Experimental Results on Flavour Physics

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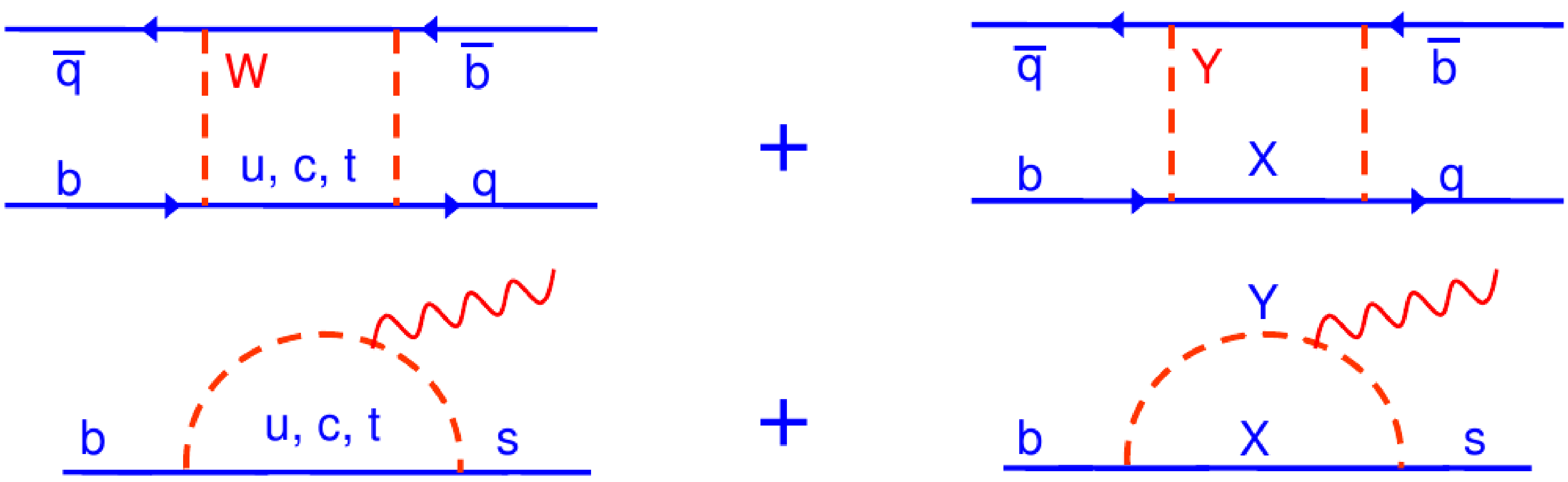
on behalf of the LHCb, ATLAS, Babar, Belle, CDF, CMS and D0 collaboration

this talk will describe the measurements, their impact on NP models is part of the next talk of Jernej Kamenik

Search for New Physics in the Flavour Sector

New Physics are corrections to Standard Model processes:

Standard Model   New Physics

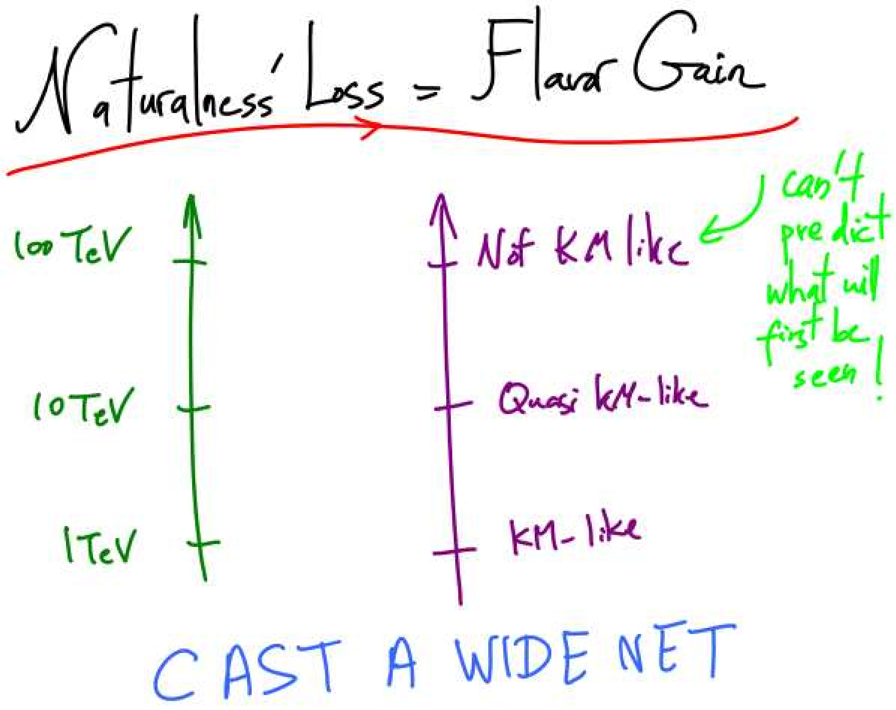


$$\mathcal{A}_{BSM} = \mathcal{A}_0 \left(\frac{C_{SM}}{m_W^2} + \frac{C_{NP}}{\lambda_{NP}^2} \right)$$

