CP violation and rare decays in the b and c-quark sector

(and more)

Rencontres du Vietnam
ICISE Inaugural Conference, Windows on the Universe
Quy Nhon, Vietnam, 11-17 August 2013

T. Nakada
EPFL-LPHE
Lausanne, Switzerland

To start

- I had a pleasure and honour to participate in the 2nd Rencontres du Vietnam on 21st to 28th Oct 1995 in Ho Chi Minh City (with an excursion to observe the total eclipse.) The title of my talk was "EXPERIMENTAL PROSPECTS FOR CP VIOLATION IN B-MESON DECAYS"

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  - ATLAS and CMS were well advancing
  - LHCb (called LHC-B at that time) just submitted the LoI
- Now almost 20 years later,
  - PEP-II, KEKB, HERA-B completed
  - ATLAS, CMS and LHCb are in the middle of physics production.
  - SuperKEKB in construction, LHCb upgrade TDR in preparation

In the very past

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  - From $\mathrm{Br}(K_L \rightarrow \mu^+\mu^-)$ and K^0-$\overline{K}^0$ oscillations (Δm_K) $\Rightarrow$
    Glashow-Iliopoulos-Maiani mechanism(1970),
    Value of m_c Lee&Gaillard (1974)
    Charm discovery Aubert et al., Augustin et al., 1974 (Niu et al. 1971?)
  - CP violation: J.H. Christenson et al. (1964), $\mathrm{Br}(K^0_L \rightarrow \pi^+\pi^-) \neq 0 \Rightarrow$
    Third family introduced by Kobayashi & Maskawa (1973)
  - B^0-$\overline{B}^0$ oscillations (Δm_B): ARGUS (1987) $\Rightarrow$
    $m_t > 50$ GeV/c^2 (NB: UA1 1984 $20 < m_t < 50$ GeV/c^2)
    top discovery by CDF and D0 in 1995 ($m_t = 171.2 \pm 2.1$ GeV/c^2)

Top quark mass?

UA1, 1984

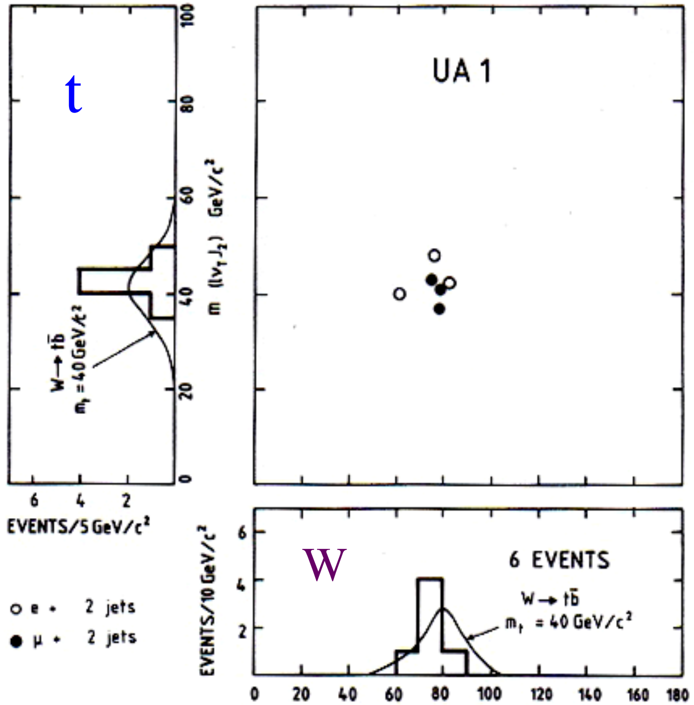
$p\bar{p} \rightarrow W^{+} + X$

$\quad \hookrightarrow t\,\bar{b} \longrightarrow$ jet

$\quad\quad \hookrightarrow b l \nu$

$\quad\quad\quad \hookrightarrow$ jet

$m_t = 30 \sim 50$ GeV/c^2



Phys. Lett. 147B (1984) 493

Phys. Lett. B 192 (1987) 245

ARGUS, 1987

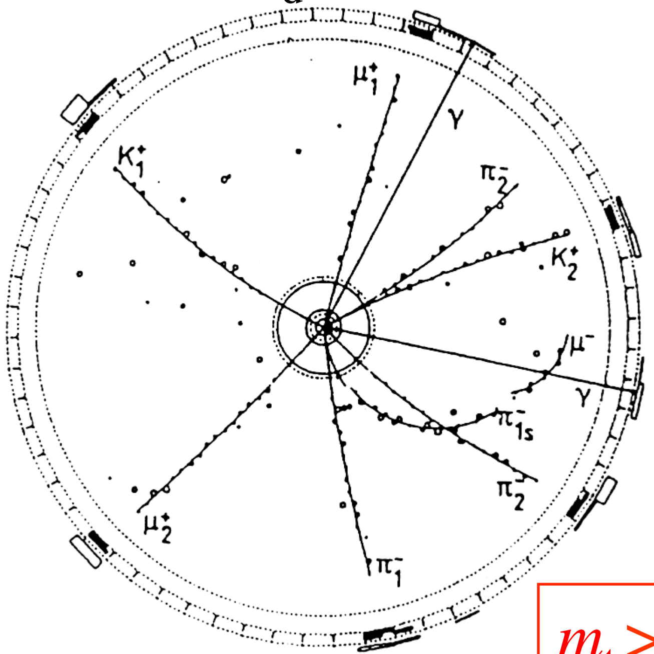
$\Upsilon(4S) \rightarrow B_d^0 \overline{B}_d^0$

$\rightarrow B_d^0 B_d^0$ or $\overline{B}_d^0 \overline{B}_d^0$

$\rightarrow \ell^+ \ell^+$ or $\ell^- \ell^-$

24.8±7.6±3.8

$\Delta m(B_d) \sim 100 \times \Delta m(K^0)$



$m_t > 50$ GeV/c^2

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Indirect evidence
before the direct discovery of c, b and t

By the early 90's

- The Standard Model model description of "flavour" through the Cabibbo-Kobayashi-Maskawa mass mixing matrix established well enough (nuclear β decays, kaon decays, charm decays and b decays, in particular with ε_K and Δm_d with little uncertainty from the still unmeasured m_t), to make a firm statement such as
  - If CPV is generated by the CKM phase, CPV in the $B \to J/\psi K_S$ decays must be observed with >5σ within a few years of running with an asymmetric B factory with a luminosity of $\sim 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- This was the main motivation for asymmetric B factories

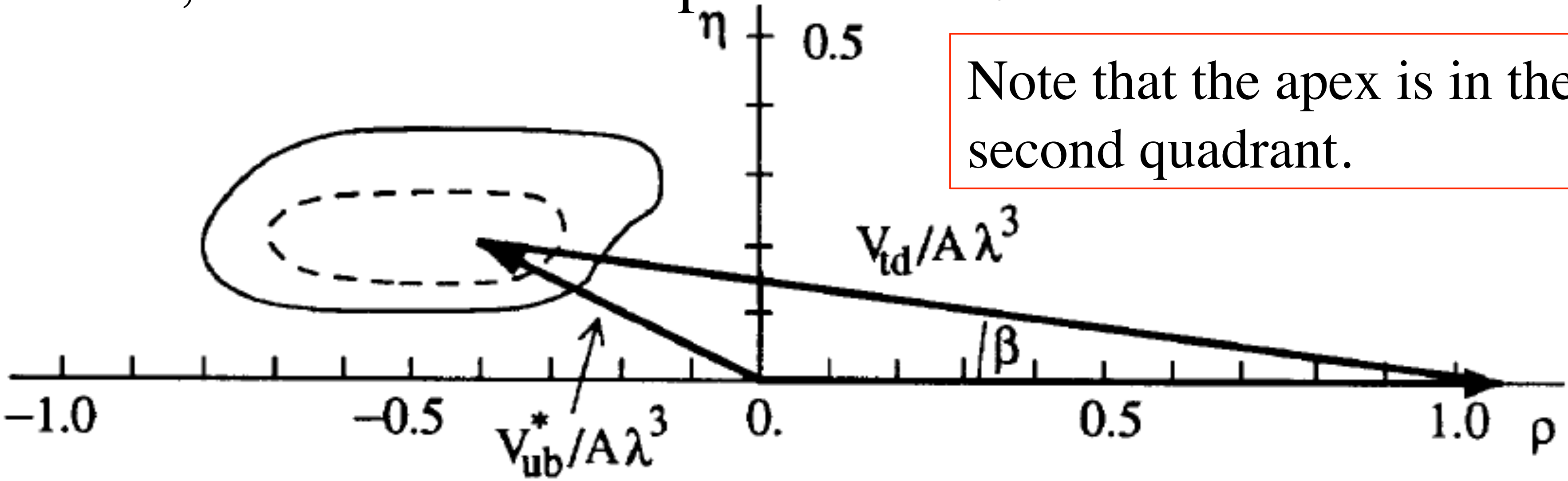
Example of early 90's

- An interesting formula: (I. Dunietz&TN, 87)

$$\mathrm{Im}(\lambda) \approx \frac{2\sqrt{2}|\varepsilon|}{A^2 S_c^4}\left(\frac{\Delta m_K}{\Delta m_B}\right)\left(\frac{m_B}{m_K}\right)\left(\frac{\eta_B}{\eta_3}\right)\left(\frac{f_B^2 B_B}{f_K^2 B_K}\right)$$
$$\approx 0.3 \cdot \left(\frac{1}{A^2}\right) \cdot \left(\frac{f_B^2 B_B}{f_K^2 B_K}\right). \qquad (10)$$

f_B was considered to be $\approx$ 110 MeV at that time
Now $\approx$ 230 MeV

- From "Feasibility study for a B-meson factory in the ISR tunnel", CERN Yellow Report CERN 90-02

