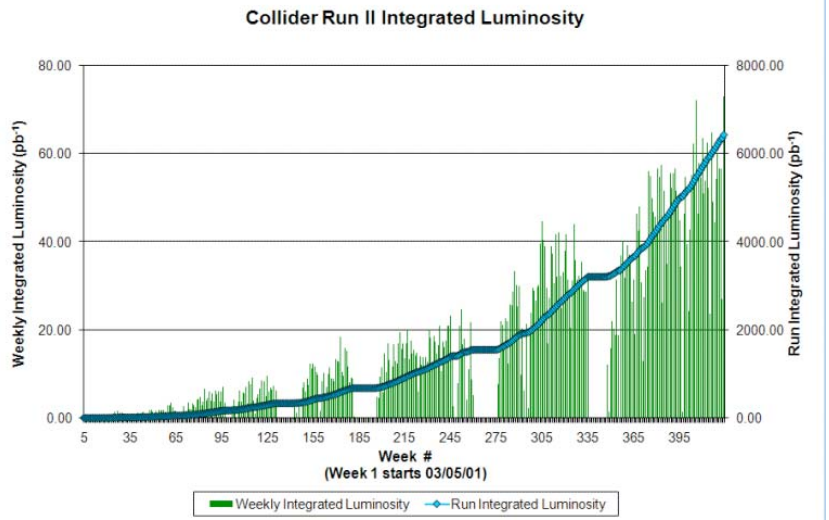
☺☺Tevatron running well…

End of 2008, Run-II statistics

CDF = 4.2 fb^{-1} D0 = 4.4 fb^{-1}

(1.5 fb^{-1} in 2008) (1.6 fb^{-1} in 2008)

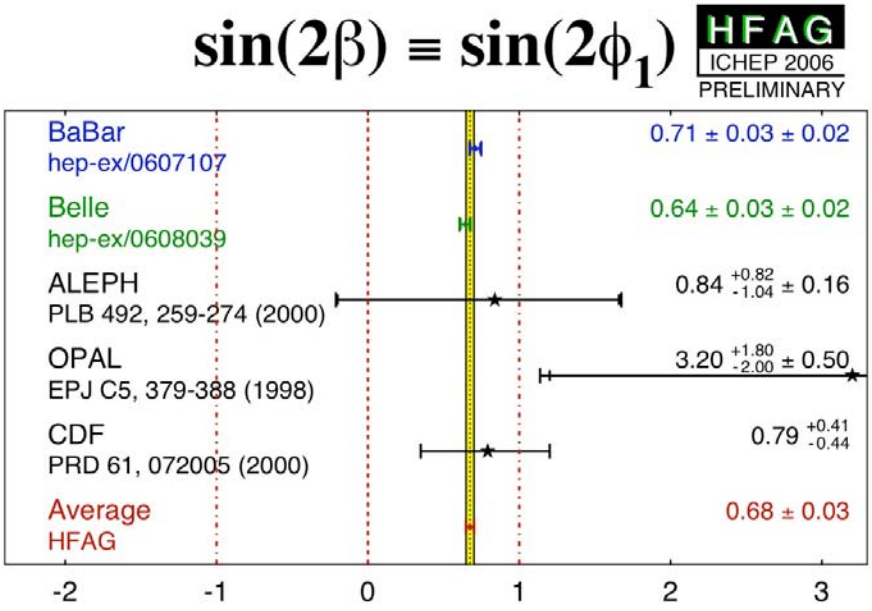
Running in 2009 and 2010 total ~9 fb^{-1}/experiment



In the physics front…

- $2\beta^{d}_{(c\bar{c})(s\bar{d})_{CP}}$

  in 2006



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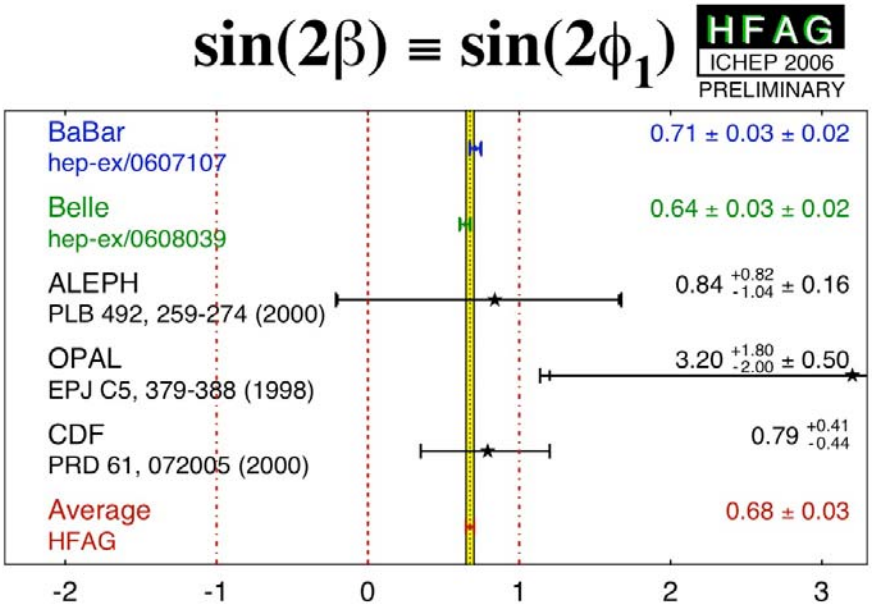
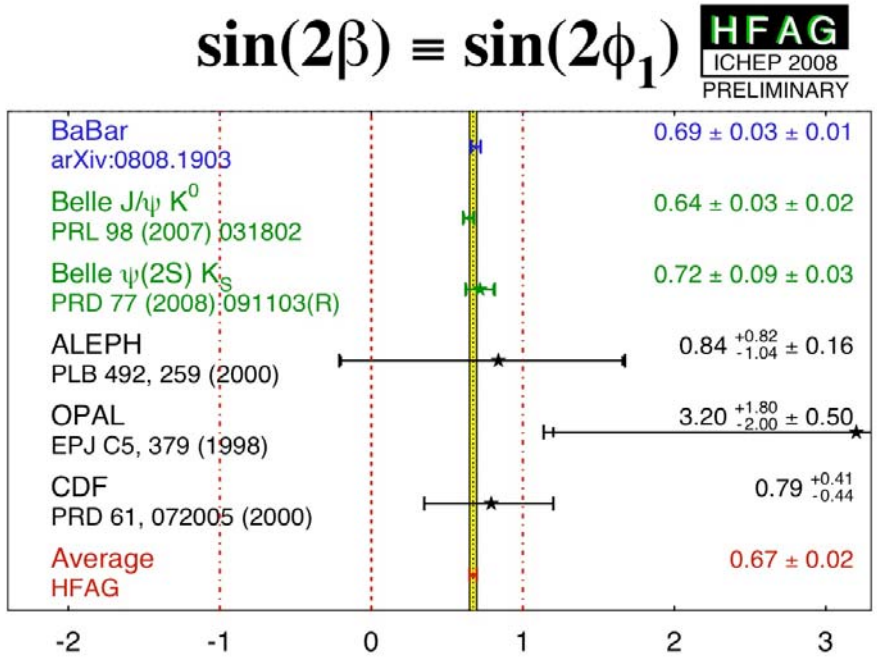
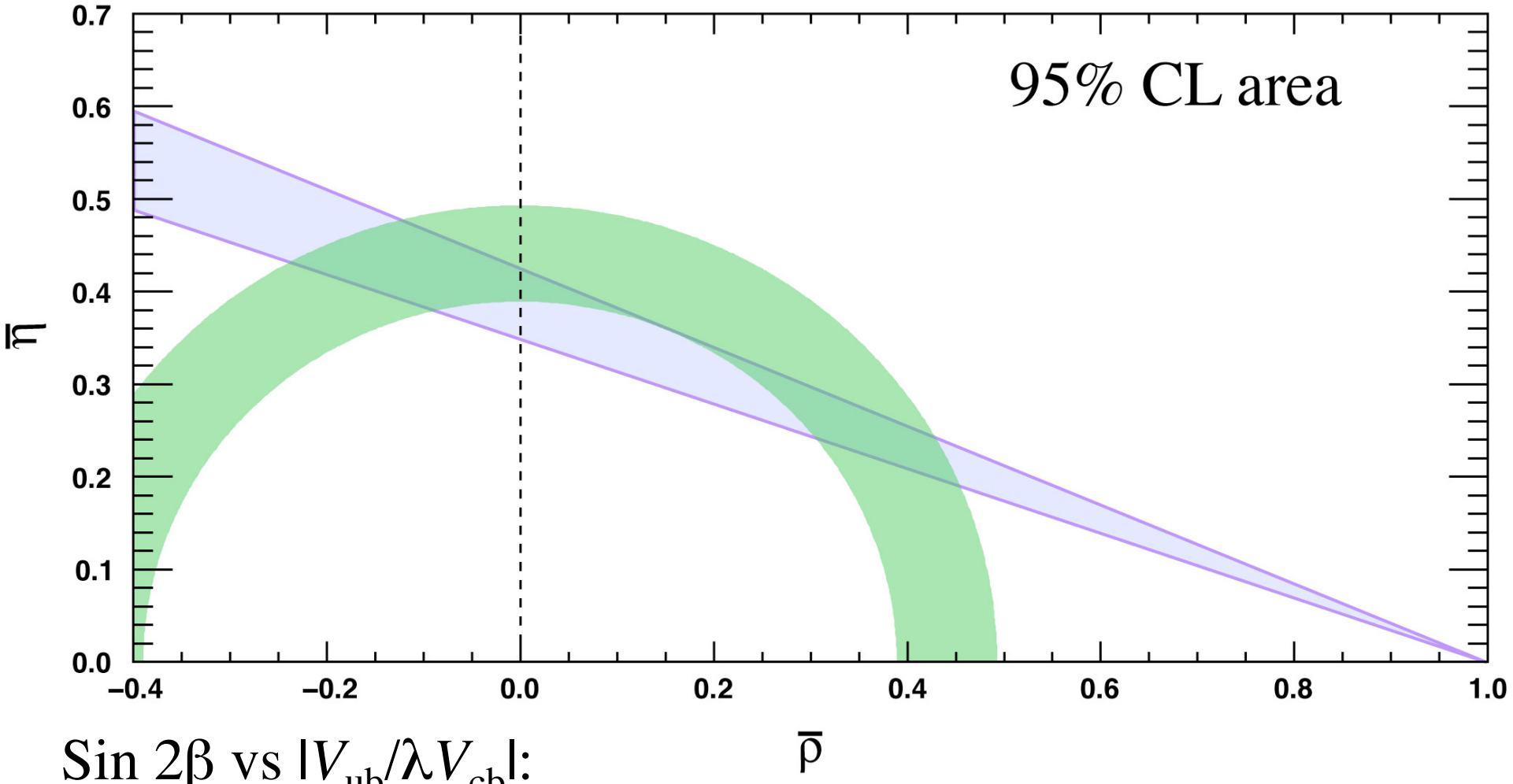