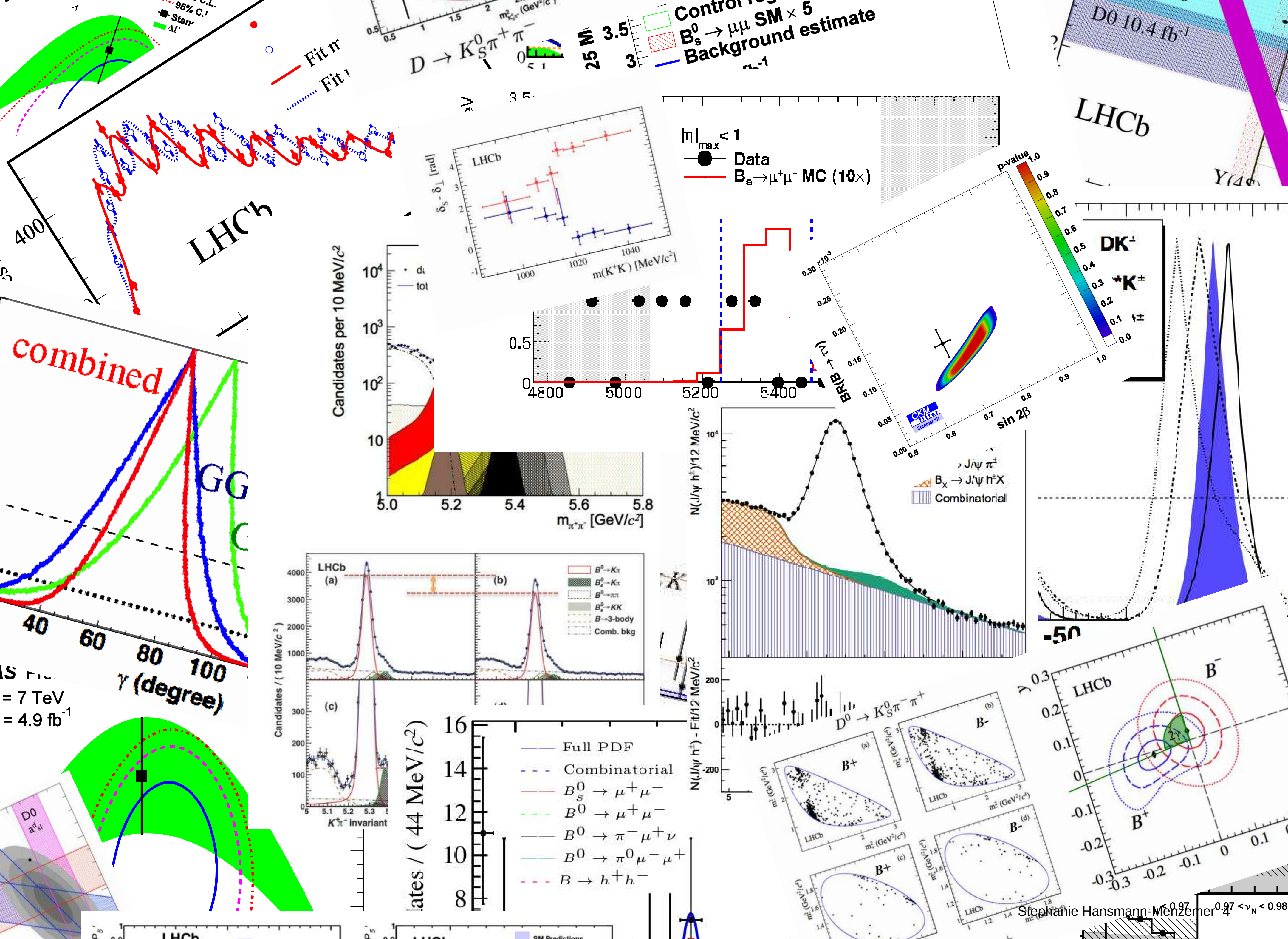
What is the scale of λ_{NP}? How much different are C_{NP} and C_{SM}?

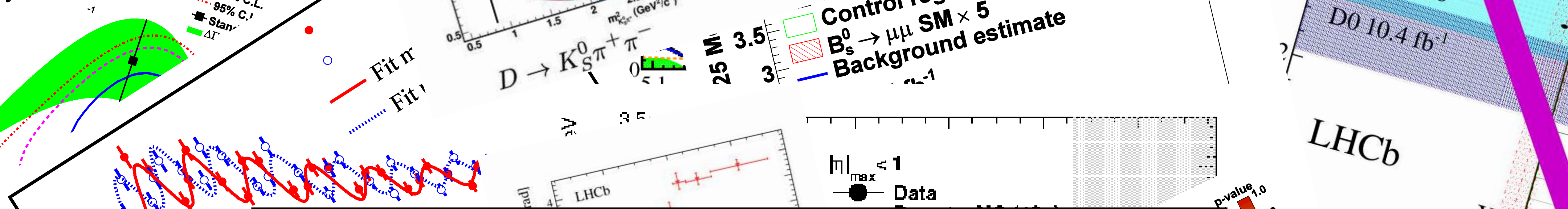
Loss of Naturalness = Gain in Flavour

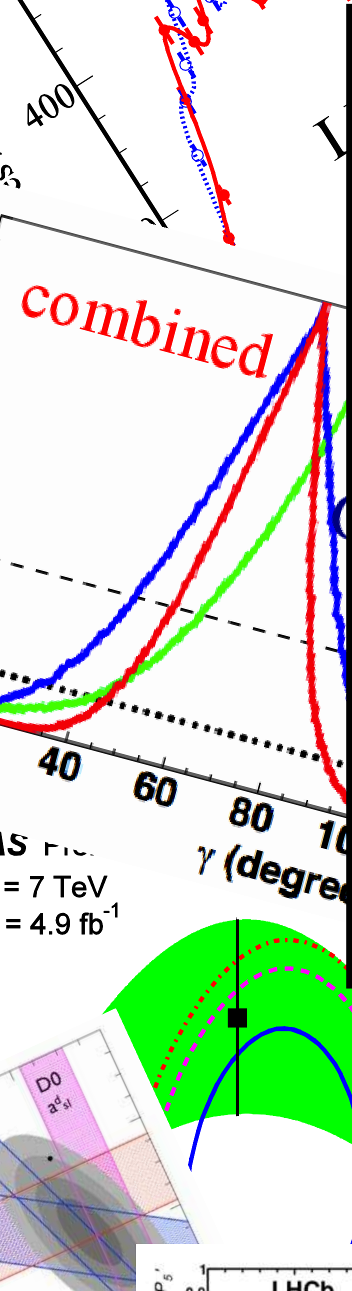
- Before LHC $\lambda_{NP} \sim 1$ TeV seemed “naturally” to reduce “fine tuning” of the EW energy scale.
- Absence of NP effects in flavour physics (even before LHC) $\longrightarrow$ “fine tuning” in the flavour sector (MFV)
- As LHC pushes the energy scale of NP higher, hypothesis like MFV less likely $\longrightarrow$ chances to see NP in flavour physics