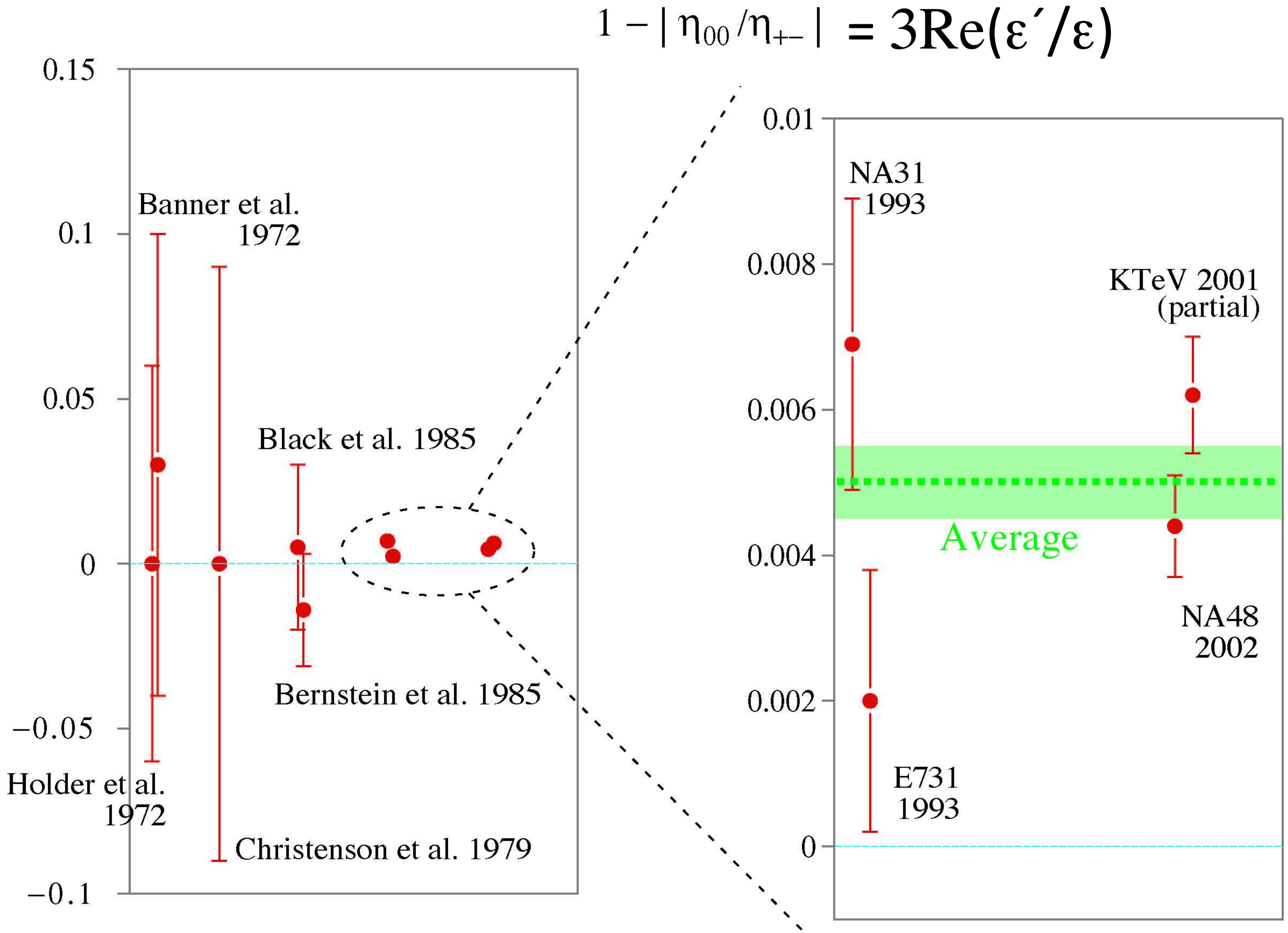


Note that the apex is in the second quadrant.

Two major events on CPV in 2002

1. Discovery of CP violation in the decay amplitudes, i.e.
   $Re(\varepsilon'/\varepsilon) \propto |A(\bar{K}^0 \to \pi\pi)| - |A(K^0 \to \pi\pi)| \neq 0$: fixed target

$$1 - |\eta_{00}/\eta_{+-}| = 3Re(\varepsilon'/\varepsilon)$$



Effort over 30 years!

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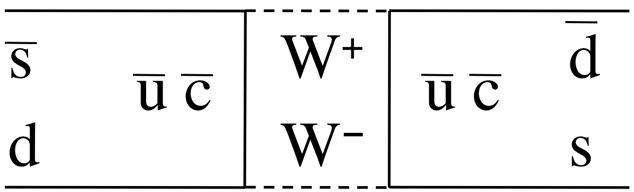
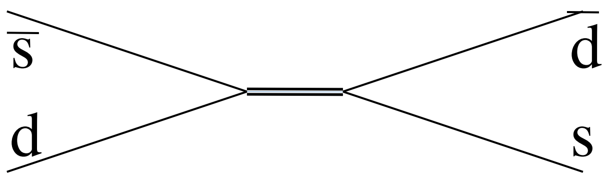
1. Discovery of CP violation in the decay amplitudes, i.e. $\mathrm{Re}(\varepsilon'/\varepsilon) \propto |A(\overline{K}^0 \rightarrow \pi\pi)| - |A(K^0 \rightarrow \pi\pi)| \neq 0$: fixed target
   - Superweak model (Wolfenstein 1964) was finally excluded as a (major) source of CP violation

VIOLATION OF *CP* INVARIANCE AND THE POSSIBILITY OF VERY WEAK INTERACTIONS*

L. Wolfenstein
Carnegie Institute of Technology, Pittsburgh, Pennsylvania
(Received 31 August 1964)

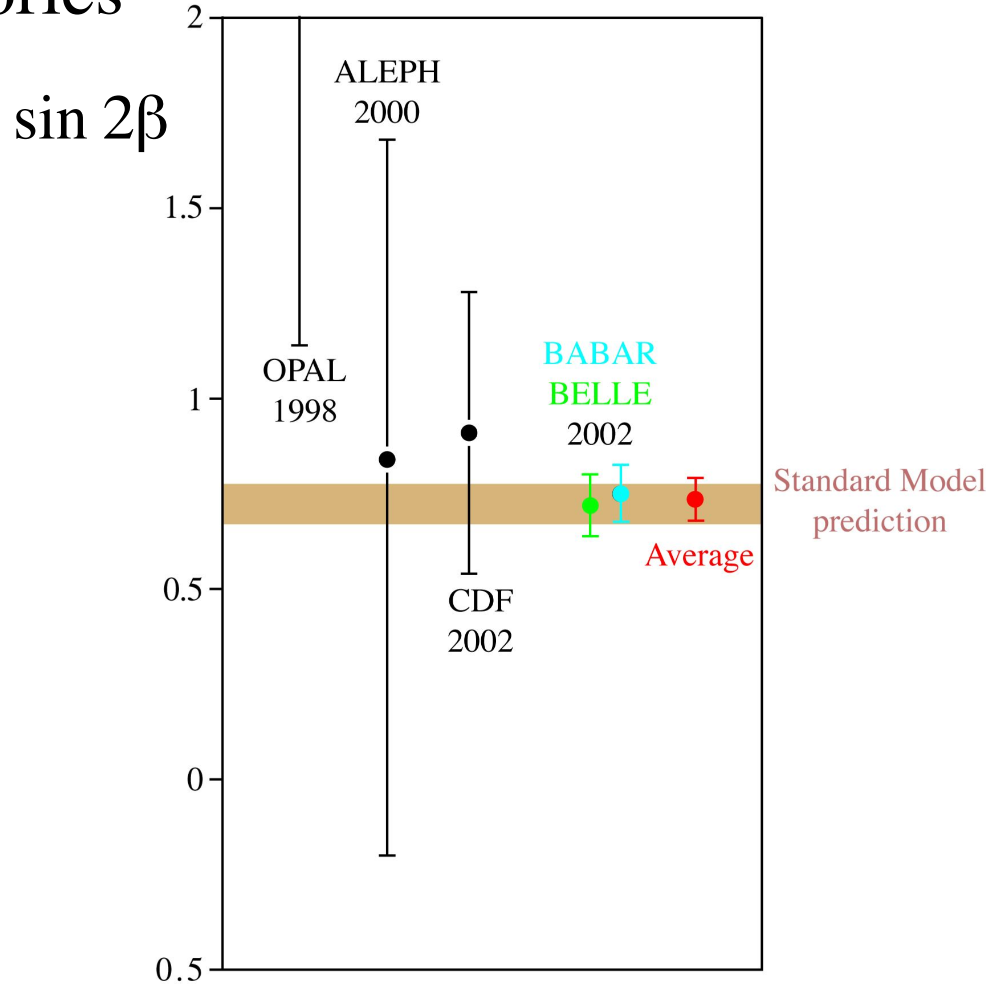
CPV only in $\Delta S = 2$ transitions





Two major events on CPV in 2002

2. Discovery of CP violation in $B_d \to J/\psi K_S$ decays, i.e.
   $\sin 2\beta \propto N(\overline{B}^0_{t=0} \to J/\psi K_S \text{ at } t) - N(B^0_{t=0} \to J/\psi K_S \text{ at } t) \neq 0$
   two e^+e^- B factories



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   two e^+e^- B factories
   - First concrete indication that the Standard Model appears to be the (major) source of CP violation

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Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

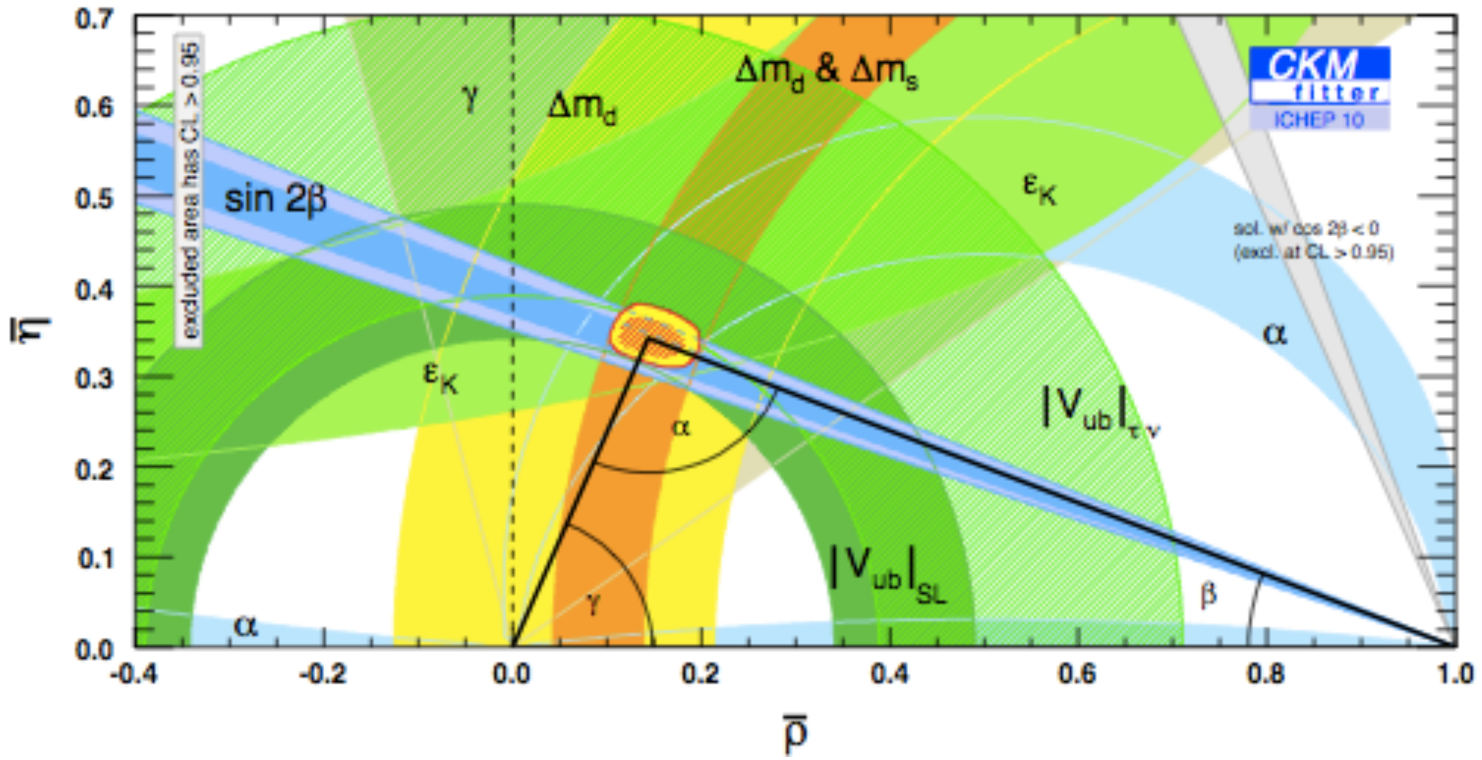
In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

Since then till the LHC start up

- BABAR and Belle, with high statistics B_u and B_d sample, successfully demonstrated that the quark flavour can be quantitatively well described by the CKM mechanism of the Standard Model, including CP violation. Their analysis went well beyond the original expectations, e.g. angle γ (ϕ_3) measurement.
- CDF and D0 have started to explore the B_s meson system: e.g. discovery of $\overline{B}_s$-B_s oscillations:
- However, CP violation in the B_s system remained as a largely unexplored territory, as well as very rare decays, e.g. $B_{s,d}\rightarrow\mu^+\mu^-$, and high statistic decay topology studies of rare decays, e.g. $B_d\rightarrow K^{*0}\mu^+\mu^-$.
- Several evidences were seen for D-$\overline{D}$ oscillations, but statistics were not enough to explore CP violation.