In 2009
BABAR: full statistics
Belle: ~60% statistics



0.67 ± 0.2

Famous “tension”



Sin 2β vs $|V_{ub}/\lambda V_{cb}|$:

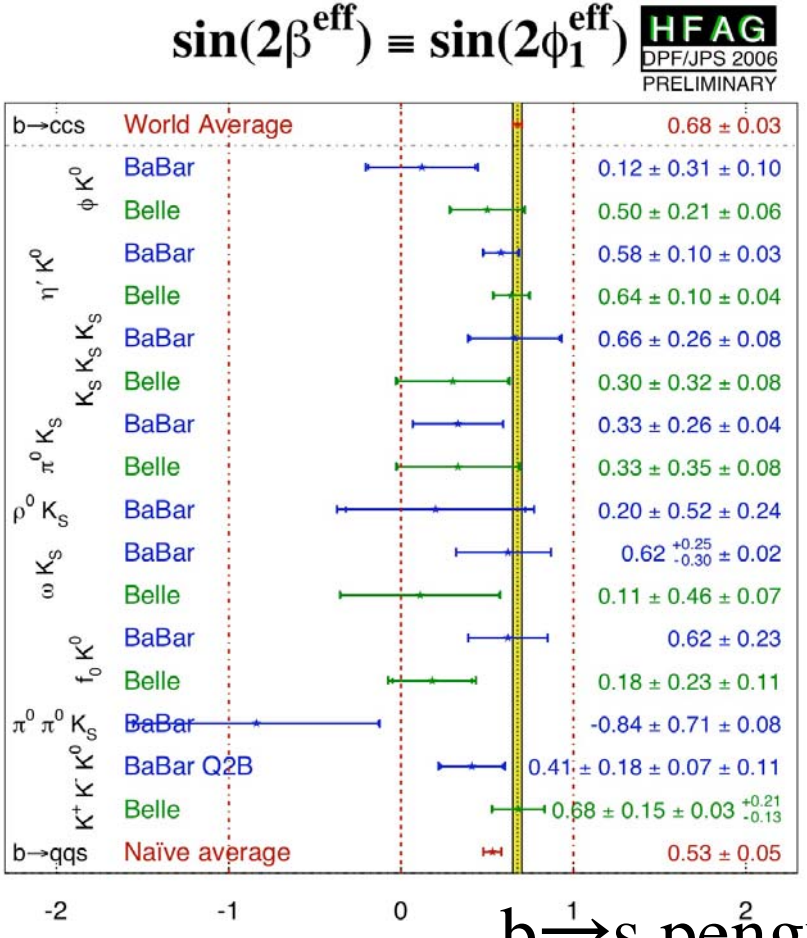
No real improvement from the experiments in near future

Hope for theory for a better V_{ub}, e.g. down to 5% less error?

$2\beta^{d}_{(c\bar{c})(s\bar{d})_{CP}}$ vs $2\beta^{d}_{(s\bar{s})(s\bar{d})_{CP}}$

- i.e. tree phase vs penguin phase

in 2006



b→s penguin phase ≠ standard model phase?

$2\beta^{d}_{(c\bar{c})(s\bar{d})_{CP}}$ vs $2\beta^{d}_{(s\bar{s})(s\bar{d})_{CP}}$

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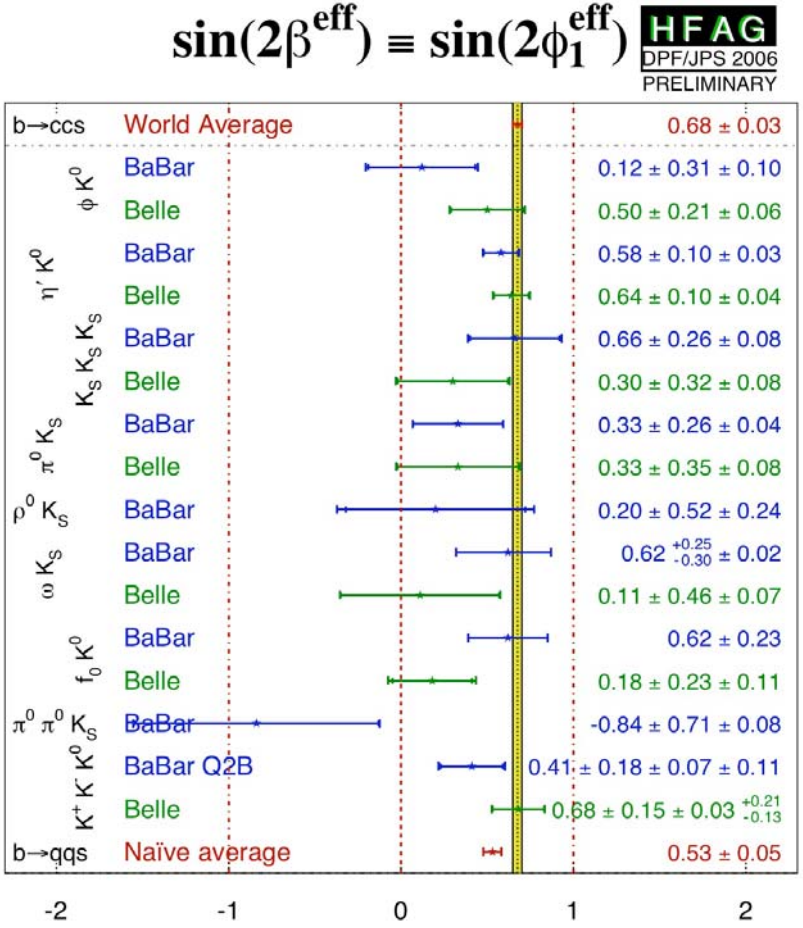