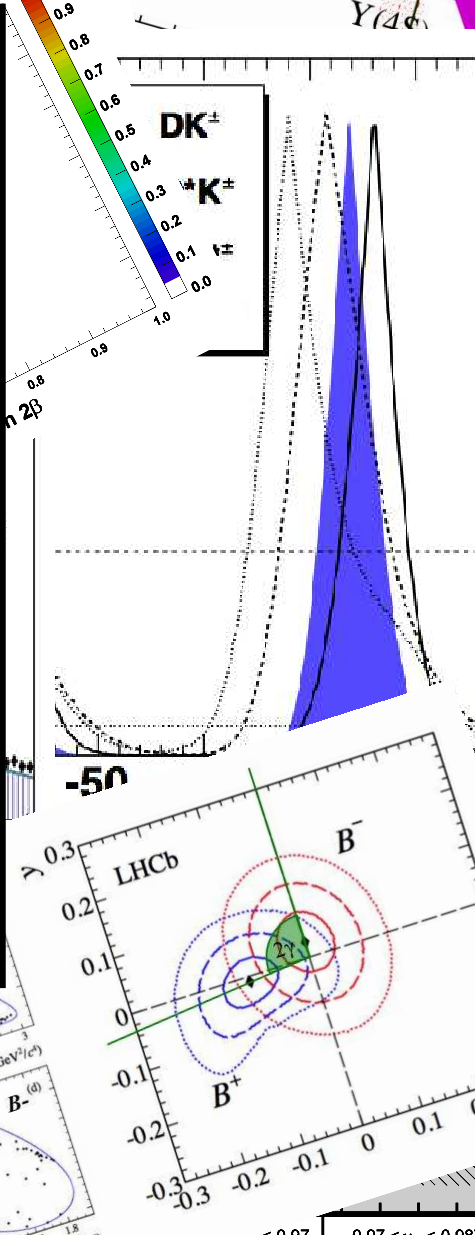
N. Arkani-Hamed
Intensity Frontier Workshop, 2011

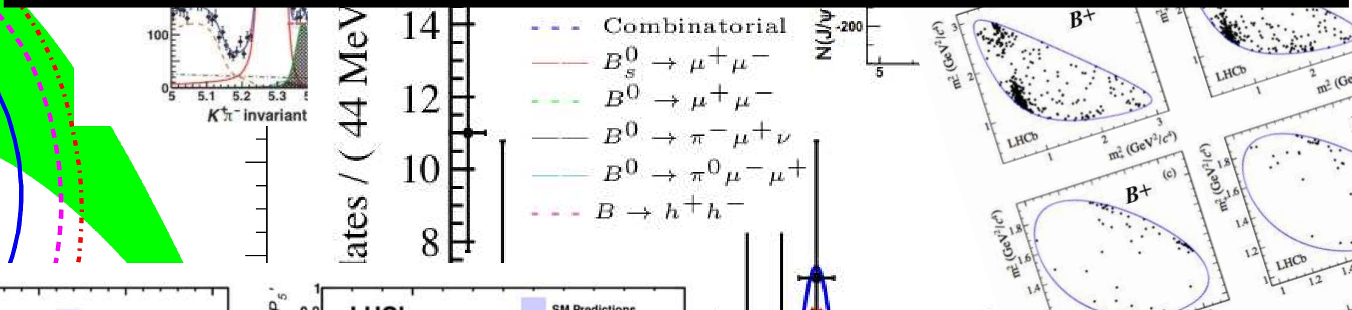

LHCb
combined
γ (degree)
= 7 TeV
= 4.9 fb-1
D → K0S π+ π−
Control reg
B0s → μμ SM × 5
Background estimate
|η|max < 1
Data
Bs→μ+μ- MC (10×)
Candidates per 10 MeV/c2
mπ+π- [GeV/c2]
δS - δ⊥ [rad]
m(K+K-) [MeV/c2]
p-value
sin 2β
BR(B → τν)
D0 10.4 fb-1
DK±
N(J/ψ h±)/12 MeV/c2
Bx → J/ψ h±X
Combinatorial
B0→Kπ
B0s→Kπ
B0→ππ
B0s→KK
B→3-body
Comb. bkg
Candidates / (10 MeV/c2)
Full PDF
Combinatorial
B0s → μ+μ−
B0 → μ+μ−
B0 → π−μ+ν
B0 → π0μ−μ+
B → h+h−
D0 → K0S π− π+
B+
B-
2γ





- Direct CP violation in B decays
- Measurement of CKM angle γ
- CP violation in B mixing
- Tension in $B \to D^{(*)}\tau\nu_\tau$
- B lifetimes
- (Very) rare B decays
- Charm physics
- Production & spectroscopy



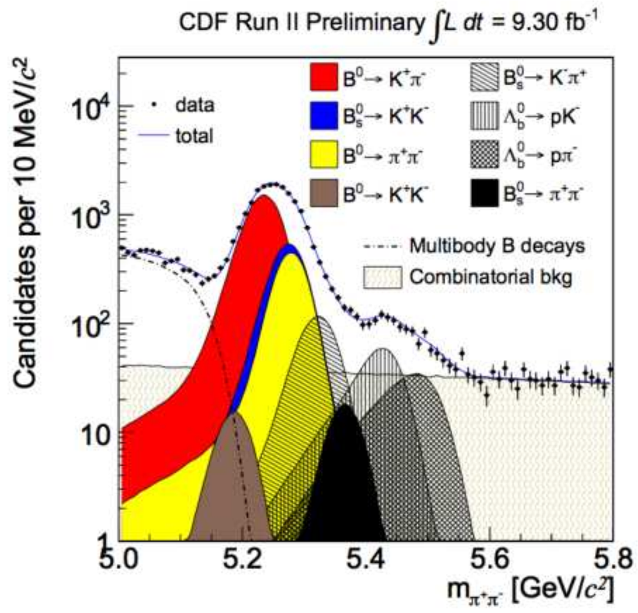


Time integrated CPV in $B \to K\pi$

CDF (CDF public note 10726: 9.3 fb^{-1})

$A_{CP}(B^0 \to K^+\pi^-)$ = -0.083 $\pm$ 0.013 $\pm$ 0.003

$A_{CP}(B_s \to K^-\pi^+)$ = +0.22 $\pm$ 0.07 $\pm$ 0.02



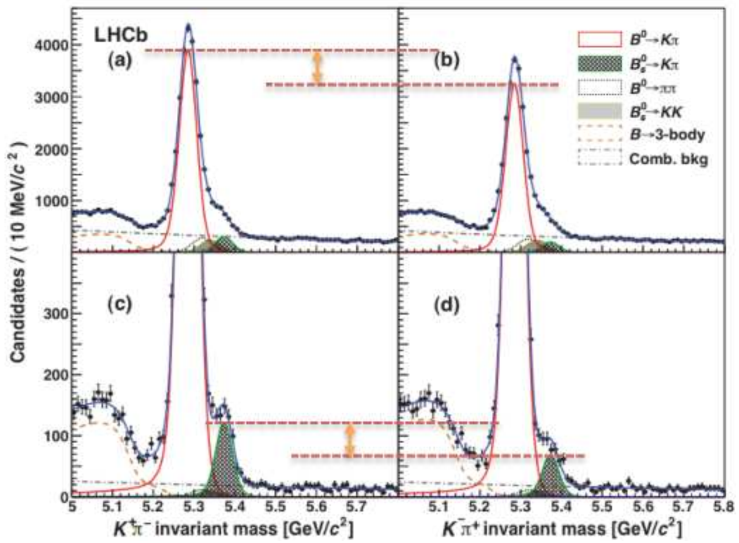
LHCb (PRL110(2013)221601: 1 fb^{-1})