Triumph of the CKM description

- All the flavour changing processes are described by the four parameters of the CKM mass mixing matrix (λ, A, ρ, η)



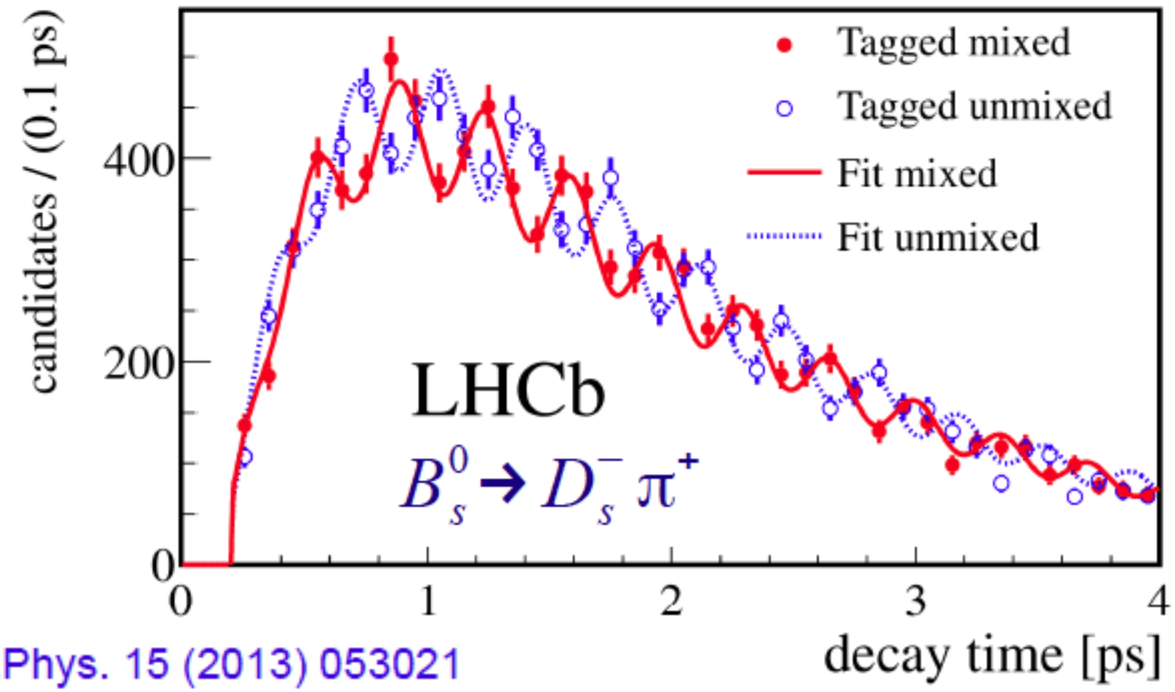
- From this plot, we know already either new physics energy scale is >> TeV (far beyond LHC) or the flavour structure of new physics is very special.

Once LHC started

- The LHC experiments, particularly LHCb, are overtaking quickly the physics of b and c quarks
- e.g. the best B_s-$\overline{B}_s$ oscillation frequency measurements: a proof that the LHCb detector is ready for CPV measurements: mass resolution, decay time resolution, flavour tagging, controlling background

B_s at $t = 0 \rightarrow \overline{B}_s$ at t

B_s at $t = 0 \rightarrow B_s$ at t



New J.Phys. 15 (2013) 053021

Note the related parallel session talks

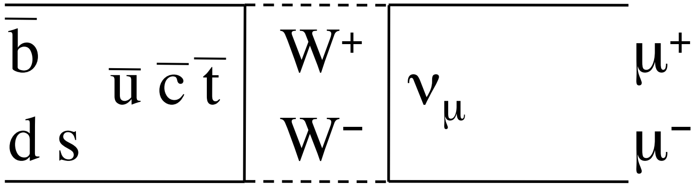
- Study of rare decays of B mesons at B factories,
  Fabrizio Bianchi (University of Torino and INFN Torino)
- Latest results on b-physics from the ATLAS and CMS experiments,
  Enrico Pasqualucci (INFN Rome)
- Recent results on hadronic B decays from Belle
  Marko Petric (Jozef Stefan Institute, Ljubljana)
- Rare decays of beauty and charm hadrons at LHCb
  Justine Serrano (CPPM, Marseille)
- Studies of CP violation in B decays at LHCb
  Florian Kruse (TU Dortmund)
- Latest results from the NA62 and NA48 experiments at CERN,
  Antonino Sergi (University of Birmingham)
- The MEG experiment: past, present and future
  Elisabetta Baracchini (ICEPP, Tokyo)

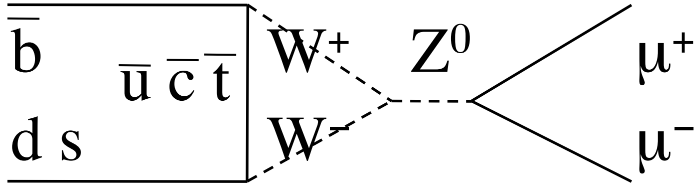
Success of B physics at LHC is due to

- Large b-$\overline{\text{b}}$ cross sections ($\sqrt{s}$ of LHC)
- High statistics (7-8 TeV data: close to 30 fb^{-1} each for ATLAS and CMS and 3 fb^{-1} for LHCb)
- Vertex resolutions (ATLAS**, CMS**, LHCb***)
- Momentum resolutions (ATLAS**, CMS**, LHCb***)
- Particle identification
  muons and electrons (ATLAS, CMS, LHCb)
  hadron (LHCb)
- Trigger
  muons and electrons (ATLAS, CMS, LHCb)
  hadron (LHCb)

Any sign of new particles in box?

- Box generated rare decays: B_s, $B_d \rightarrow \mu^+\mu^-$

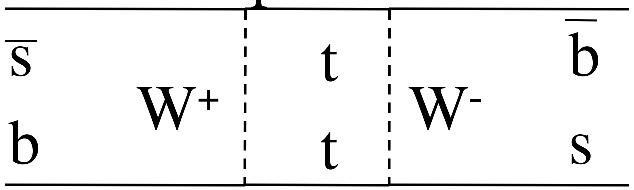




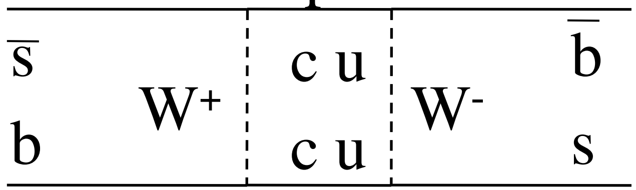
+ new virtual particles?

- CPV in B_s-$\bar{B}_s$ oscillations: $\bar{B}_s \rightarrow B_s \neq B_s \rightarrow \bar{B}_s$

dispersive

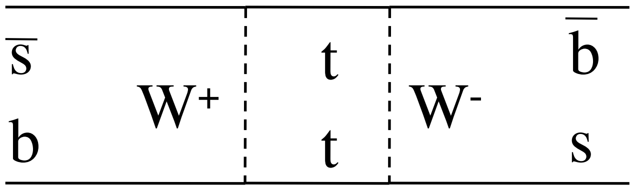


absorptive

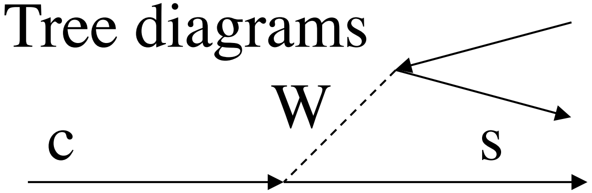


+ new virtual particles?

- CPV in oscillations ⊗ decay: $\bar{B}_s \rightarrow J/\psi\phi \neq B_s \rightarrow J/\psi\phi$



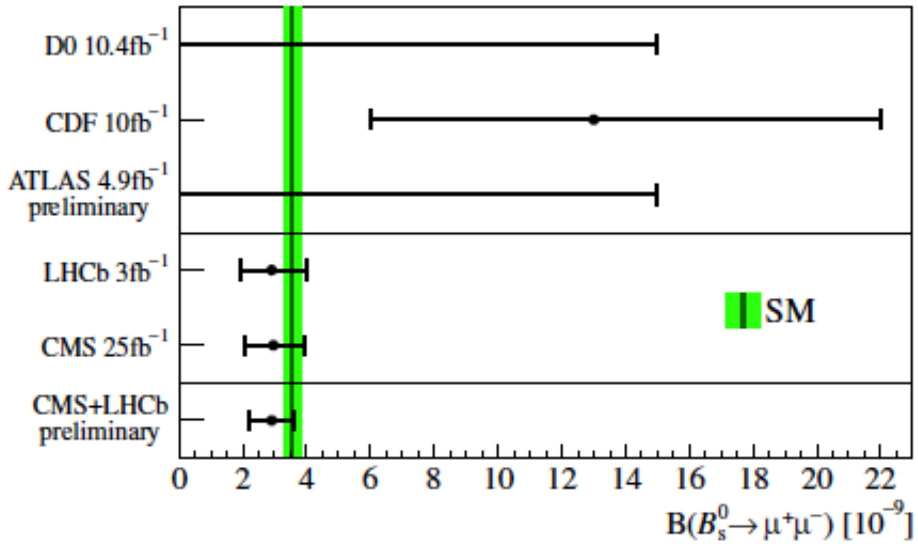
Tree diagrams

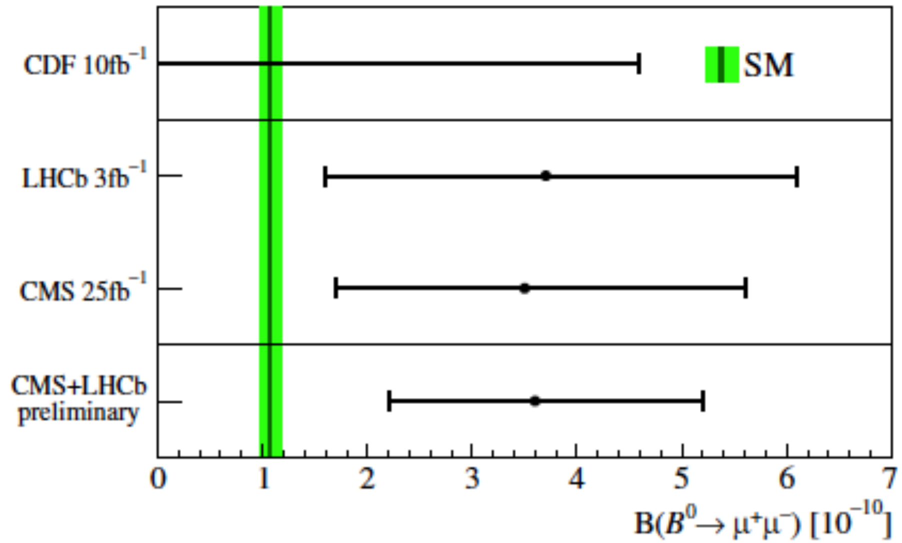


+ new virtual particles?