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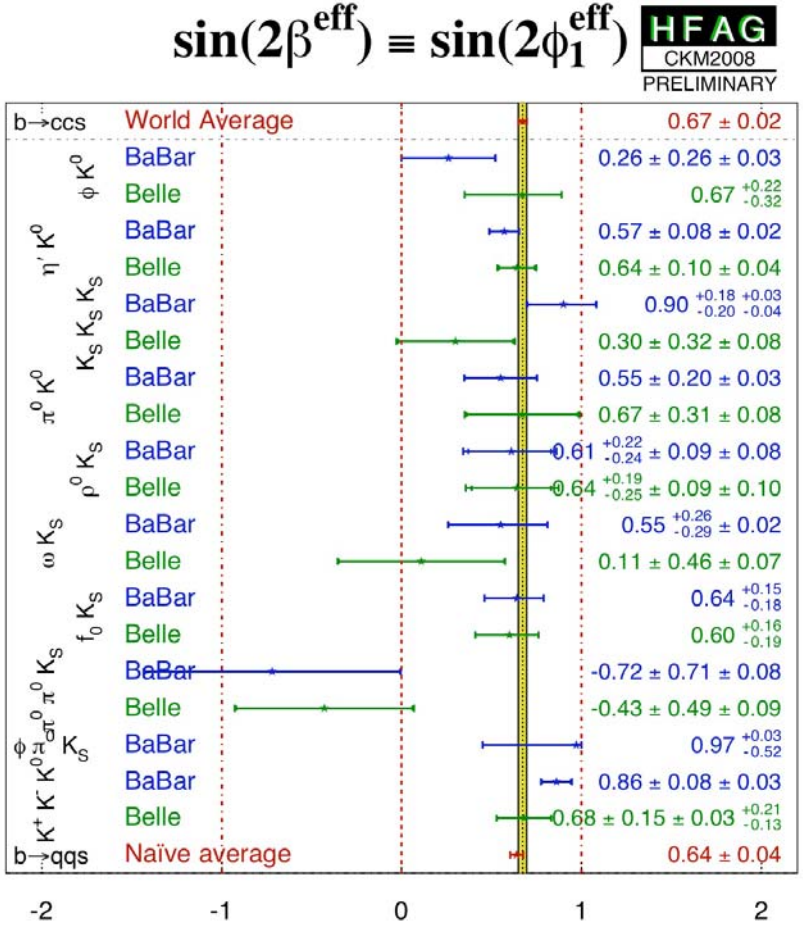

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In 2009
BABAR: full statistics
Belle: ~70% statistics

Statistically, I do not see the two being different…

$\phi K_S = 0.44^{+0.17}_{-0.18}$

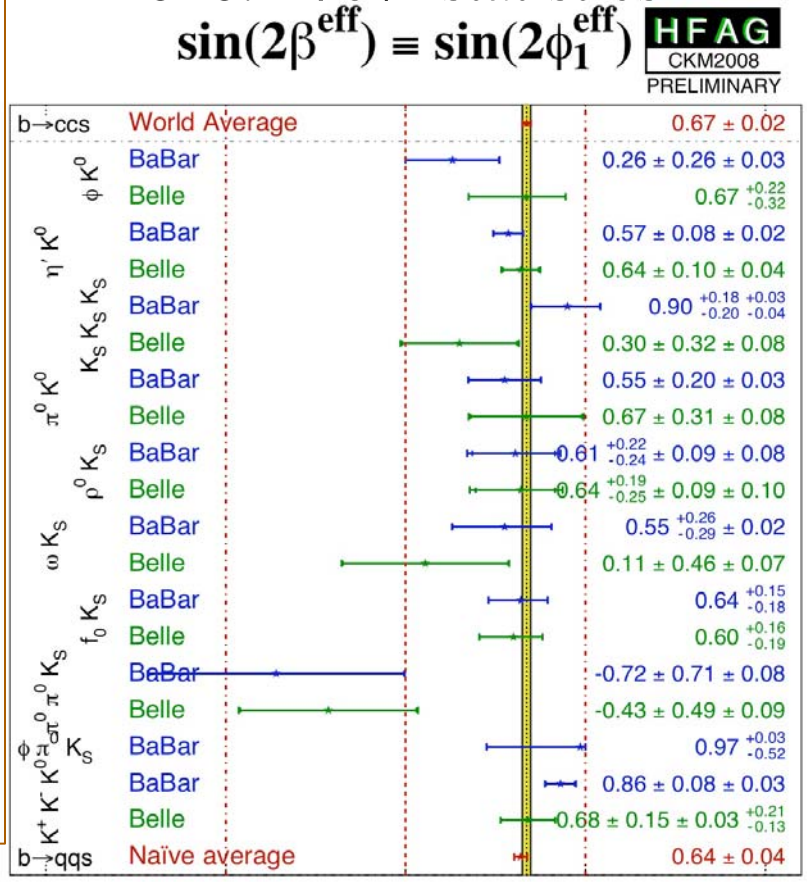
$\eta' K_S = 0.59 \pm 0.07$

Average: 0.57 ± 0.07

$J/\psi K_S = 0.67 \pm 0.02$

This is only 1.37σ effect…

Even with B factories full statistics we need 0.3 difference for 5σ discovery



b→s penguin phase = standard model phase

An alternative channel

- LHCb $B_s \to \phi\phi$
  (LHCb is not too good at $B_d \to \phi K_S$)

Yield (2 fb^{-1}): 3100 events, B/S <0.8

With 10 fb^{-1} data: $\sigma(S_{B_s \to \phi\phi}) = 0.05$

cf.