$A_{CP}(B^0 \to K^+\pi^-)$ = -0.080 $\pm$ 0.007 $\pm$ 0.003

$A_{CP}(B_s \to K^-\pi^+)$ = +0.27 $\pm$ 0.04 $\pm$ 0.01

first observation of CPV in B_s

$D \to K\pi/KK$ decays used to get kaon detection asymmetry



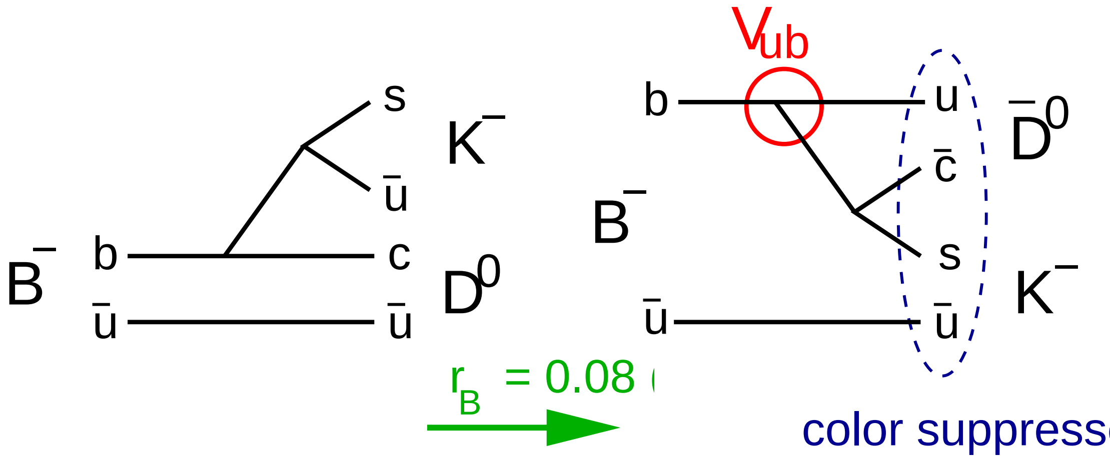
Test SM prediction (PLB 221(2005)126)

$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s \to K^-\pi^+)} + \frac{BR(B_s \to K^-\pi^+)}{BR(B^0 \to K^+\pi^-)} \frac{\tau_d}{\tau_s} = 0$$

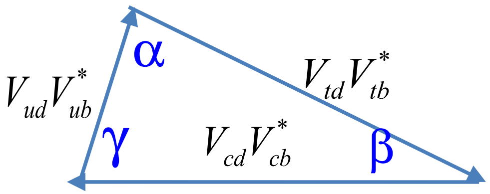
LHCb: Δ = -0.02 $\pm$ 0.05 $\pm$ 0.04

New LHCb results for time dependent CPV in $B^0_{(s)} \to hh$ (penalty of tagging at hadron colliders)

γ in Trees: $B \rightarrow Dh$



color suppressed



- $B \rightarrow DK$ still most important channel to measure γ
- study $D/\overline{D}$ meson in final state accessible to both to achieve interference

  unknowns: r_B, δ_B, γ, r_D, δ_D (r: ratio, δ: strong phase)

  $\rightarrow$ simultaneous analysis of several modes

  - GLW: CP eigenstate (e.g. K^+K^-, $\pi^+\pi^-$);
  - ADS: common flavour state (e.g. $K^+\pi^-$, $K^+3\pi$, ...);
  - GGSZ - “Dalitz”: self-conjugate 3-body final state (e.g. $K_S hh$)

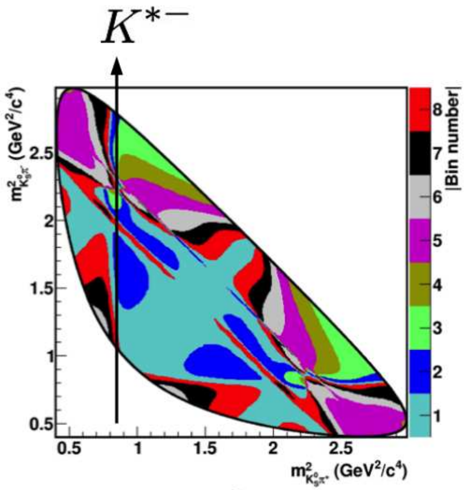
} no flavour tagging

γ in Trees: $B \to Dh$

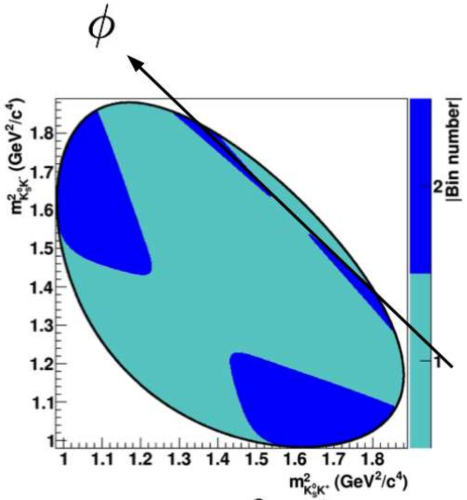
model independent GGSZ

- Variation of strong phases over Dalitz space from CLEO

  (Phys. Rev. D 82 112006)