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

- Very rare decays. Analysis based on multiple variables





CMS-ATLAS combined

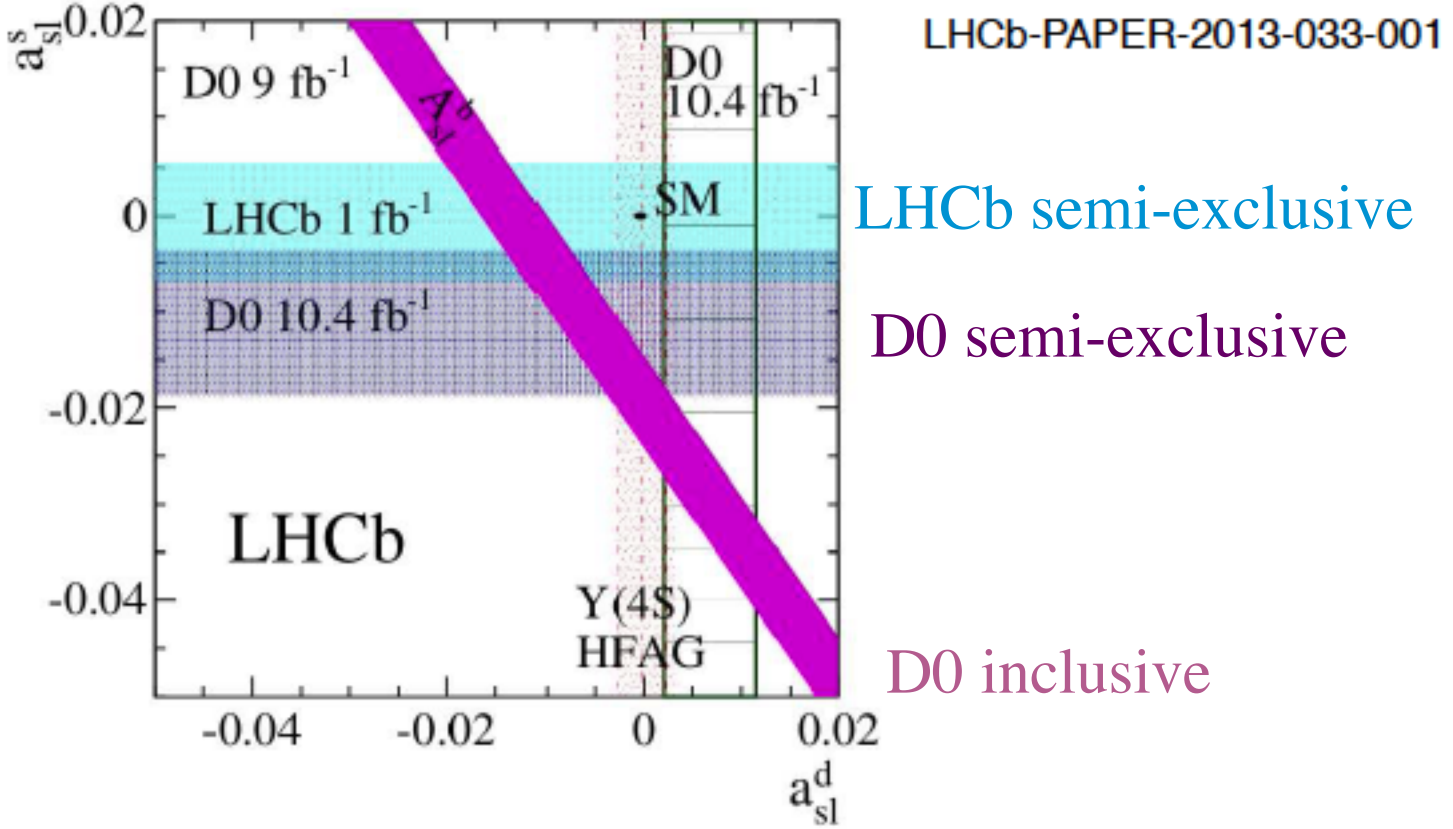
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}, \quad \text{LHCb-CONF-2013-012}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.6\,^{+1.6}_{-1.4}) \times 10^{-10}, \quad \text{CMS-PAS-BPH-13-007}$$

$B_s \rightarrow \mu^+\mu^-$ observed, in agreement with the Standard Model

$B_d \rightarrow \mu^+\mu^-$ still insignificant, in agreement with the Standard Model

CP violation in B-$\bar{B}$ oscillations

- Measured by the flavour specific decay modes, e.g. semileptonic decays: inclusively or semi-exclusively



Results are inconclusive: further studies at LHC essential

CP violation in $B_s \to J/\psi\phi$

- Time dependent decay rate studies for $B_s \to J/\psi\phi$ decays
  - need to distinguish $J/\psi\phi_{CP=+1}$ and $J/\psi\phi_{CP=-1}$ states from **the angular distributions of the final states**: additional complication

$$L_{J/\psi-\phi} = 0 \text{ or } 2\text{: CP} = +1\,,\ L_{J/\psi-\phi} = 1\text{: CP} = -1$$

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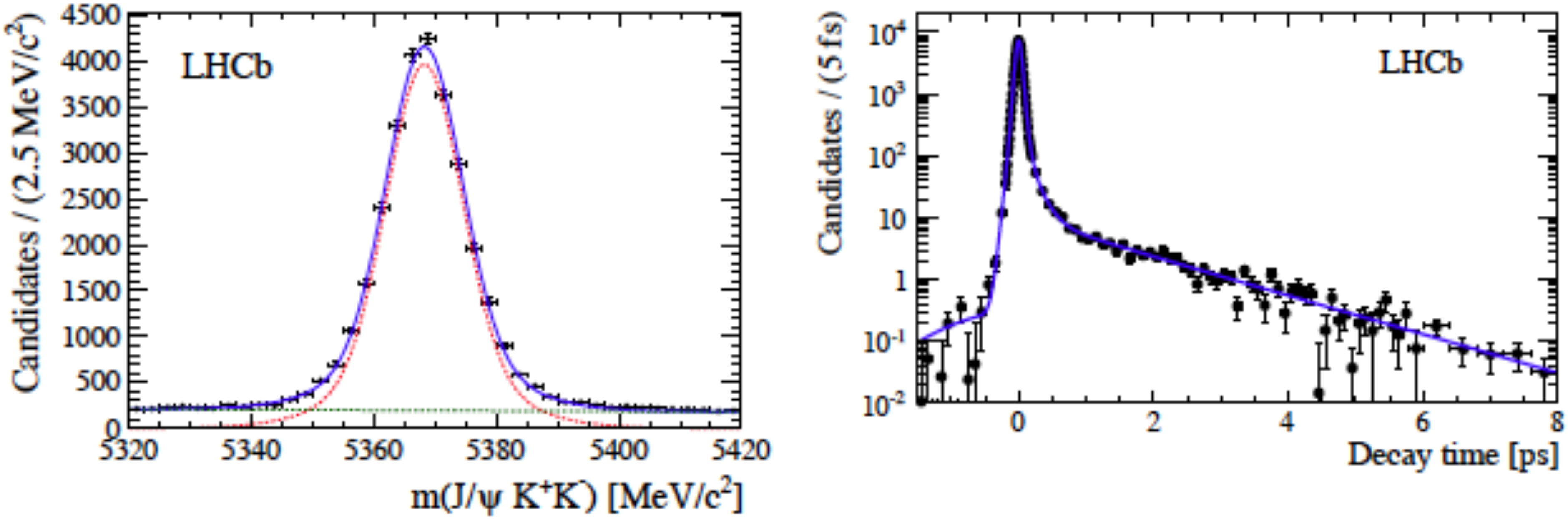
example using LHCb : Phys. Rev. D 87, 112010 (2013)



First reconstructing the final states.

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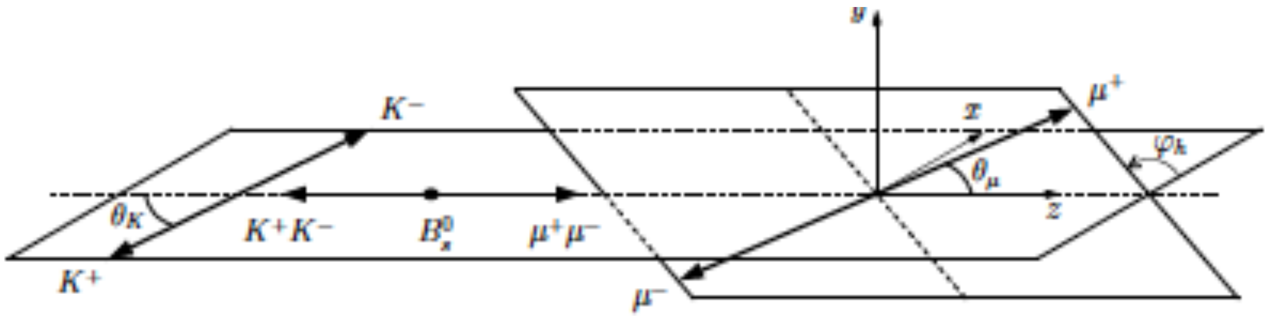

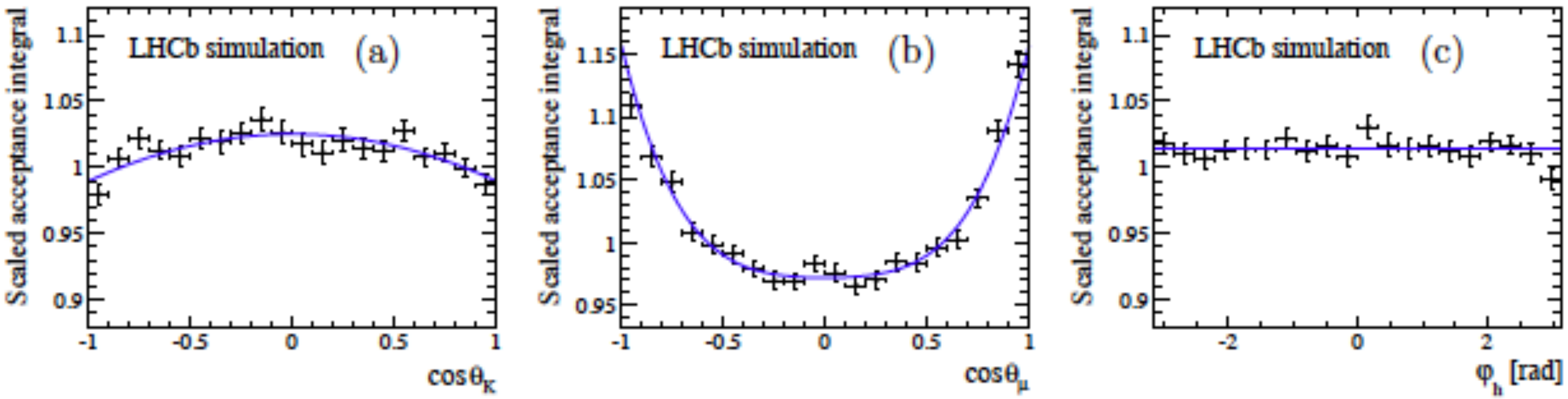

Detector acceptance for the decay angles has to be well understood.