$\sigma(S_{B_d \to \phi K_S}) = 0.17$

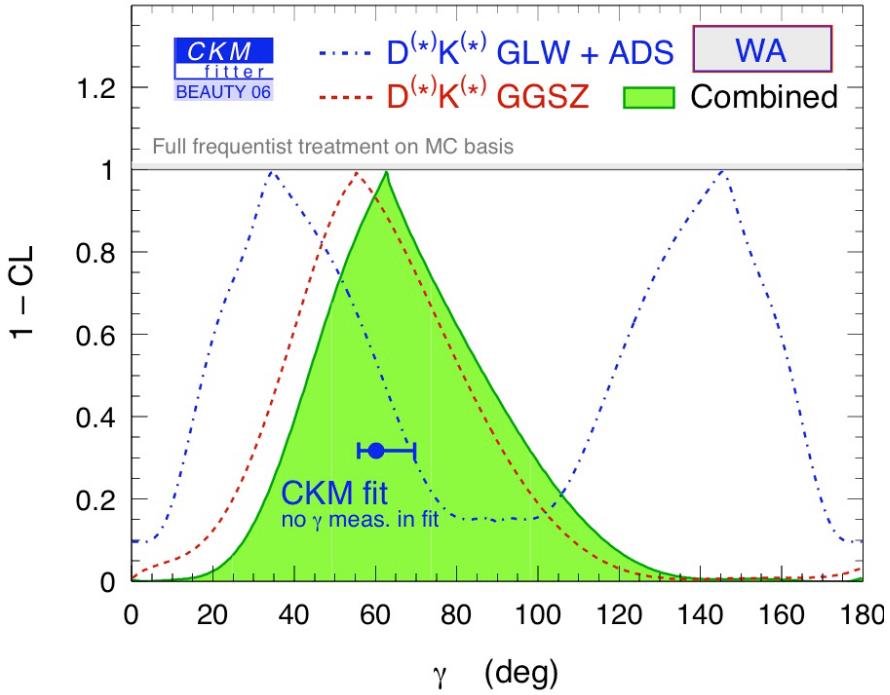
$\sigma(S_{B_d \to \eta' K_S}) = 0.06$

with B factory full statistics

γ measurement

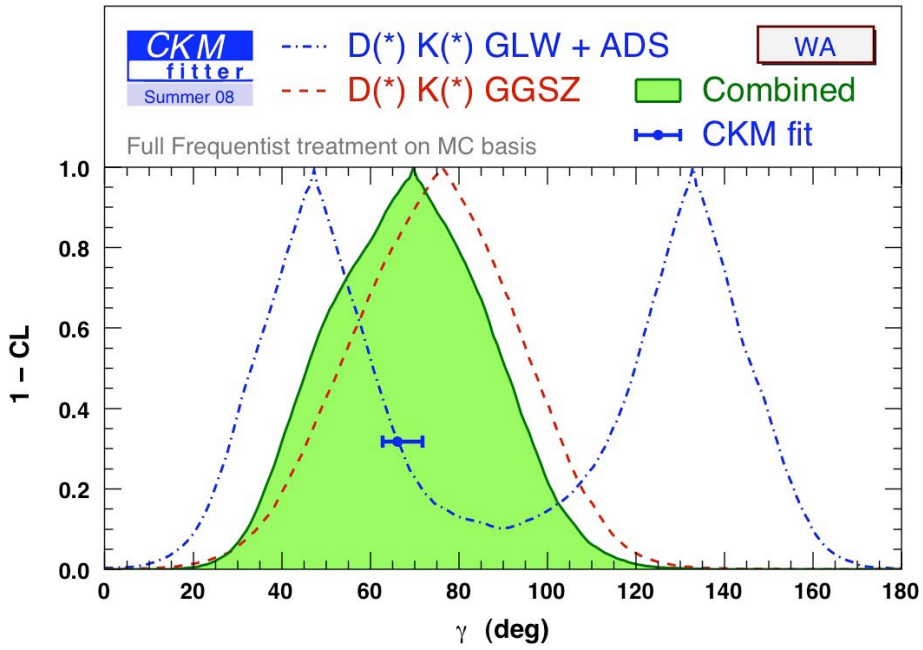
- γ measurements direct vs fit

in 2006



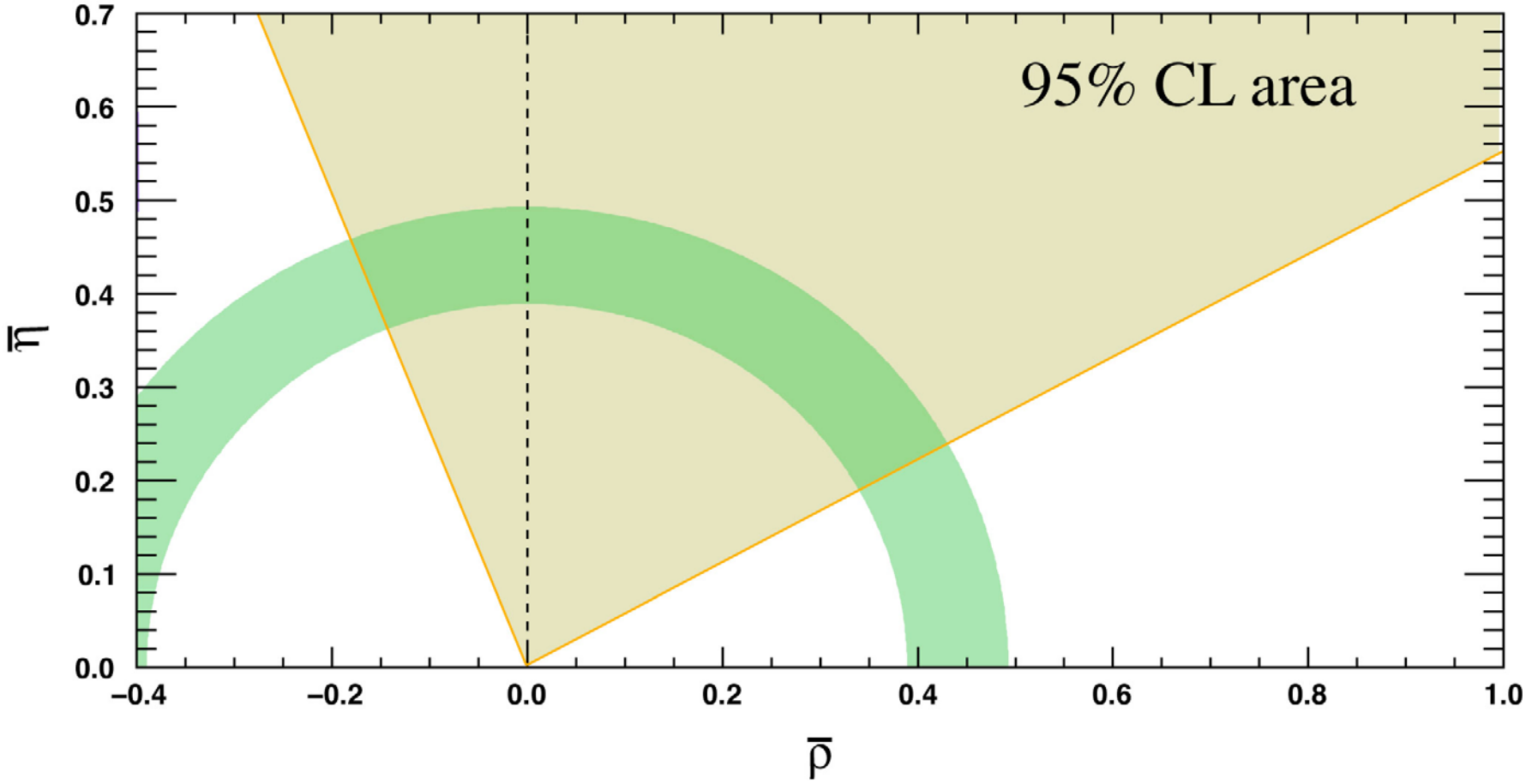
$(62^{+38}_{-24})°$

In 2009 BABAR Belle
50%~80% statistics



$(70^{+27}_{-29})°$

where improvements are needed…



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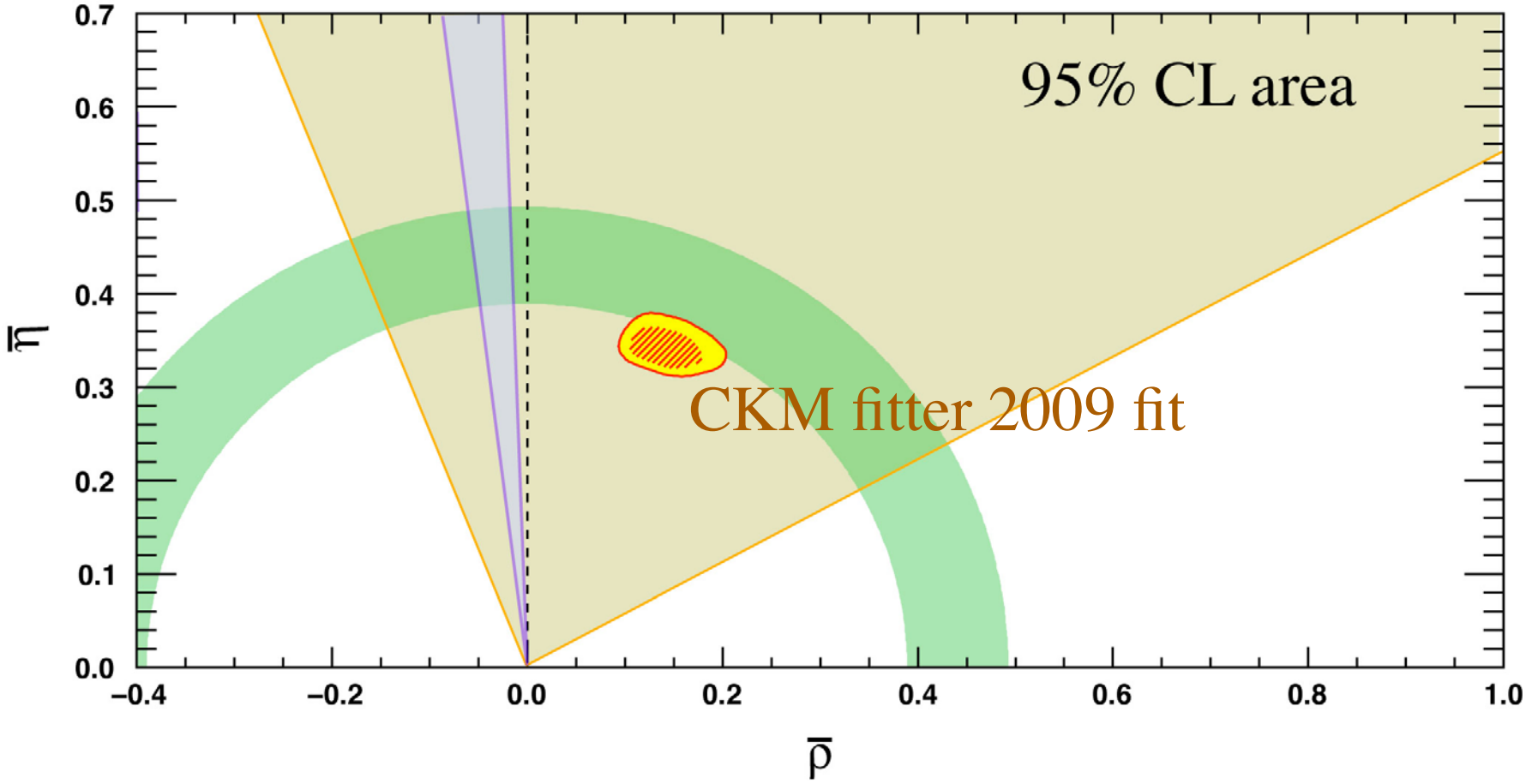
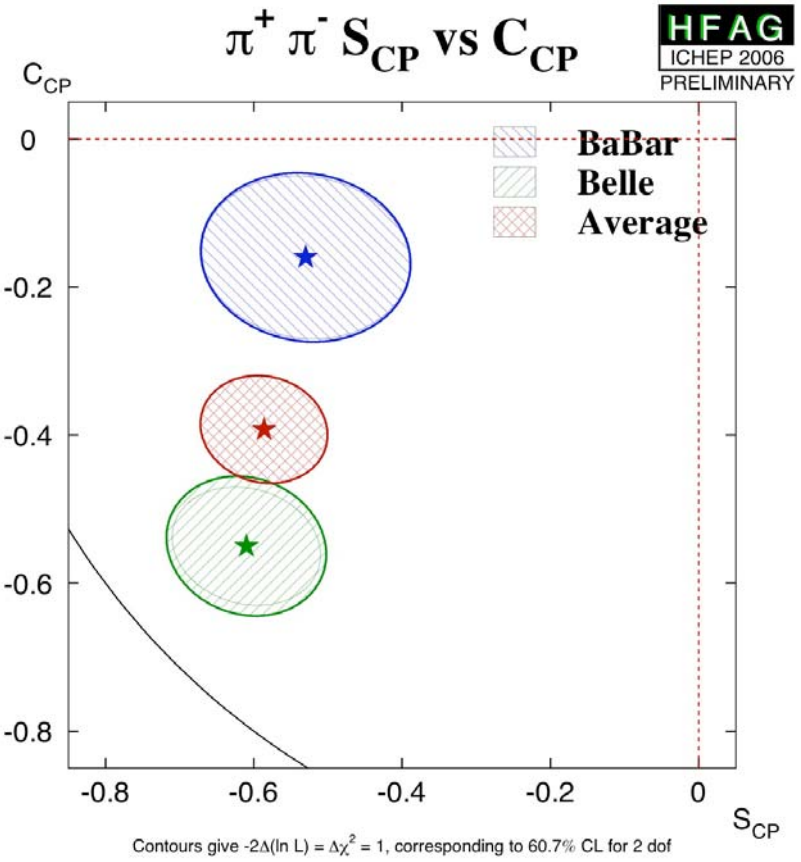