$D \to K_S^0 \pi^+ \pi^-$

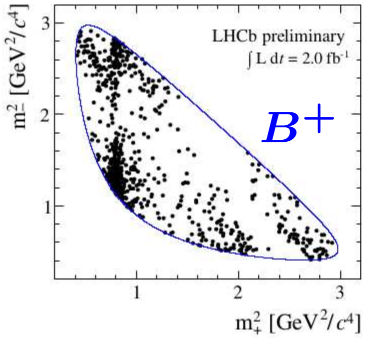


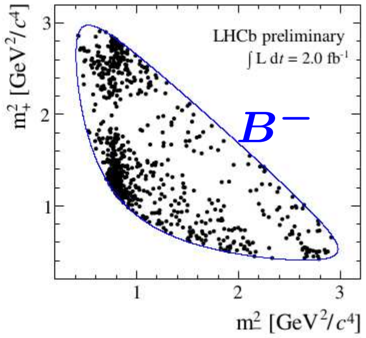
$D \to K_S^0 K^+ K^-$

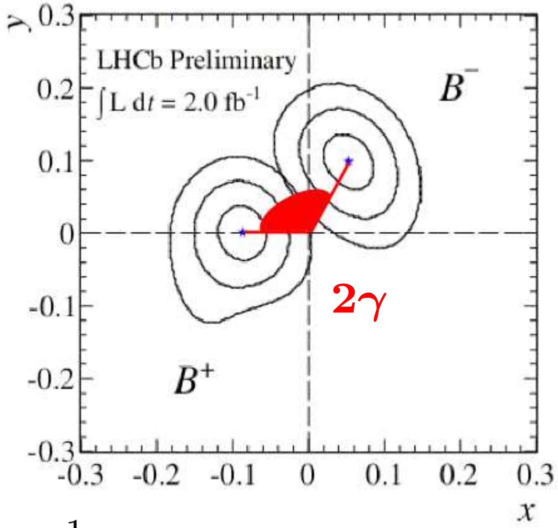
- 4 observables:

  $x_\pm = r_B \cos(\delta_B \pm \gamma)$

  $y_\pm = r_B \sin(\delta_B \pm \gamma)$







LHCb-CONF-2013-004 (2fb^{-1})

At B factories, this method is the most powerful way to measure γ!

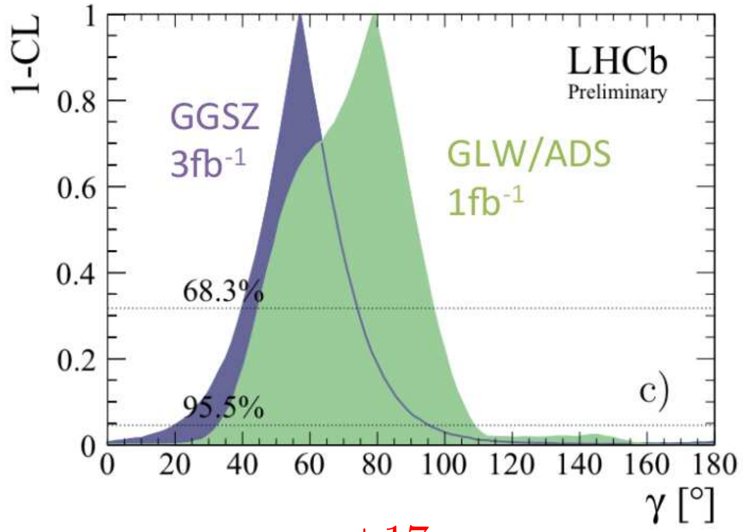
γ: Combinations

LHCb result (LHCb-CONF-2013-006)

$\gamma = (67 \pm 12)^\circ$

$r_B = (9.2 \pm 0.8) \times 10^{-2}$

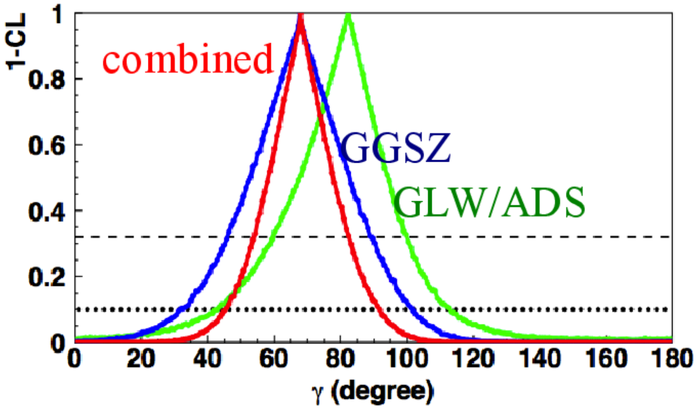
$\delta_B = (114^{+12}_{-13})^\circ$



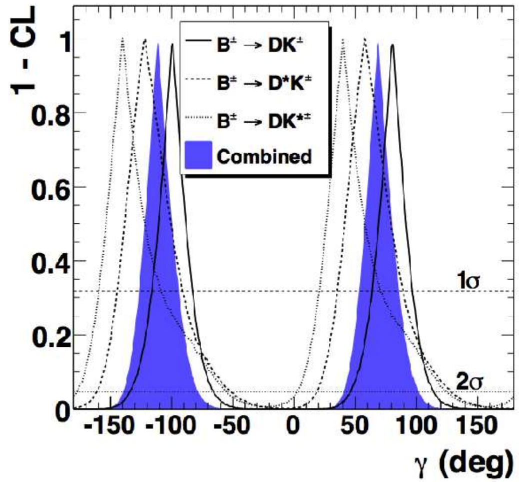
Belle: $\gamma = (68^{+15}_{-14})^\circ$

BaBar: $\gamma = (69^{+17}_{-16})^\circ$

(without new ADS result shown at this conference)



arXiv:1301.2033



Phys Rev D 87, 052015 (2013)

Prediction UTFit: $\gamma = (68.6 \pm 3.6)^\circ$

CKMFitter: $\gamma = (68.0^{+4.1}_{-4.6})^\circ$

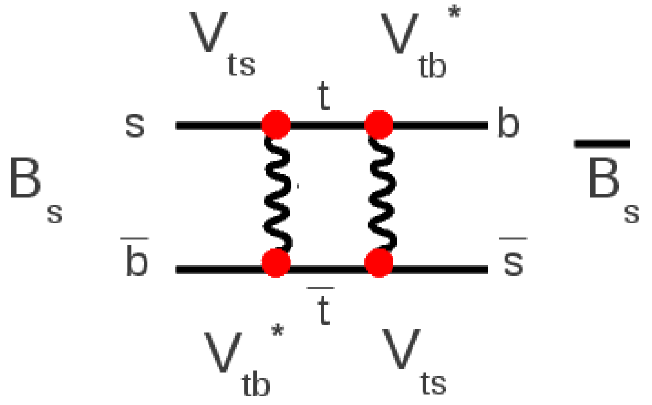
Very good agreement between direct measurements and fit