LHCb : Phys. Rev. D 87, 112010 (2013)

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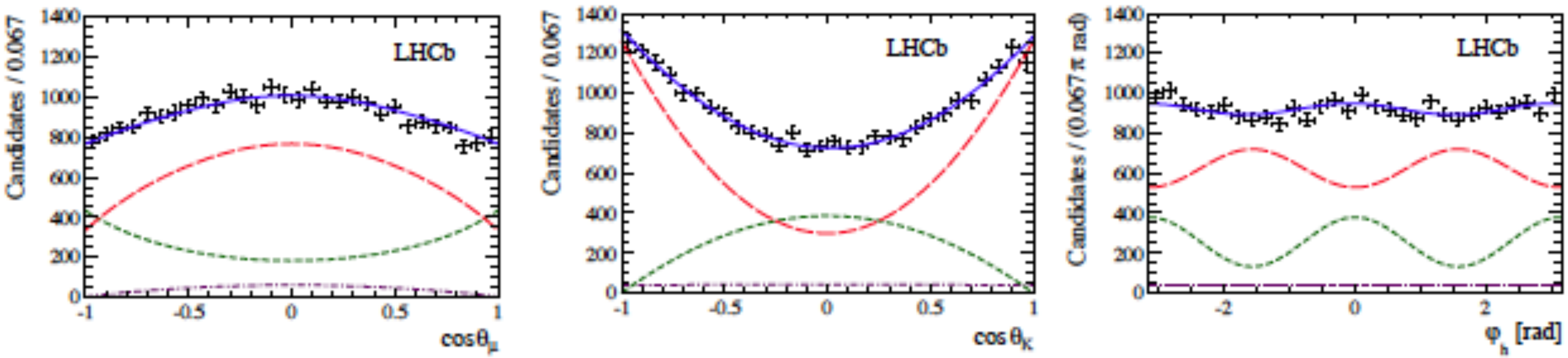

Experimental decay time distribution for $B_s^0 + \overline{B}_s^0$ contribution from the CP = +1 and −1 final states

LHCb : Phys. Rev. D 87, 112010 (2013)

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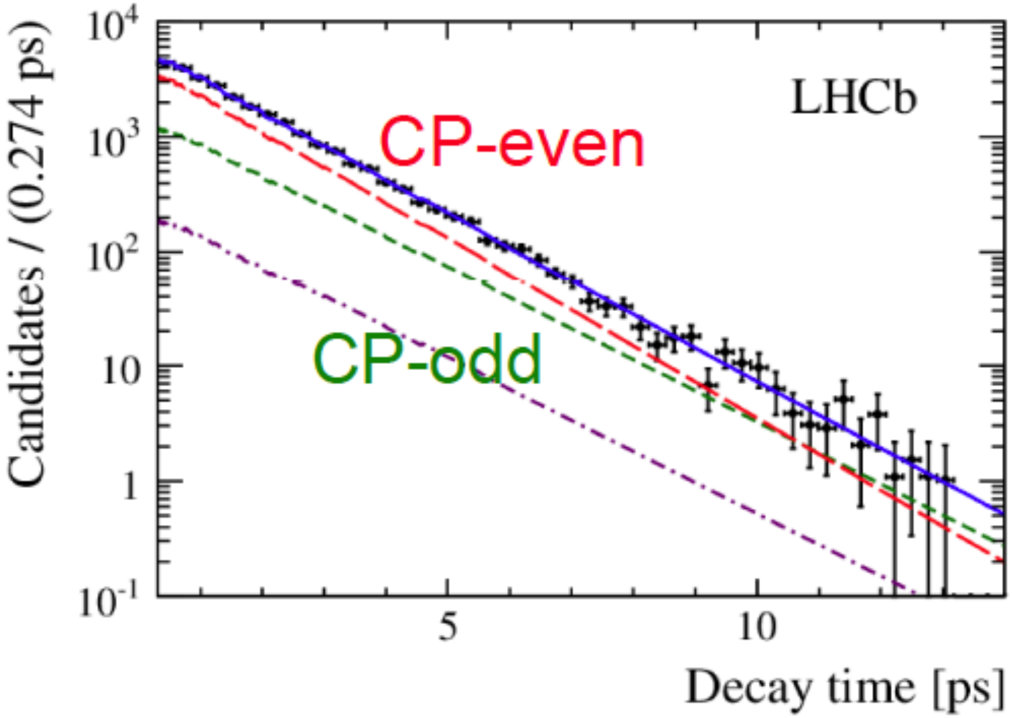
$B_s^0 + \overline{B}_s^0$ decay time distributions projected out for CP=+1 and = −1 states



Both are practically exponential decays → CP violation is small

CP=+1 state decays faster
Another phase shift study shows
CP=+1 state is lighter
As predicted by the SM.

LHCb : Phys. Rev. D 87, 112010 (2013)

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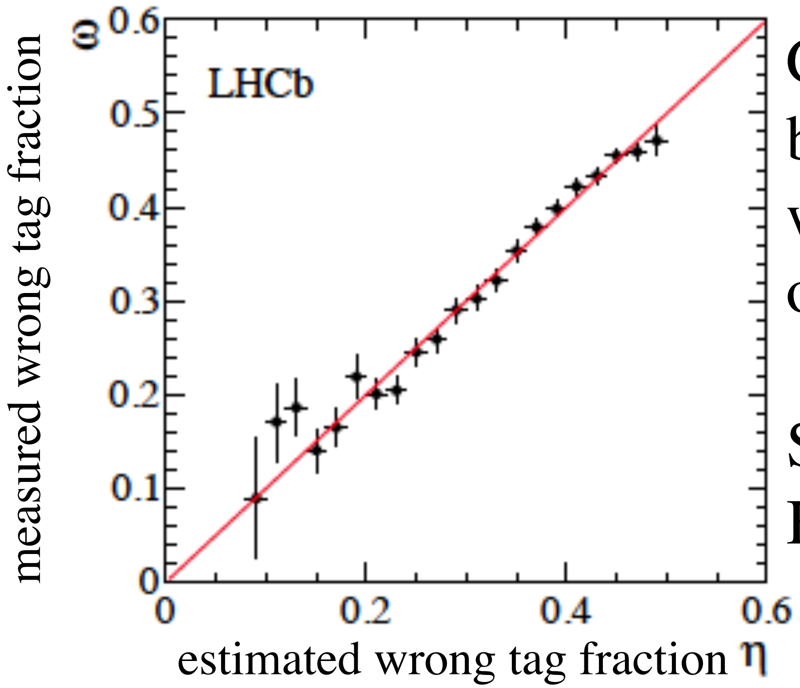
  - **with initial flavour tag**, unique solution on CP violation parameter $\phi_S^{J/\psi\phi}$ and decay width difference $\Delta\Gamma=\Gamma_L-\Gamma_H$ measurements. Calibration of flavour tag needed.



Comparison of the flavour estimate, based on leptons, kaons and vertex charges, with the calibration data $B^+ \to J/\psi K^+$ for the opposite flavour tag.

Similar work for the same sign kaon tag $B_s \to D_s\pi$ necessary

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fitting rather complicated PDF…

$$\frac{\mathrm{d}^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{\mathrm{d}t\,\mathrm{d}\Omega} \propto \sum_{k=1}^{10} h_k(t)\, f_k(\Omega)\,.$$

$$h_k(t) = N_k e^{-\Gamma_s t}\left[a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right],$$

k	$f_k(\theta_\mu, \theta_K, \varphi_h)$	N_k	a_k	b_k	c_k	d_k
1	$2\cos^2\theta_K \sin^2\theta_\mu$	$\lvert A_0\rvert^2$	1	D	C	$-S$
2	$\sin^2\theta_K\,(1-\sin^2\theta_\mu\cos^2\varphi_h)$	$\lvert A_\parallel\rvert^2$	1	D	C	$-S$
3	$\sin^2\theta_K\,(1-\sin^2\theta_\mu\sin^2\varphi_h)$	$\lvert A_\perp\rvert^2$	1	$-D$	C	S
4	$\sin^2\theta_K \sin^2\theta_\mu \sin 2\varphi_h$	$\lvert A_\parallel A_\perp\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
5	$\frac{1}{2}\sqrt{2}\sin 2\theta_K \sin 2\theta_\mu \cos\varphi_h$	$\lvert A_0 A_\parallel\rvert$	$\cos(\delta_\parallel-\delta_0)$	$D\cos(\delta_\parallel-\delta_0)$	$C\cos(\delta_\parallel-\delta_0)$	$-S\cos(\delta_\parallel-\delta_0)$
6	$-\frac{1}{2}\sqrt{2}\sin 2\theta_K \sin 2\theta_\mu \sin\varphi_h$	$\lvert A_0 A_\perp\rvert$	$C\sin(\delta_\perp-\delta_0)$	$S\cos(\delta_\perp-\delta_0)$	$\sin(\delta_\perp-\delta_0)$	$D\cos(\delta_\perp-\delta_0)$
7	$\frac{2}{3}\sin^2\theta_\mu$	$\lvert A_S\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\theta_K \sin 2\theta_\mu \cos\varphi_h$	$\lvert A_S A_\parallel\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$-\frac{1}{3}\sqrt{6}\sin\theta_K \sin 2\theta_\mu \sin\varphi_h$	$\lvert A_S A_\perp\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	$C\sin(\delta_\perp-\delta_S)$	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\theta_K \sin^2\theta_\mu$	$\lvert A_S A_0\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