With 10 fb^{-1}, LHCb will do $\sigma_\gamma = 2\sim3°$
even better than the current global fit value

in 2006

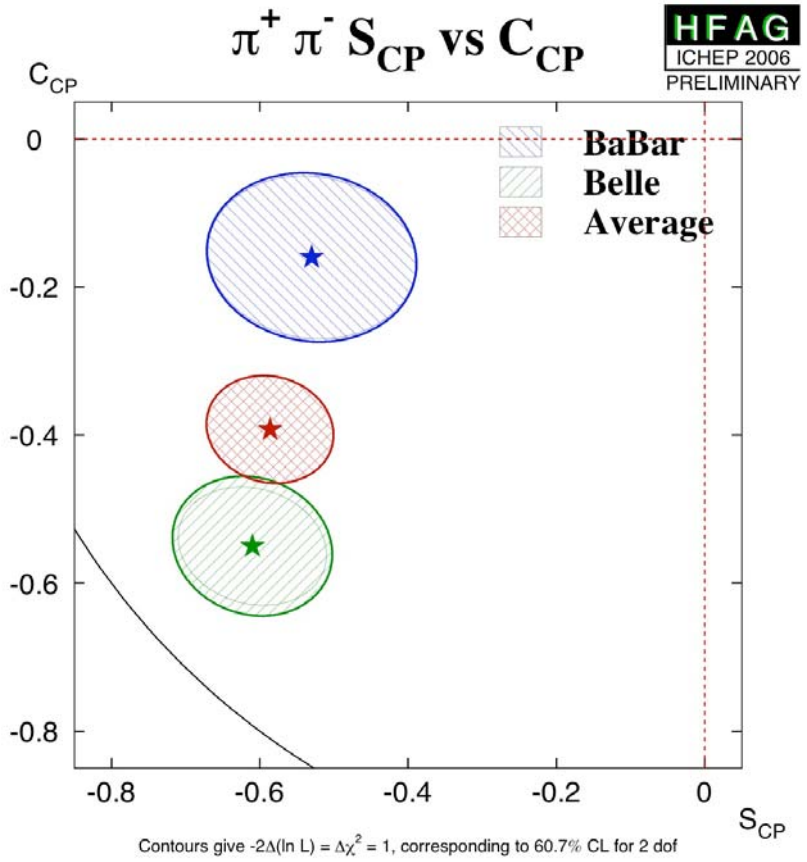
$B_d \to hh$



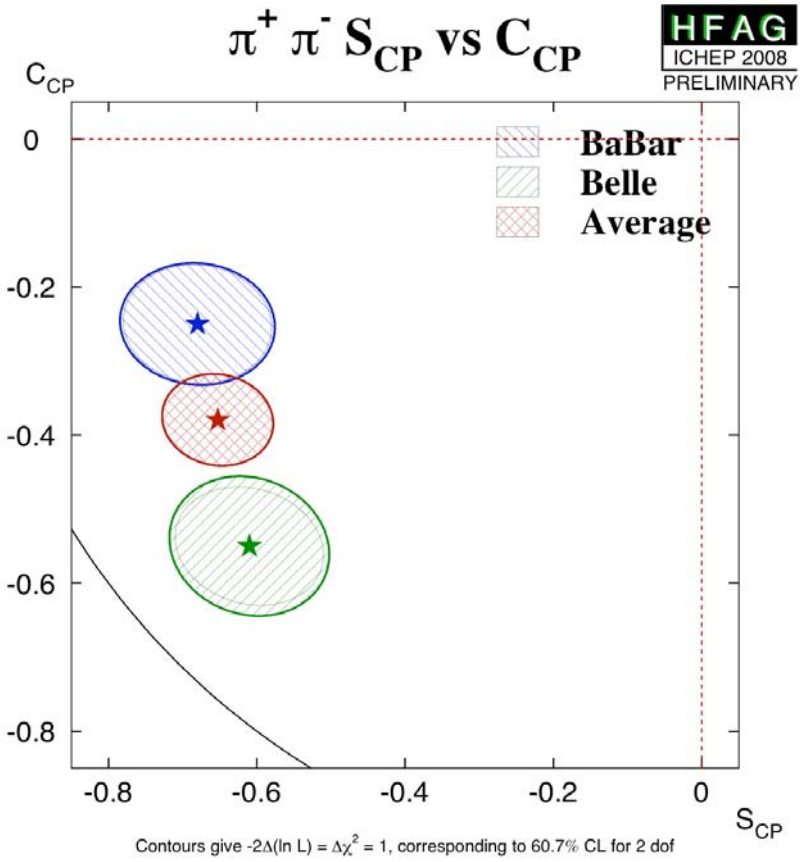
Is there CP violation in the decay amplitudes?

$B_d \rightarrow hh$

in 2006



in 2009



Is there CP violation in the decay amplitudes?

BABAR full statistics, Belle ~70%: →no clear answer

Belle: ~1500 $B \rightarrow \pi^+\pi^-$ LHCb: 36k/2 fb^{-1} $\varepsilon D^2 \approx 6\%$

Combine with $Bs \rightarrow K^+K^-$ a la R. Fleischer

$B_d \to hh$

If we care experimentally established effects, i.e. $>5\sigma$ effect, there is

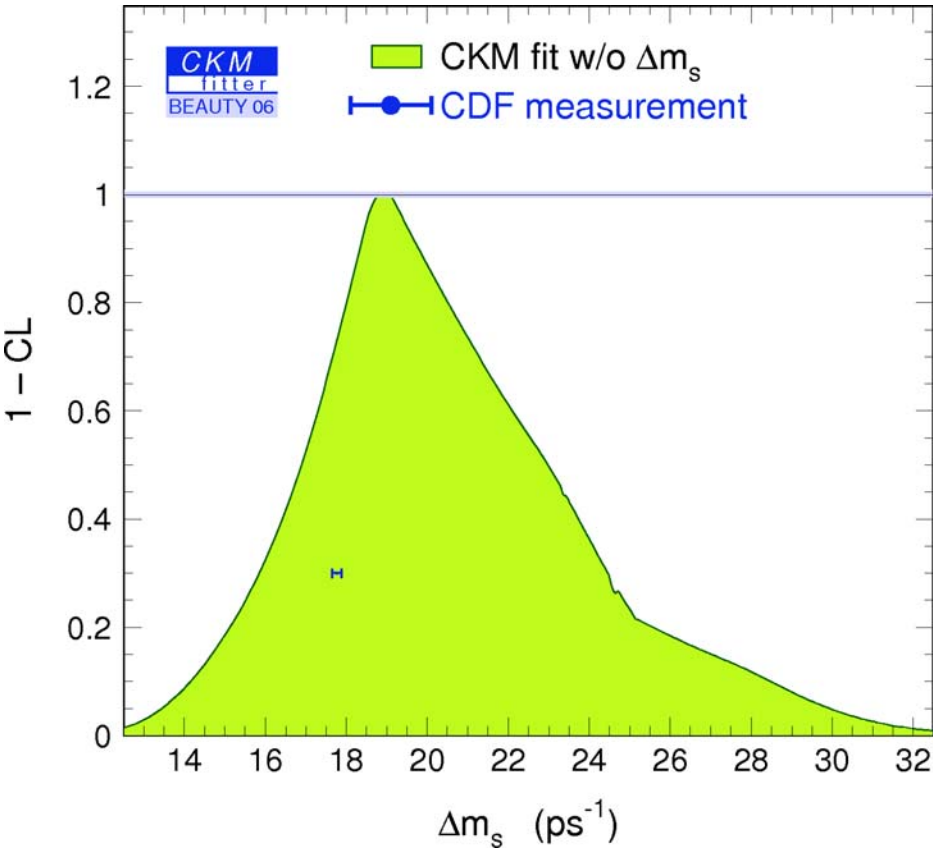
A_{CP} difference between B^+ and $B^0 \to K\pi$

LHCb will have high statistics samples for $K\rho$ or B_s equivalent.