$B_s - \overline{B_s}$ Oscillation

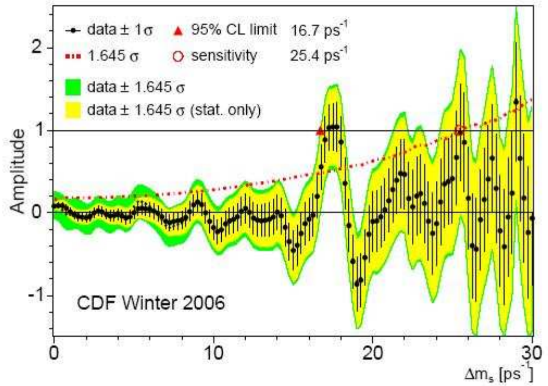
weak eigenstate $\neq$ mass eigenstates

two eigenstates with diff. mass and width

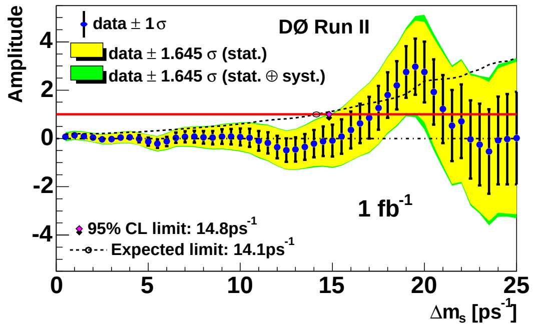
(5 parameters: m, Γ, $\Delta\Gamma$, Δm_s, ϕ_s)



discovery in 2006

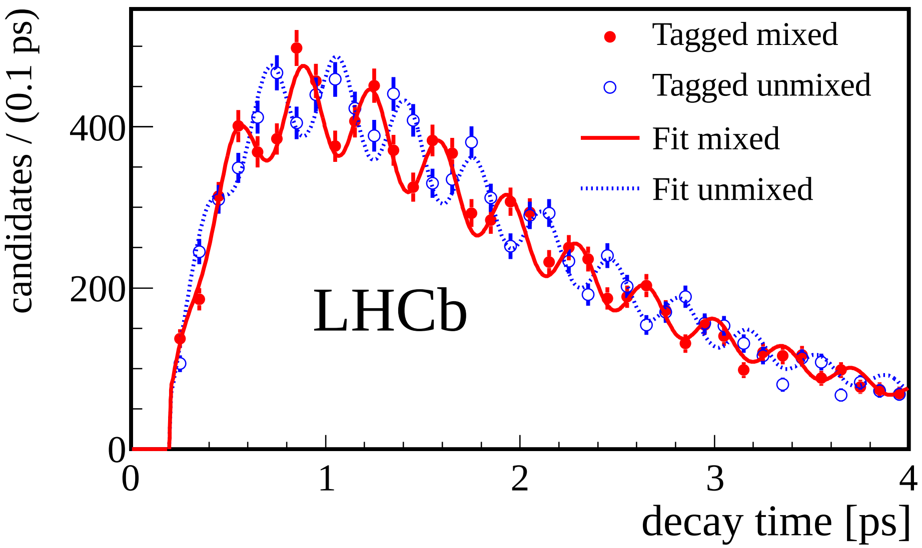


PRL 97, 24 2003 (2006) (1 fb^{-1})



Phys. Rev. Lett. 98, 121801 (2006)

precision measurement 2013



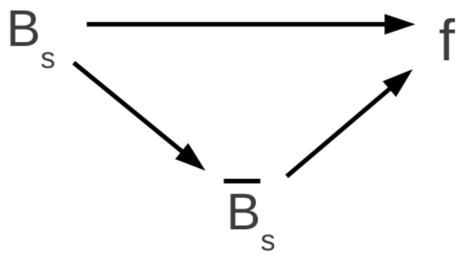
New J. Phys. 15 (2013) 053021 (1 fb^{-1})

B_s Mixing Phase ϕ_s

Access to phase via interference of mixing + decay

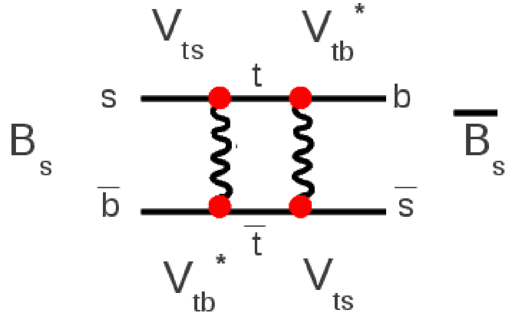
and direct decay into a CP eigenstate f

(e.g. $B_s^0 \to J/\Psi K^+ K^-$ - mixture of CP eigenstates, angular analysis needed,
$B_s^0 \to J/\psi \pi^+ \pi^-$ - CP odd 95% CL)



SM expectation (Phys. Rev. D84 (2011) 033005, http://ckmfitter.in2p3.fr):

$\phi_s^{SM} \approx -2\arg(V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) = -0.0364 \pm 0.0016$ rad



measurement of modulation

in decay time distribution

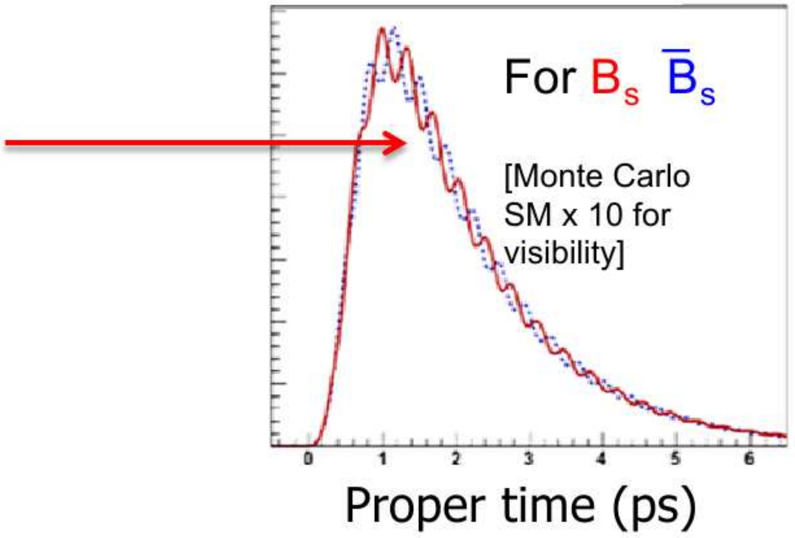
observable: $\sin\phi_s \times \sin\Delta m_s t$