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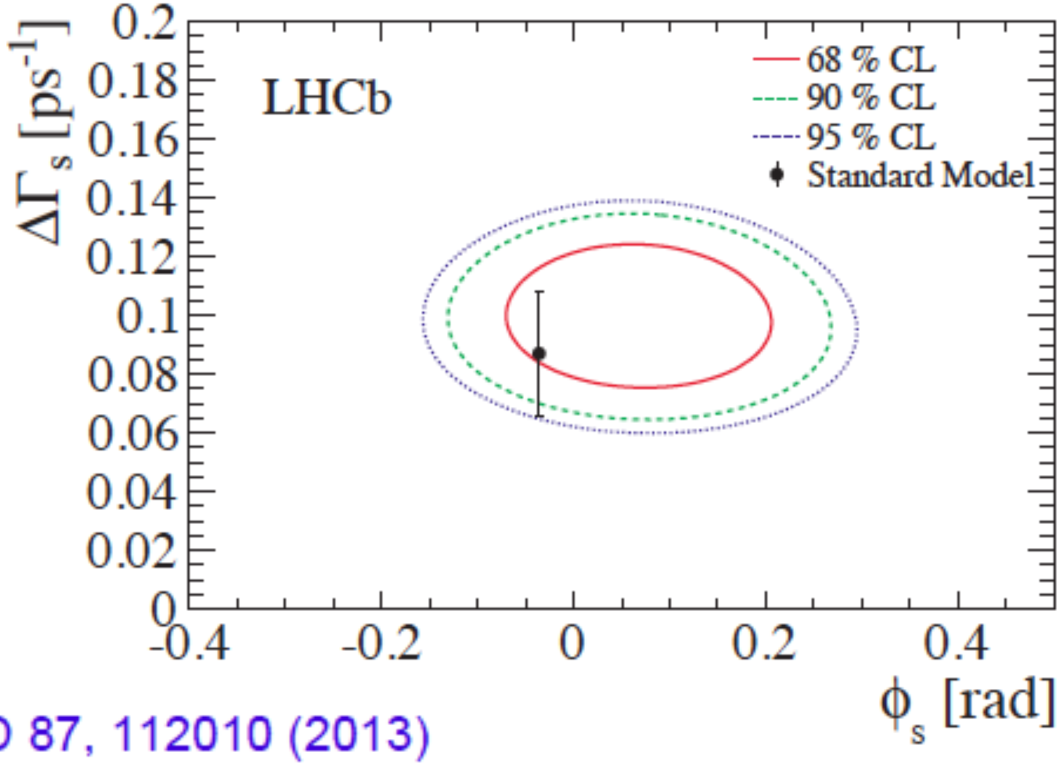
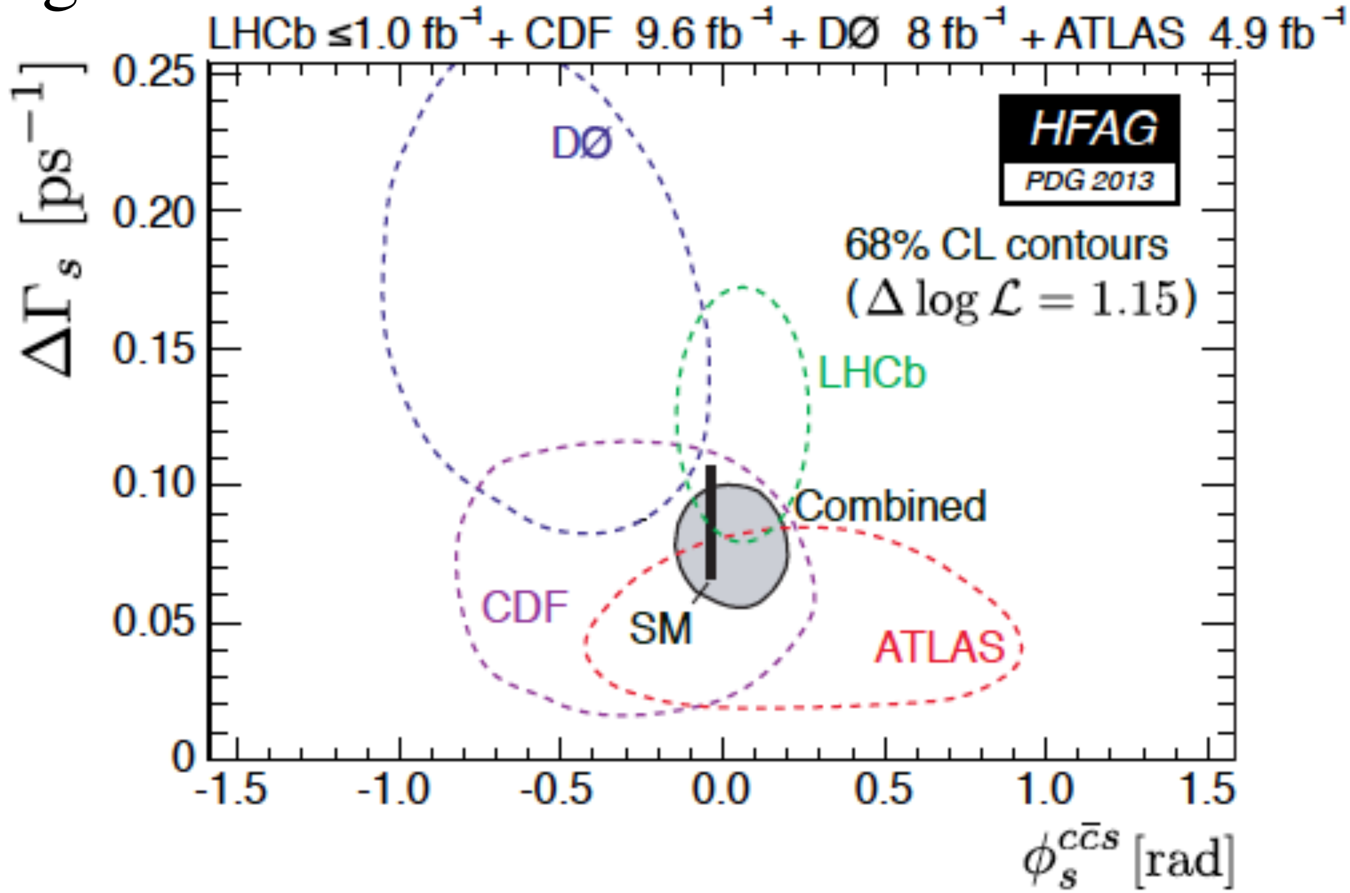
- Time dependent decay rate studies for $B_s \to J/\psi\phi$ decays
  - need to distinguish $J/\psi\phi_{CP=+1}$ and $J/\psi\phi_{CP=-1}$ states from **the angular distributions of the final states**:
  - **with initial flavour tag**, unique solution on CP violation parameter $\phi_S^{J/\psi\phi}$ and decay width difference $\Delta\Gamma=\Gamma_L-\Gamma_H$ measurements.



LHCb : Phys. Rev. D 87, 112010 (2013)

CP violation in $B_s \to J/\psi\phi$

- Good agreement with the Standard Model

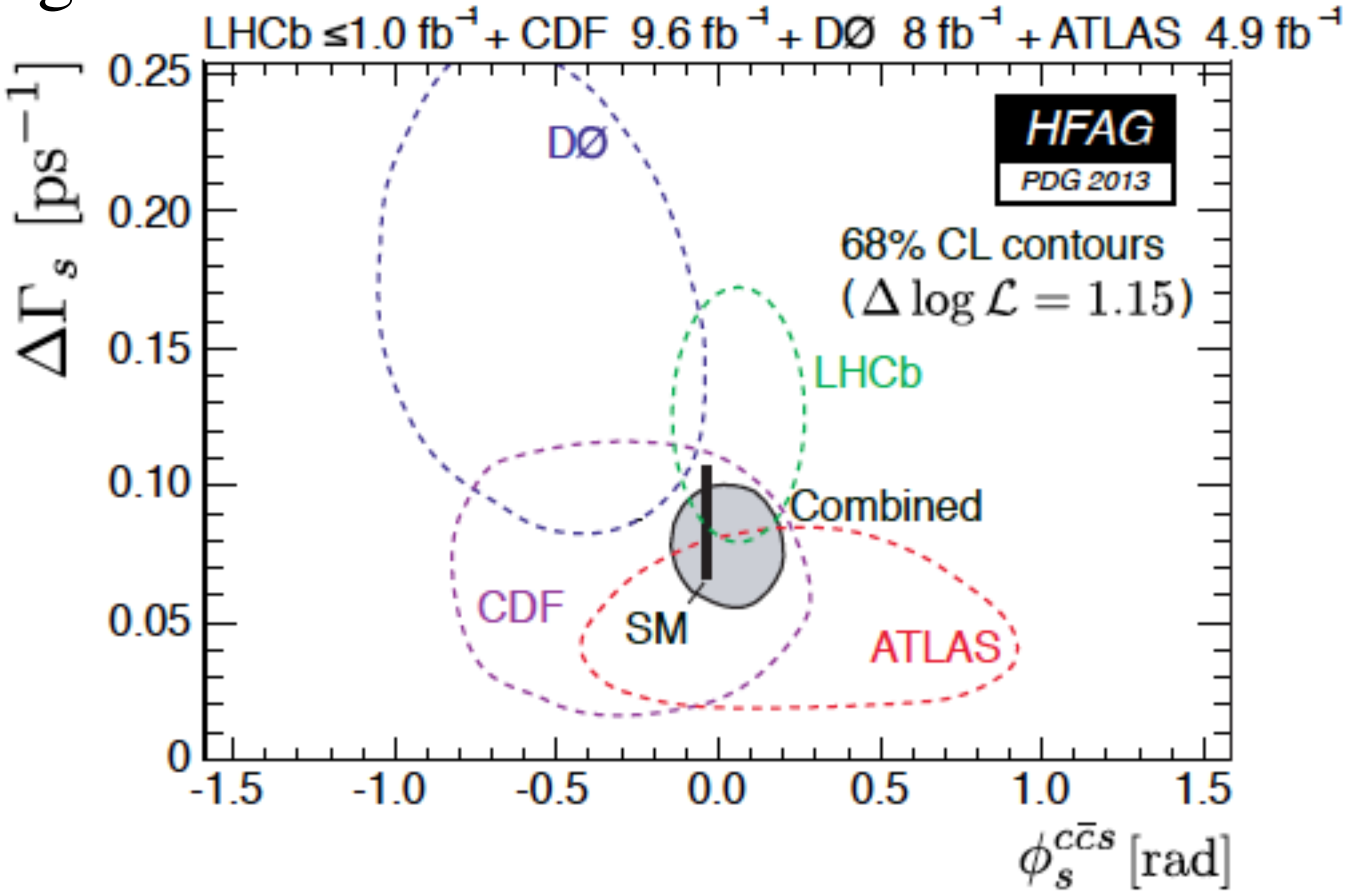


Updated by the recent ATLAS result shows 40% improvement in $\phi_s^{J/\psi\phi}$ with the flavour tag, and the most recent LHCb value

$$\phi_s^{J/\psi\phi} = 0.01 \pm 0.07 \pm 0.01 \ (KK + \pi\pi),$$

CP violation in $B_s \to J/\psi\phi$

- Good agreement with the Standard Model

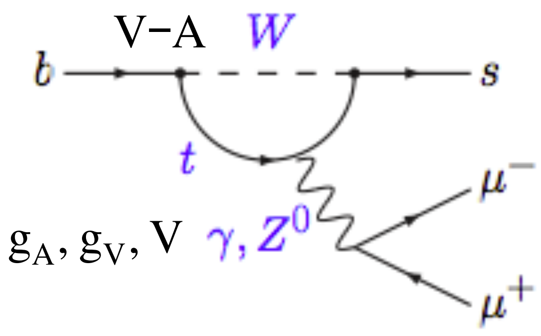


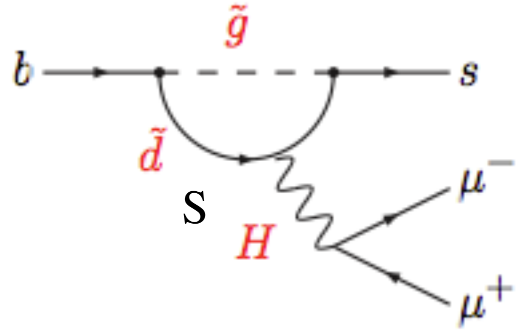
Sign of new particle neither in the mass (M_{12}) nor decay matrices (Γ_{12})

→large "a_{sl}" is inconsistent

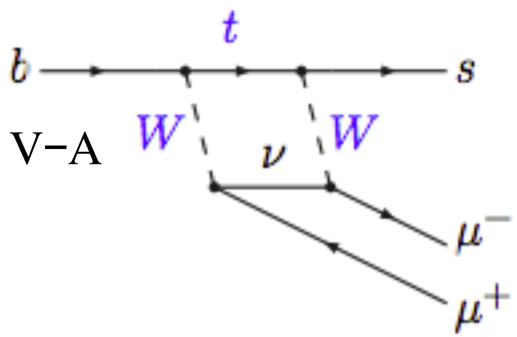
Rare semi-leptonic decays

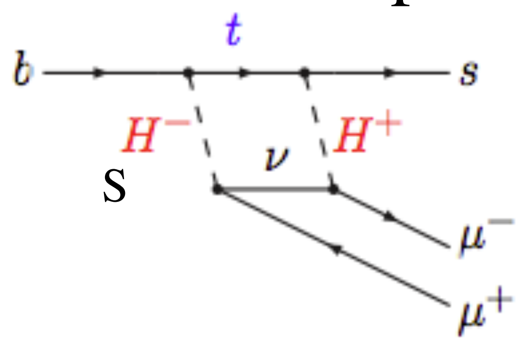
- Study of the Lorentz structure in the loop diagram $b \rightarrow s + \gamma^{*}(\mu^{+}\mu^{-})$ in the angular distribution of the decay products in $B_d(B_s) \rightarrow \mu^{+}\mu^{-}K^{*0}(\phi)$





+ new virtual particles?