Too difficult to digest for theory?

In the B_s sector

in 2006

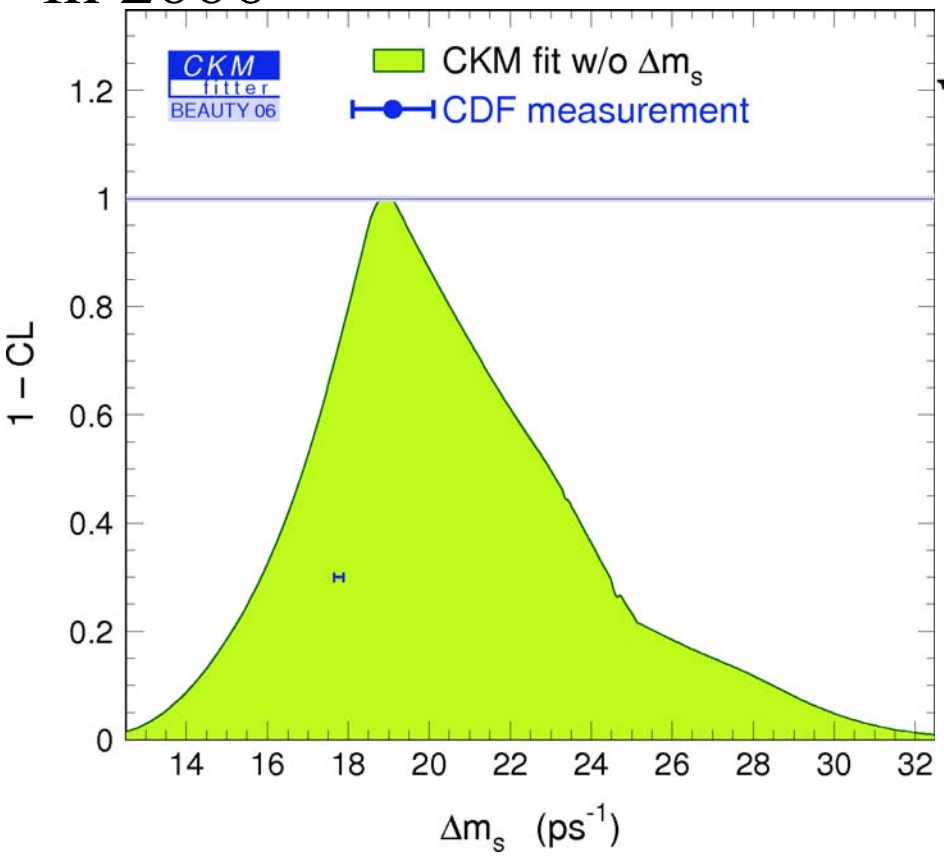


Δm_s measurement was already (too) good! (and still is)

Can theory drastically improve $B_s \times f_{Bs}^2$?

In the B_s sector

in 2006



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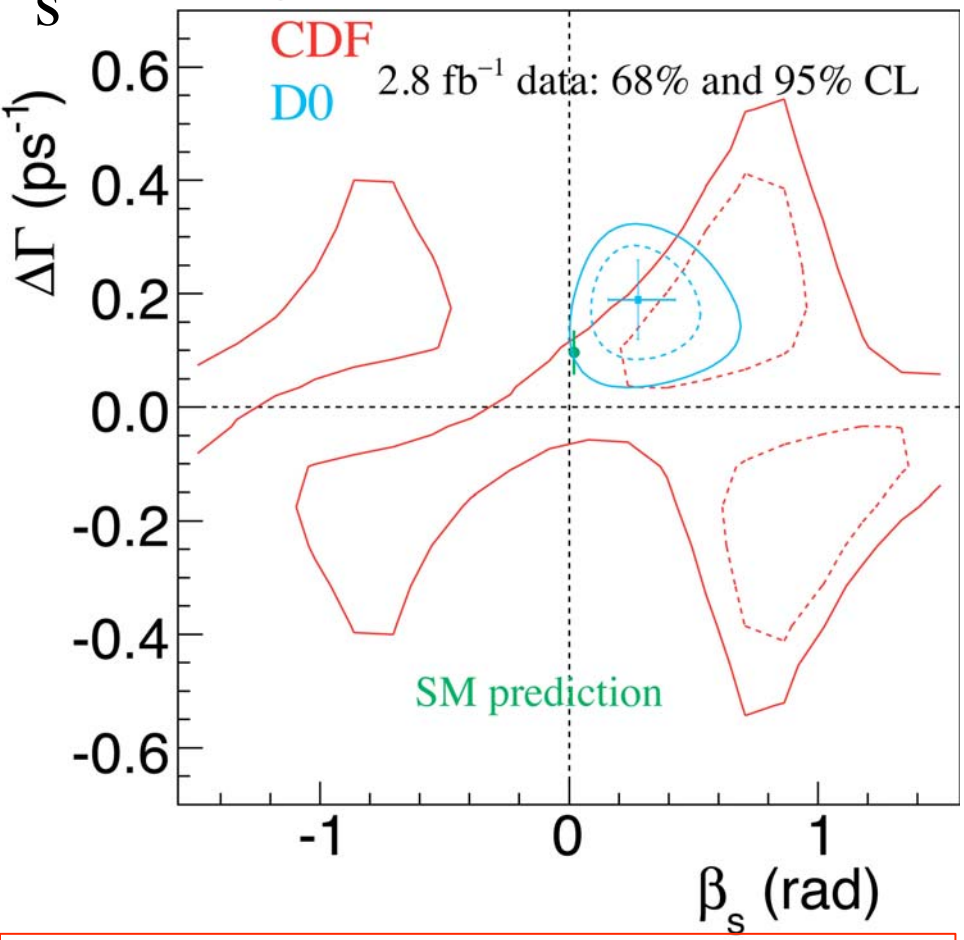

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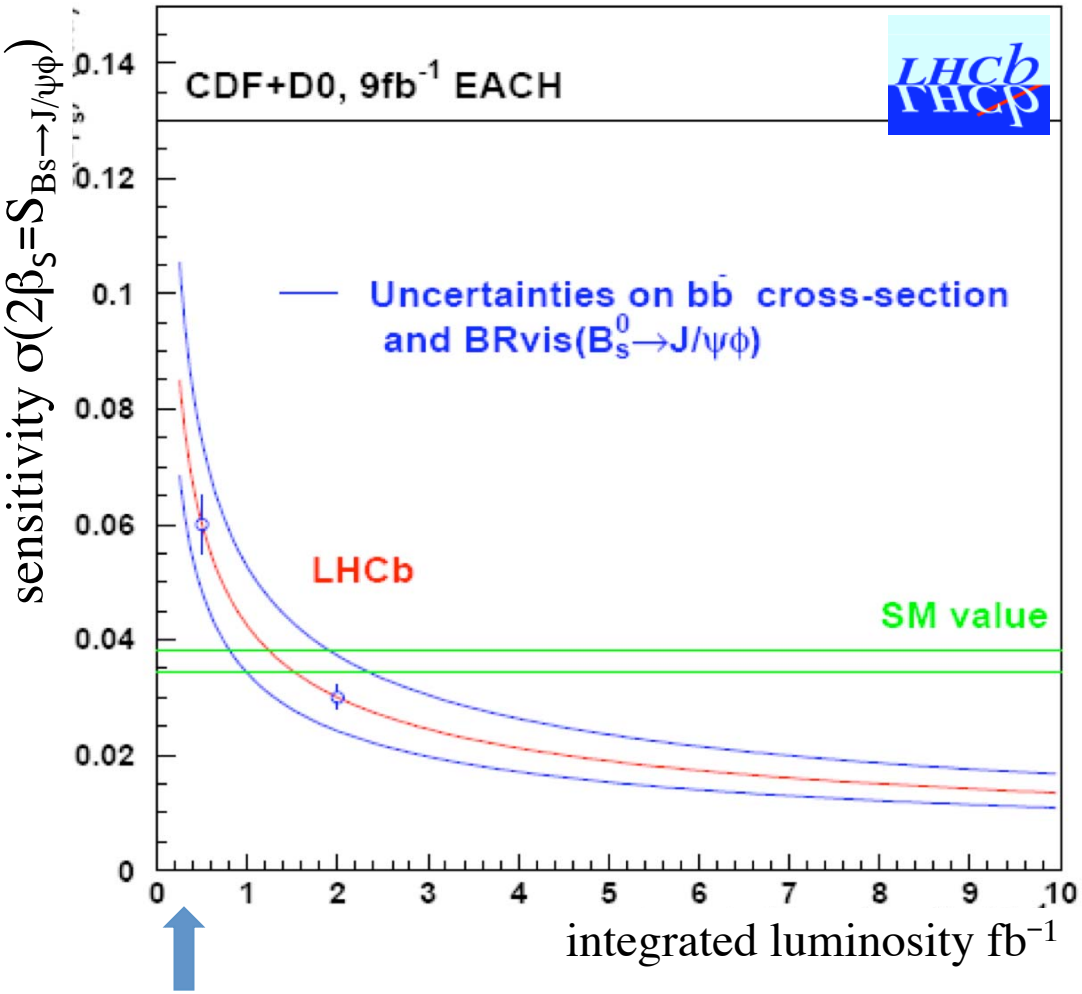
Can theory drastically improve $B_s \times f_{Bs}^2$?