important tools:

flavour tagging,

decay time resolution

& angular analysis

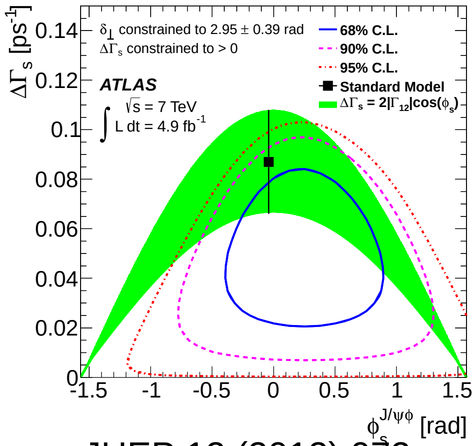


$B_s \to J/\psi\phi$

	CDF	D0	LHCb	ATLAS	CMS*)
$\int \mathcal{L}$ [fb^{-1}]	9.6	8.0	1.0	4.9	5.0
# $B_s \to J/\psi KK(f_0)$	11k	5.6k	27.6k (7.4k)	22.7k	14.5k
ϵD^2 OS [%]	1.39 ± 0.05	2.48 ± 0.22	2.29 ± 0.22	1.45 ± 0.05	-
ϵD^2 SS [%]	3.5 ± 1.4	-	0.89 ± 0.18	-	-
σ_t [fs]	100	100	48	100	-
Reference	PRL 109(2012) 171802	PRD85(2012) 032006	PRD87(2013) 112010	ATLAS-CONF-2013.029	CMS-PAS BPH-11-006

* CMS: $\Delta\Gamma$ only: $0.048 \pm 0.024 \pm 0.003$ ps^{-1}

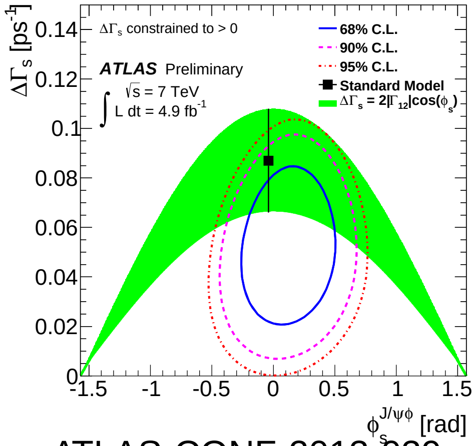
ATLAS untagged result



JHEP 12 (2012) 072

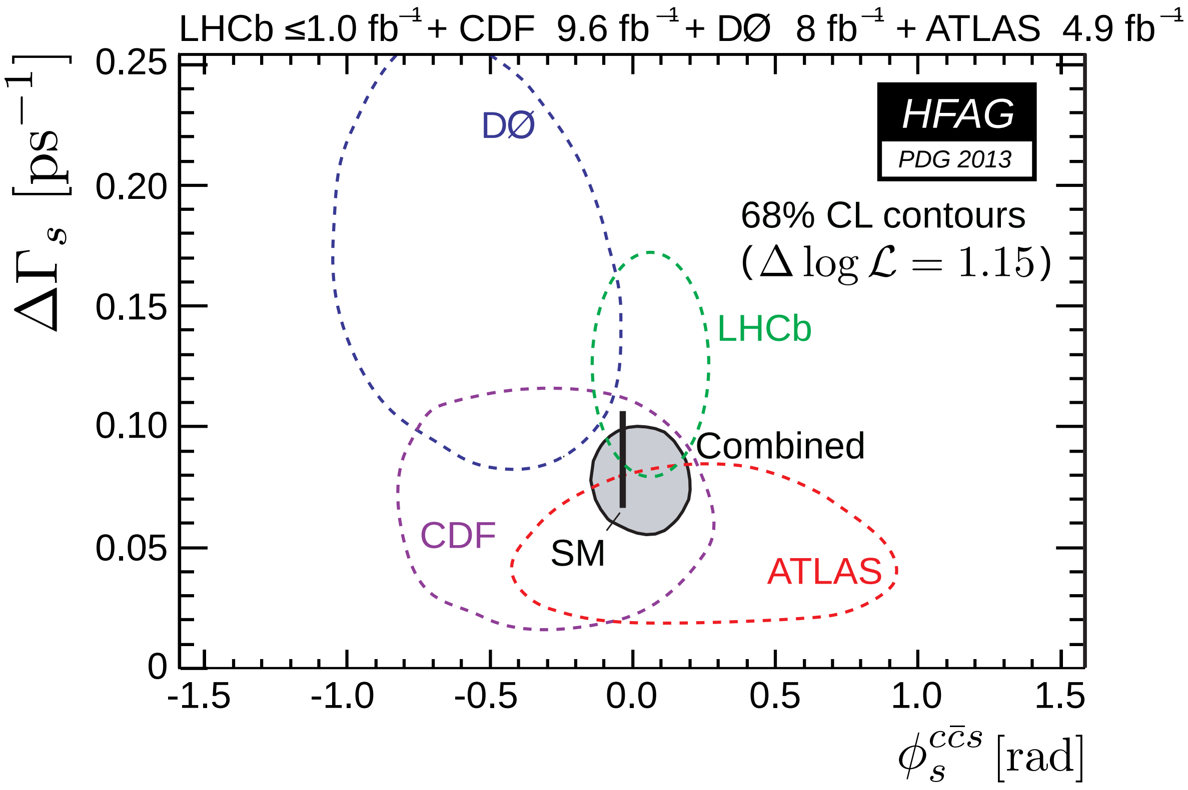
uncertainty on ϕ_s improved by 40%

ATLAS tagged result



ATLAS-CONF-2013-039

Results



LHCb result (Phys. Rev. D 87 112010 (2013) - 1fb^{-1}):