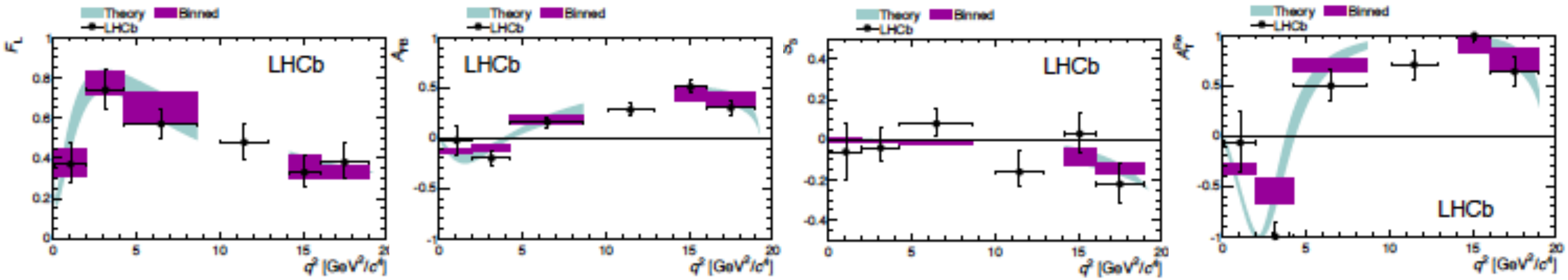




A bit like the Michel parameter measurement in the muon decays

Angular distribution

- Most agree well with the SM



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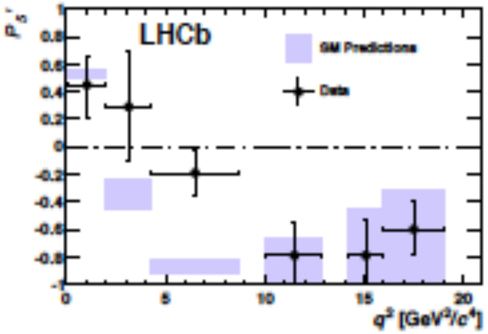
- But some not so well



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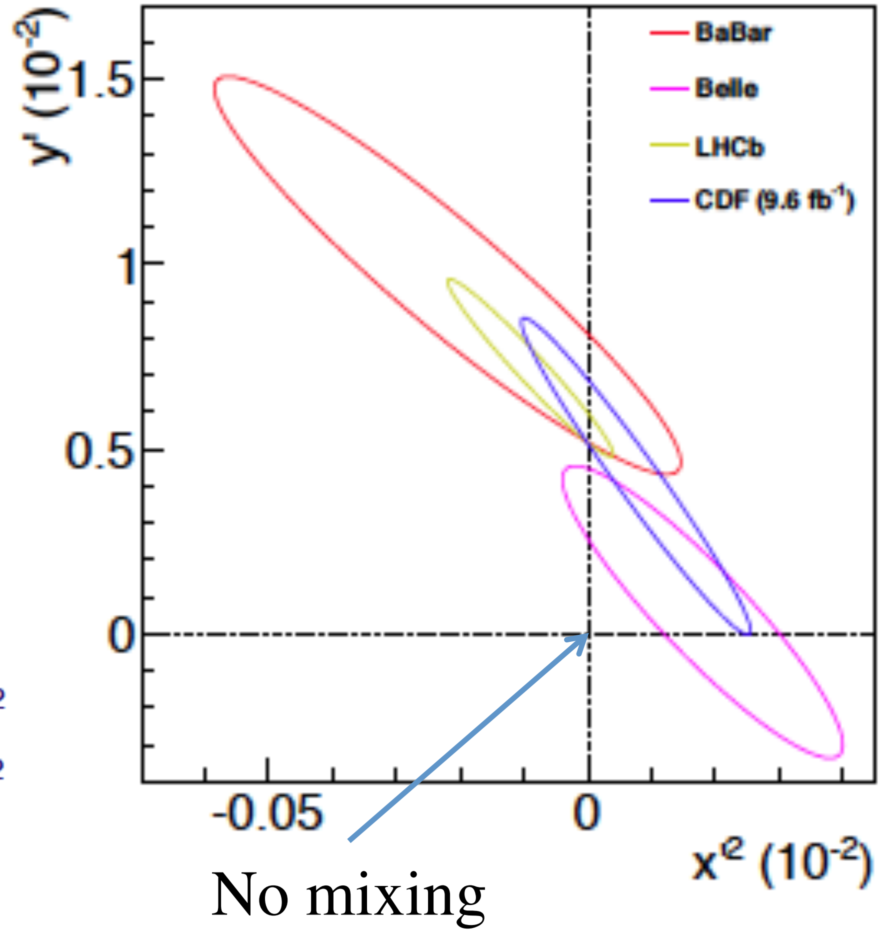
- Clearly, still too early to conclude.
- This kind of analysis, sensitive to the Lorentz structure, could remain sensitive to new physics even for MFV case

Interesting development in D decays

- D-$\overline{\text{D}}$ mixing confirmed
  No-mixing excluded. The SM predictions have large uncertainties
  x: mixing via mass-matrix
  y: mixing via decay-matrix



CDF: 6.1 σ; CDF Public Note 10990,

LHCb: 9.1 σ; Phys. Rev. Lett 110 (2013) 101802

Babar: 3.9 σ; Phys. Rev. Let 98 (2007) 211802

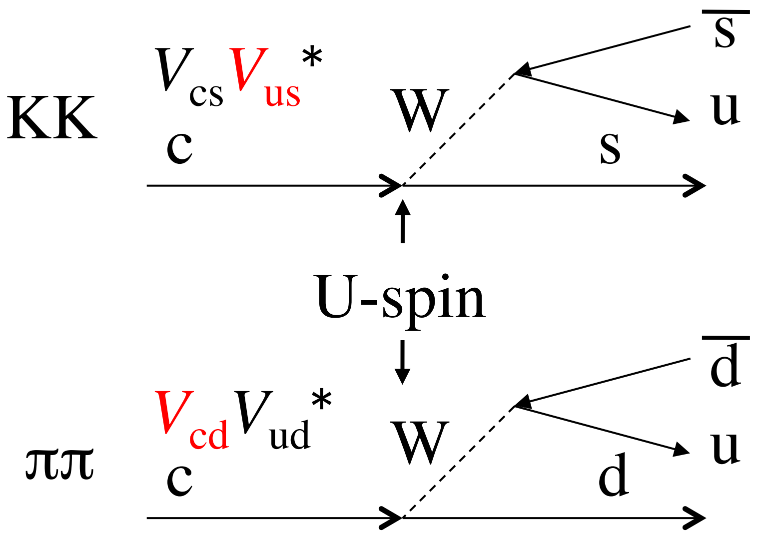
Belle: 2.0 σ; Phys. Rev. Lett 96 (2006) 151801

Interesting development in D decays

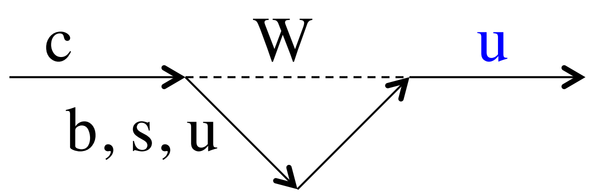
- D-$\overline{\text{D}}$ mixing confirmed
  No-mixing excluded.
- CP violation in D decay amplitudes
  $\Delta A_{\text{CP}} = A_{\text{CP}}(\text{D} \rightarrow \text{K}^+\text{K}^-) - A_{\text{CP}}(\text{D} \rightarrow \pi^+\pi^-)$

Interesting development in D decays

- D-$\overline{\text{D}}$ mixing confirmed
  No-mixing excluded.
- CP violation in D decay amplitudes
  $\Delta A_{CP} = A_{CP}(D \rightarrow K^+K^-) - A_{CP}(D \rightarrow \pi^+\pi^-)$
  naïve SM expectation: $A_{CP}(K^+K^-)$ and $A_{CP}(\pi^+\pi^-)$ have opposite signs and expected to be small, $\leq 10^{-3}$



+



$V_{ub}V_{cb}^* \{F(m_b) - F(m_d)\}$
$+ V_{cs}V_{us}^* \{F(m_s) - F(m_d)\}$

Interesting development in D decays

- D-$\overline{\text{D}}$ mixing confirmed
  No-mixing excluded.
- CP violation in D decay amplitudes
  $\Delta A_{CP} = A_{CP}(D \to K^+K^-) - A_{CP}(D \to \pi^+\pi^-)$
  LHCb result with slow-pion tagged "D" from the prompt
  $D^{*\pm}$ (0.6 fb^{-1}) generated an excitement
  $\Delta A_{CP} = (-8.2 \pm 2.1 \pm 1.1) \times 10^{-3}$ PRL108.111602
  followed by
  CDF $(-6.2 \pm 2.1 \pm 1.0) \times 10^{-3}$ PRL109.111801
  Belle $(-8.7 \pm 4.1 \pm 0.6) \times 10^{-3}$ arXiv:1212.1975

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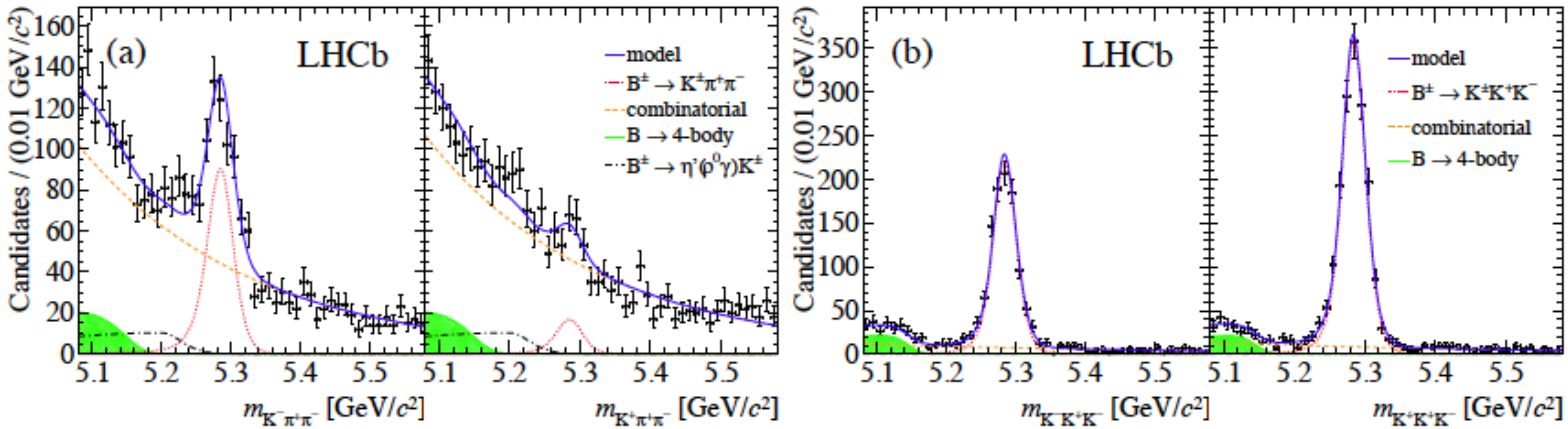
  Belle $(-8.7 \pm 4.1 \pm 0.6)\times 10^{-3}$ arXiv:1212.1975
  The latest LHCb results with $1\ fb^{-1}$ LHCb-CONF-2013-003 and PLB 723 (2013) 33
  $\Delta A_{CP} = (-3.4 \pm 1.5 \pm 1.0)\times 10^{-3}$ slow-pion tag
  $\Delta A_{CP} = (4.9 \pm 3.0 \pm 1.4)\times 10^{-3}$ μ tagged from $B \rightarrow \overset{(-)}{D}{}^0 \mu^{+(-)} X$
  average = $(-1.5 \pm 1.6)\times 10^{-3}$