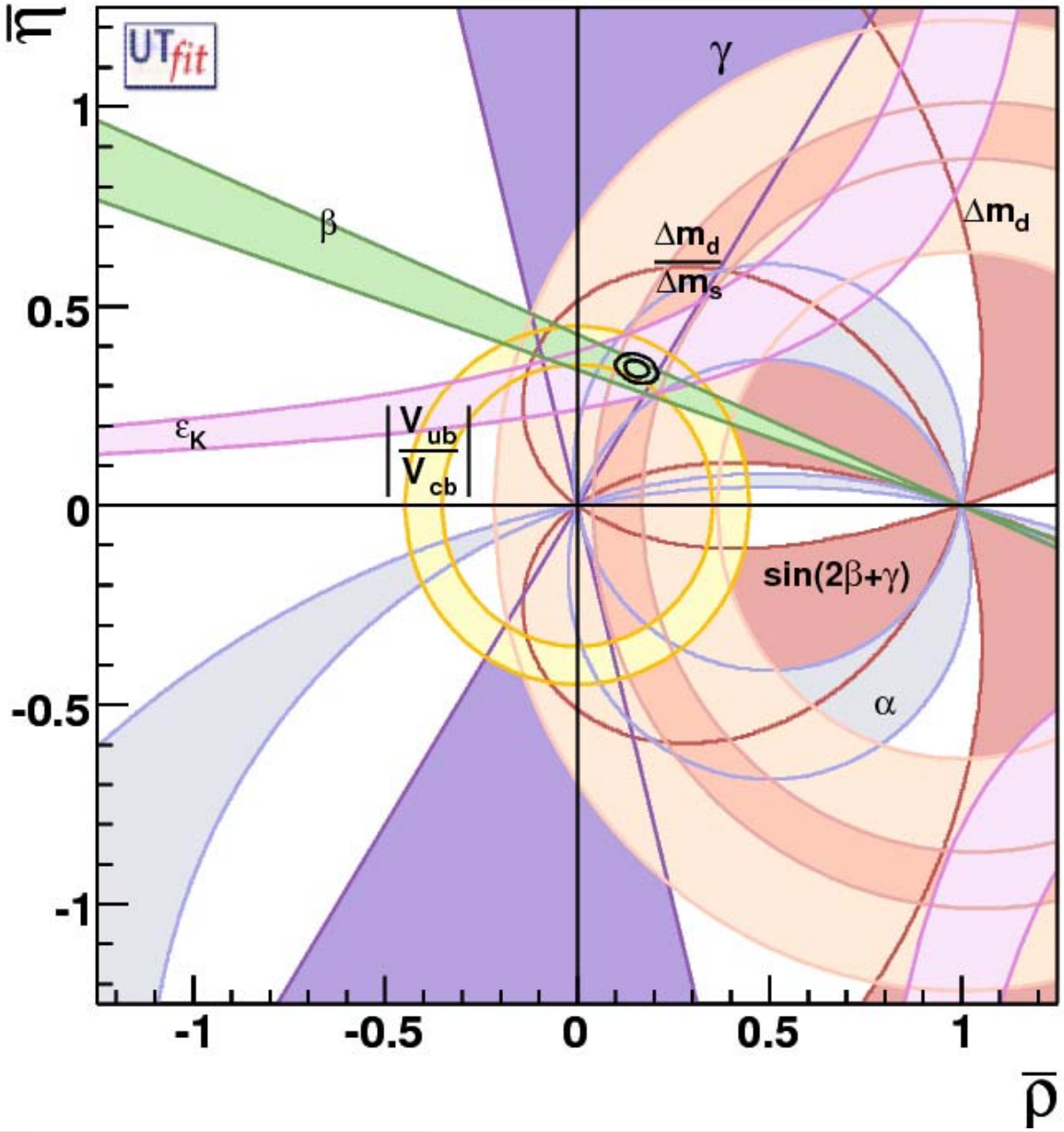
Too large experimental errors.
CDF&D0 experimental errors will be reduced by ~60%

In the B_s sector



LHCb expected
2010 statistics

Usual CKM fit…



Usual CKM fit…

- What remarkable is that ε_K agrees with the measurements from the B system

ε_K: $s \to t \to d$,

$\beta_{(c\bar{c})(s\bar{d})CP}$: $b \to t \to d$

$\beta_{(s\bar{s})(s\bar{d})CP}$: $b \to t \to s$

and

γ: $b \to u$

$\Downarrow$

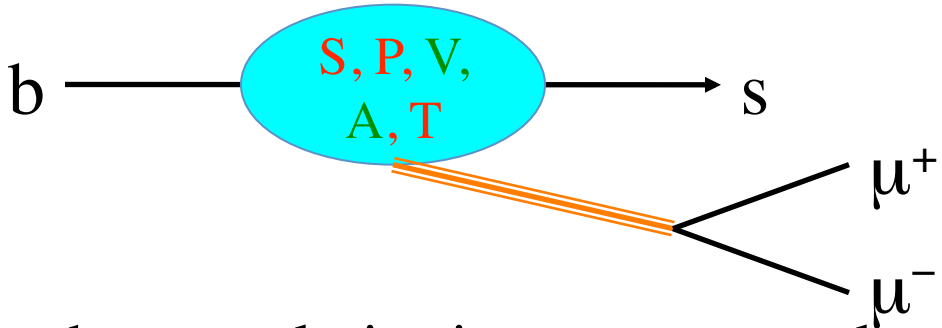
May be new physics phases are very close to the Standard Model phase…

If the NP phase ≈ SM phase?

- Phase measurements via CP violation would not be sensitive to new physics.
- Absolute values of the amplitudes are still sensitive to new physics.
  → rare and forbidden decays
- Lorentz structure of the amplitudes are still sensitive to new physics
  → photon polarisation in radiative decays
  virtual γ: angular distribution of the final states, A_{FB}
  real γ: CP in decay-oscillation interplay, $S_{b\to s\gamma}$

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

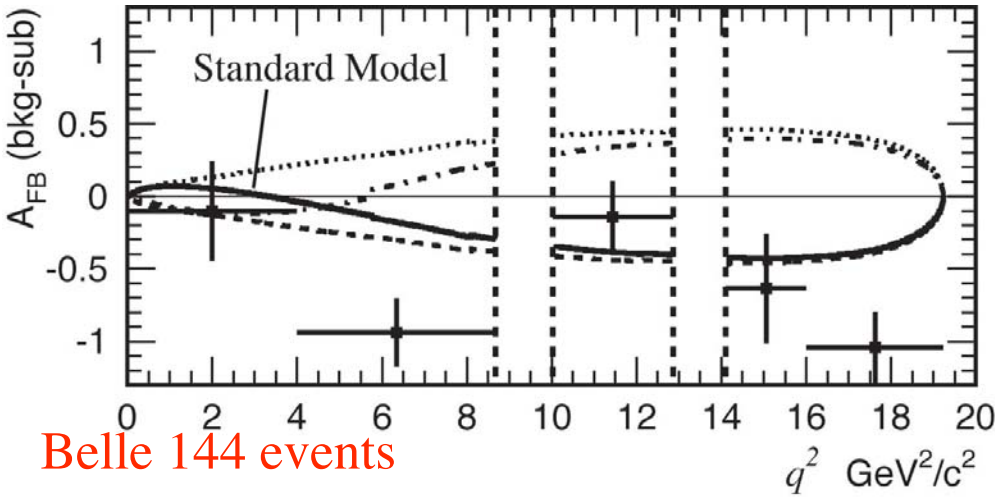
- Virtual γ probing the Lorentz structure