Interesting development in D decays

- D-$\overline{\text{D}}$ mixing confirmed
  No-mixing excluded.
- CP violation in D decay amplitudes
  $\Delta A_{CP} = A_{CP}(D \rightarrow K^+K^-) - A_{CP}(D \rightarrow \pi^+\pi^-)$
  Inconclusive whether CPV is >>10^{-3}
  if ~10^{-3}, could be within the SM

Many many other studies

- Large CP Violation in $B^{\pm}\rightarrow K^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm}K^{+}K^{-}$ decays,



$0.08 < m^2_{\pi^+\pi^-} < 0.66\,\mathrm{GeV}^2/c^4$
$m^2_{K^\pm\pi^\mp} < 15\,\mathrm{GeV}^2/c^4$

$1.2 < m^2_{K^+K^-\,\mathrm{low}} < 2.0\,\mathrm{GeV}^2/c^4$
$m^2_{K^+K^-\,\mathrm{high}} < 15\,\mathrm{GeV}^2/c^4$

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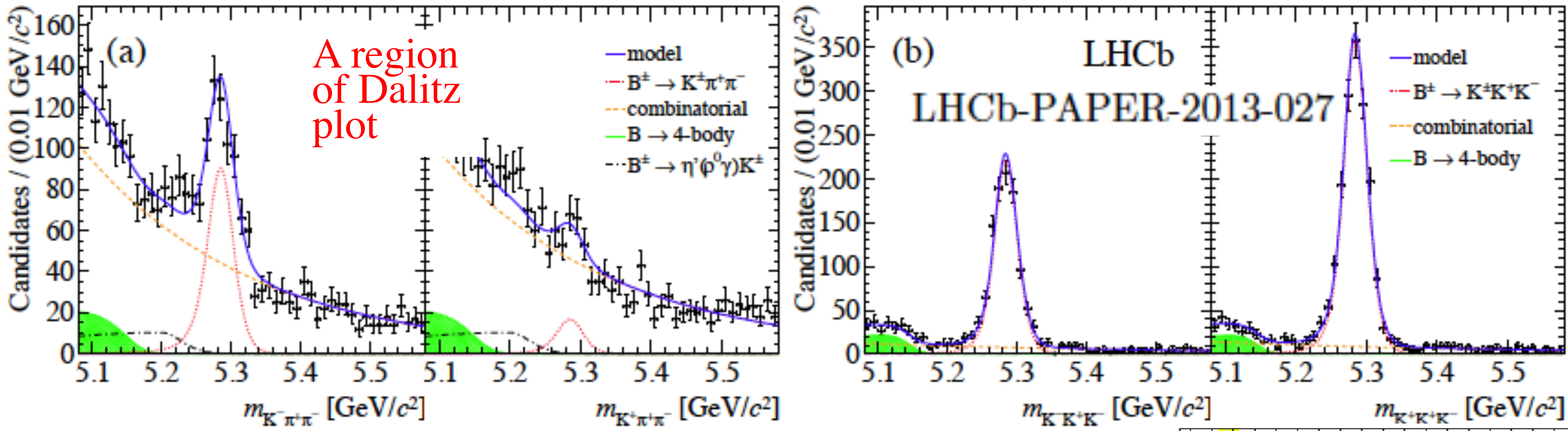
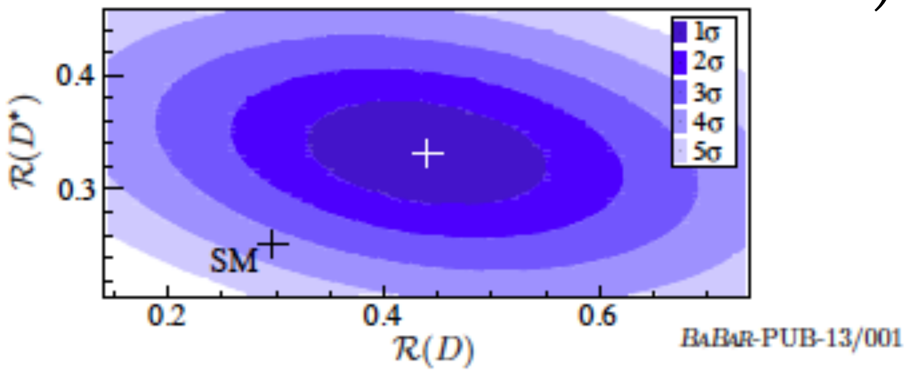
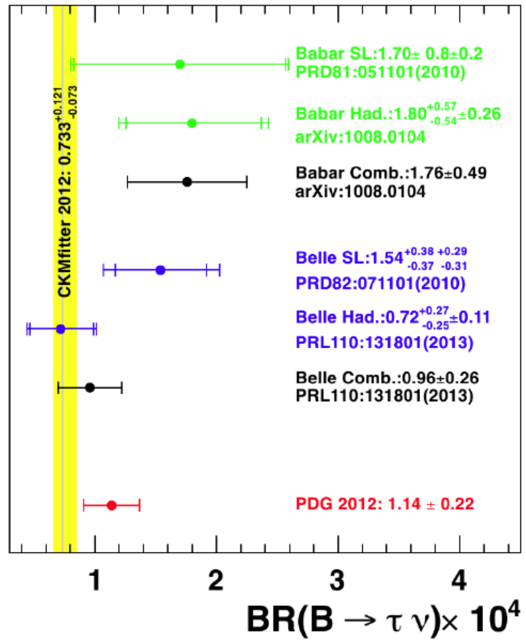
Many many other studies

- Large CP Violation in $B^{\pm}\to K^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm}K^{+}K^{-}$ decays



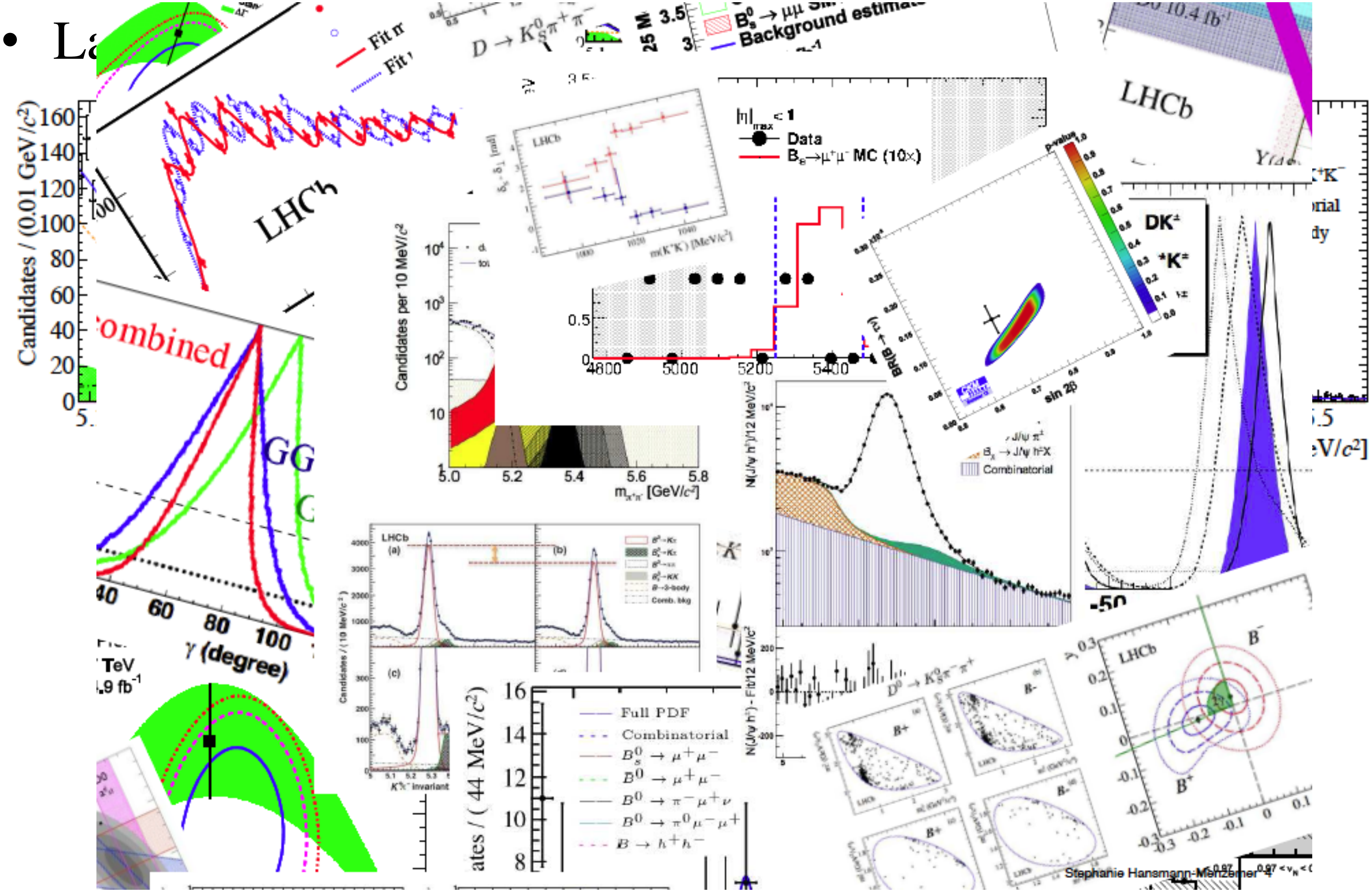
- Search for charged Higgs in the tree diagram with not so rare decays : $B\to D^{(*)}\tau\nu$ / $B\to D^{(*)}\mu$(or e)ν also $B\to\tau\nu$





Many many other studies

- La



Near future

- Analysis with 7-8 TeV full data set within the next year.
- Further gain in statistics from higher b-b cross section (×~2) and running time: three to four times increase in "effective" statistics by the end of 2017? (more for some decay modes fro ATLAS and CMS?)
- More and more sophisticated analysis methods are being developed.
- Belle II will become online in ~2016
- LHCb Major upgrade during the 2018-2019 long-shutdown to boost the statistics by $\gtrsim$10

Also important to remember

- Results will come from
  - the kaon system in rare decays ($K^+ \to \pi^+ \nu\nu$) and CPV ($K_L \to \pi^0 \nu\nu$)
  - charge lepton violating μ decays; →3e, →eγ, μ-e conversion and, and τ decays, →3μ, →μγ, →eγ
  - Flavour conserving quantities such as neutron electric dipole moment and $(g-2)_\mu$
- i.e. flavour should be considered more globally.
- Accurate Standard Model predictions are essential in the precision measurements. Strong interactions are still the most problematic issue in many measurements ⇒ help from our theory friends are always needed!
- By the way, axions have not been discovered so far, and $\theta_{QCD} < 10^{-10}$ appears to me as another "fine tuning"…

Reflection

- CP violation & rare decays made essential contributions to establish the flavour structure of the SM in the past
- Main motivation of flavour related measurements now is to search for new physics: with e.g. rare decays, CPV, etc.
- In B and D sector, LHC starts to lead the way. Possibility of large new physics contribution in the B_s sector has already been eliminated
- Despite of cosmological "proof" for new physics as well as the neutrino mass, and many clever theoretical works, we have little idea where the energy threshold of new physics.
- We need to observe a clear sign of new physics, directly or indirectly, in particle physics, to know this. And I am afraid there is no obvious road for a discovery

Reflection

- There are many motivated people working in the broad field. Since there is no obvious road, pursuits must be carried away as wide as possible.
- And the exploitation at LHC has just started!

My standard joke of the past years…

My hope, expectation and possible realities
matrix for 2014 at LHC

ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

Oh, no more space left…

Particle Physics in LHC Era,
T. Nakada

XXVIII Encontro Nacional de Física de Partículas e
Campos, Brazil, 2007

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