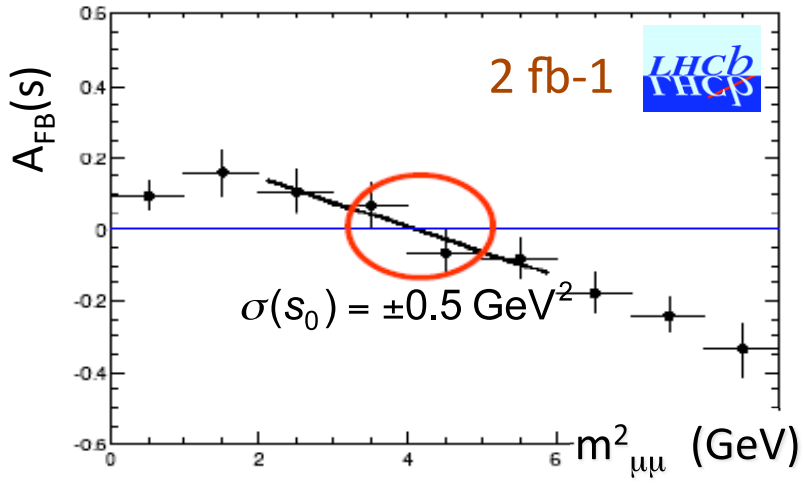
photon polarisation→$\mu^+\mu^-$ angular distribution

Belle 114 events/357 fb^{-1}, CDF 35 events/924 pb-1

B-factories + Tevatron ≈ 1000 $B_d \rightarrow K^{*0}\mu^+\mu^-$ LHCb 7200 events/$2fb^{-1}$



Belle 144 events



Photon polarisation from CP violation

- Time dependent CP violation in $B \to f_{CP}\gamma$ only through "wrongly" polarised photon
  $B_d \to K^{*0}(K_S\pi^0)\gamma$ at B factories, $B_s \to \phi\gamma$ for LHCb

$$A_{CP}(t) = \frac{C \cos \Delta m\, t + S \sin \Delta m\, t}{A^{\Delta} \sinh \Delta\Gamma\, t/2 - \cosh \Delta\Gamma\, t/2}$$

$$S = \sin 2\psi \sin\phi$$
$$A^{\Delta} = \sin 2\psi \cos\phi$$
$$\psi = \tan^{-1} \frac{|A(b \to s\gamma_R)|}{|A(b \to s\gamma_L)|}$$

For B_d $\Delta\Gamma = 0$, $\sin\phi = S_{J/\psi K_S} = 0.67$ with absence of new phase

For B_s $\Delta\Gamma \neq 0$, $\sin\phi = S_{J/\psi\phi} = 0.04$ with absence of new phase

Photon polarisation from CP violation

- Belle
  $\sigma(S)=^{+0.63}_{-0.50}$ with 253 fb^{-1} $\rightarrow \pm 0.3$ with full statistics
- BABAR
  $\sigma(S)=\pm 0.3$ with almost full statistics

$$\sigma\,(\sin 2\psi) = 0.3$$

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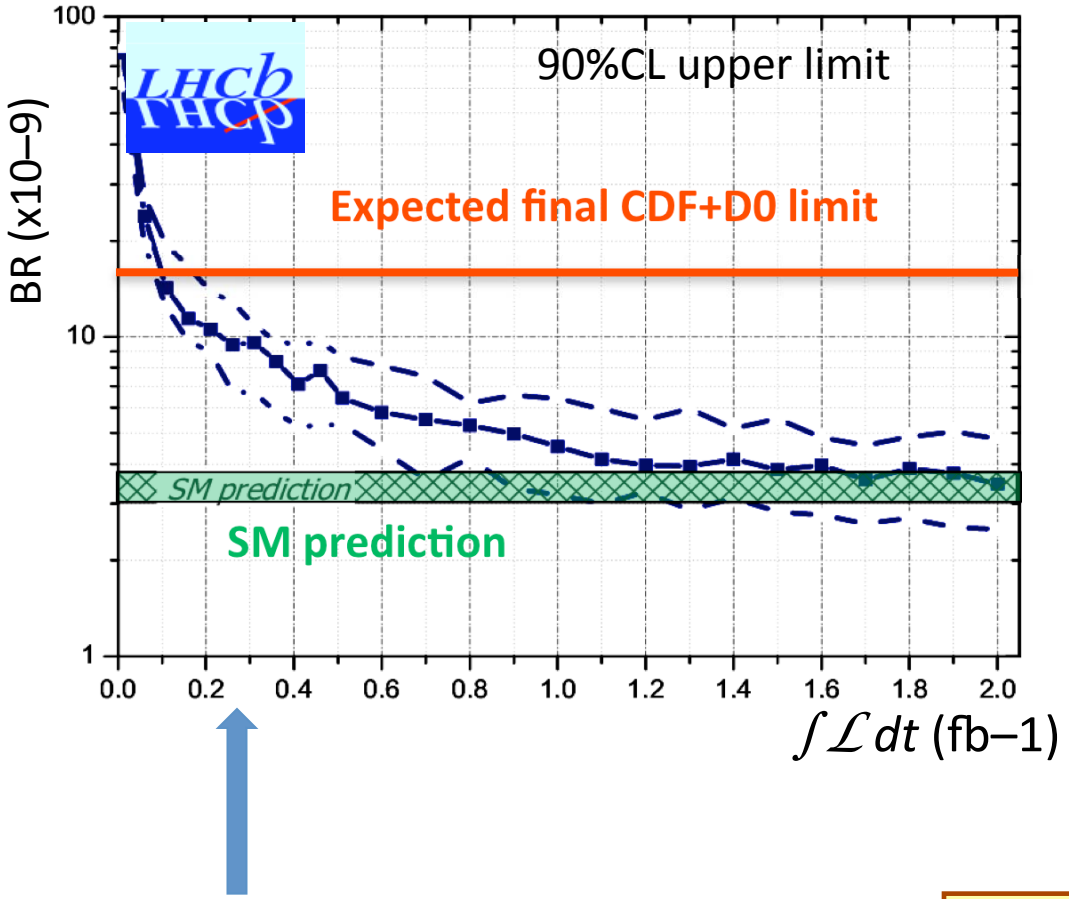
$$\sigma\,(\sin 2\psi) = 0.3$$

- LHCb
  $\sigma(A^{\Delta})=0.22$ and $\sigma(S) = 0.11$ with 2 fb^{-1}

  $\sigma\,(\sin 2\psi) = 0.1$ with 10 fb^{-1}
  i.e. fraction of wrongly polarised photon with ~5% error

$B_s \rightarrow \mu^+\mu^-$



LHCb expected 2010 statistics

Exclusion @ 90% CL

- reach SM prediction: $2fb^{-1}$

Observation if SM:

- Evidence (3σ): $3fb^{-1}$
- Discovery (5σ): $10fb^{-1}$

ATLAS	< 10-8	(2 fb^{-1})
CMS	< 1.4 × 10-8	(10 fb^{-1})

Charm physics

- Evidence of D-$\overline{\text{D}}$ oscillations have been seen by BABAR, Belle and CDF

  Compatible with the SM expectation but large hadronic uncertainties

Charm physics

- Evidence of D-$\overline{\text{D}}$ oscillations have been seen by BABAR, Belle and CDF

  Compatible with the SM expectation but large hadronic uncertainties

- The next step is toward CP violation

  LHCb D physics statistical error with 10 fb^{-1} data

  $\sigma(x'^2)=6.4\times10^{-5}$

  $\sigma(y')=8.7\times10^{-4}$

  $\sigma(y_{CP})=5\times10^{-3}$

  CP asymmetries for K^+K^- and $\pi^+\pi^-$ $<O(10^{-3})$

For coming 5 years

- 2010 data; 200 to 300 pb^{-1}

  overtake Tevatron for $B_s \rightarrow J/\psi\phi$ and $\mu^+\mu^-$ studies

  overtake B factories for $B_d \rightarrow K^{*0}\mu^+\mu^-$

- 2011 ~1 fb^{-1} data

  $S_{J/\psi\phi}$ and $Br(B_s \rightarrow \mu^+\mu^-)$ to the level of the SM, excluding the large New Physics effects which are still possible now

- 2012 >2 fb^{-1} data

  Start of comprehensive studies, γ, D, $\phi\gamma$, $K^{*0}\mu^+\mu^-$ full angular analysis, etc.

- ~2015 ~10 fb^{-1} data

  Phase I of LHCb competed, move to SLHCb, SB-factory, or something else?

A quick history of flavour physics

Leptons	Hadrons
1897 Discovery of e	1932 Discovery of n
1930 Postulation of ν	1947 Discovery of K
1936 Discovery of μ	1956 Discovery of
1956 Discovery of ν	K^0-$\overline{K}^0$ oscillations
1957 Postulation of	~1960 "quark" model
ν-$\overline{\nu}$ oscillations (P)	1963 Cabibbo mixing
1962 Discovery of ν_μ	1964 Discovery of CP violation
1962 Postulation of	1970 GIM mechanism (c)
ν_e-ν_μ mixing (NMS)	1973 Postulation of 3rd family (KM)
1975 Discovery of τ	1974 Discovery of c
2000 Discovery of ν_τ	1977 Discovery of b
Now ν mixing well	1995 Discovery of t
established	Now CKM picture well established

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Where do we find the next surprise first?

Ringberg 2012

We are all looking forward seeing a talk like:

"Discovery of physics beyond the Standard Model
in XXX
by YYY"

and better many of them!!!