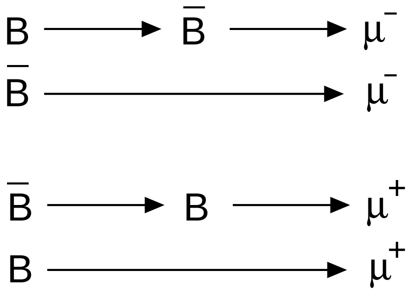
ϕ_s = 0.01 $\pm$ 0.07 $\pm$ 0.01 rad

$\Delta\Gamma_s$ = 0.106 $\pm$ 0.011 $\pm$ 0.007 ps^{-1}

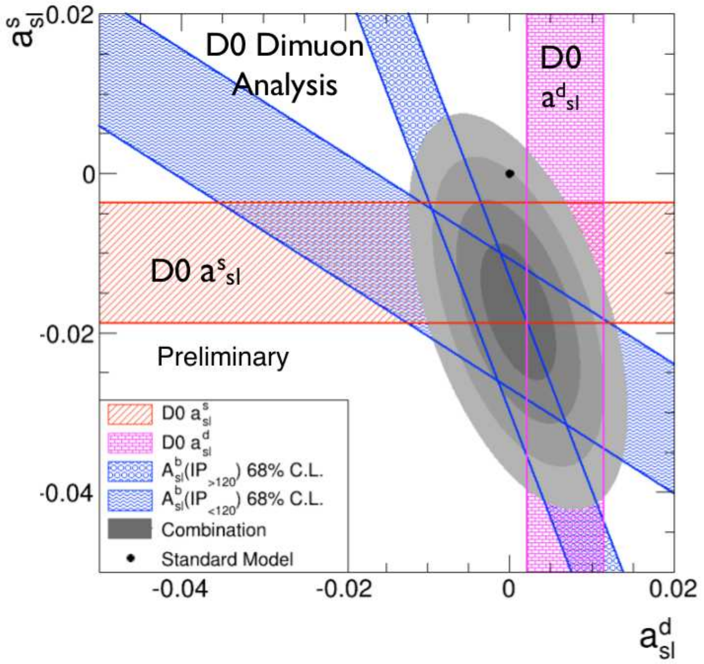
Γ_s = 0.661 $\pm$ 0.004 $\pm$ 0.006 ps^{-1}

$P(B_q \to \overline{B_q}) \neq P(\overline{B_q} \to B_q)$

di-muon asymmetry ($B^0 + B_s$)



$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$



semileptonic (untagged) asymmetry:

$$a^s_{sl} \propto \frac{N(\mu^+ D_s^{(*)-}) - N(\mu^- D_s^{(*)+})}{N(\mu^+ D_s^{(*)-}) + N(\mu^- D_s^{(*)+})}$$

$$a^d_{sl} \propto \frac{N(\mu^+ D^{(*)-}) - N(\mu^- D^{(*)+})}{N(\mu^+ D^{(*)-}) + N(\mu^- D^{(*)+})}$$

assuming no production asymmetry and

no CP in semileptonic decays

PRD 86, 072009 (2012), PRL, 10, 011801 (2013),
PRD 84, 052007 (2011)

D0 only results:

A_{CP} = (-0.276 $\pm$ 0.067 $\pm$ 0.063)% (9.0 fb^{-1})

3.9 $\sigma \equiv$ 0.33% compatible with SM

ϕ_s, a_{sl} as well not compatible in NP models ...

expected sensitivity of 10.4 fb^{-1} analysis:

A_{CP} = (xxx $\pm$ 0.064 $\pm$ 0.055)%

new @ EPS2013

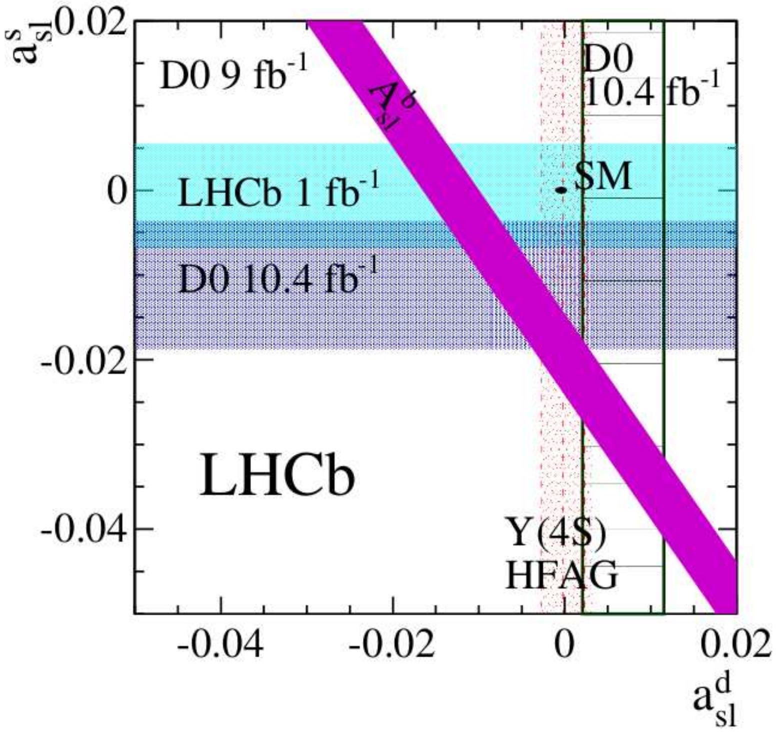
$P(B_q \to \overline{B_q}) \neq P(\overline{B_q} \to B_q)$

LHCb: pp collider $\to$ production asymmetry

$$A_{meas} = \frac{N(D_q^- \mu^+) - N(D_q^+ \mu^-)}{N(D_q^- \mu^+) + N(D_q^+ \mu^-)} = \frac{a_{sl}^q}{2} + [a_{prod} - \frac{a_{sl}^q}{2}]\kappa_q$$

due to fast B_s oscillation time integrated a_{sl}^s measurement possible ($\kappa_s = 0.2\%$)

however for a_{sl}^d time dependent analysis required ($\kappa_d \sim 30\%$)



a_{sl}^s = (-0.06 $\pm$ 0.50 $\pm$ 0.36)%

LHCb-PAPER-2013-033-001

single most precise result on a_{sl}^d

using partial reconstructed

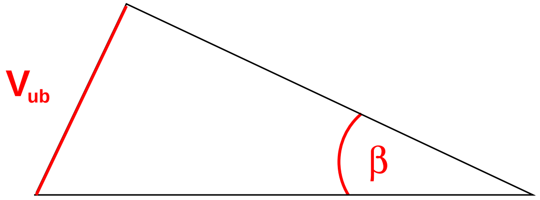
$B \to D^* \ell \nu$ + kaon tags:

a_{sl}^d = (0.06 $\pm$ 0.16$^{+0.36}_{-0.32}$)%

Babar: arXiv:1305.1575

Summary of V_{ub}

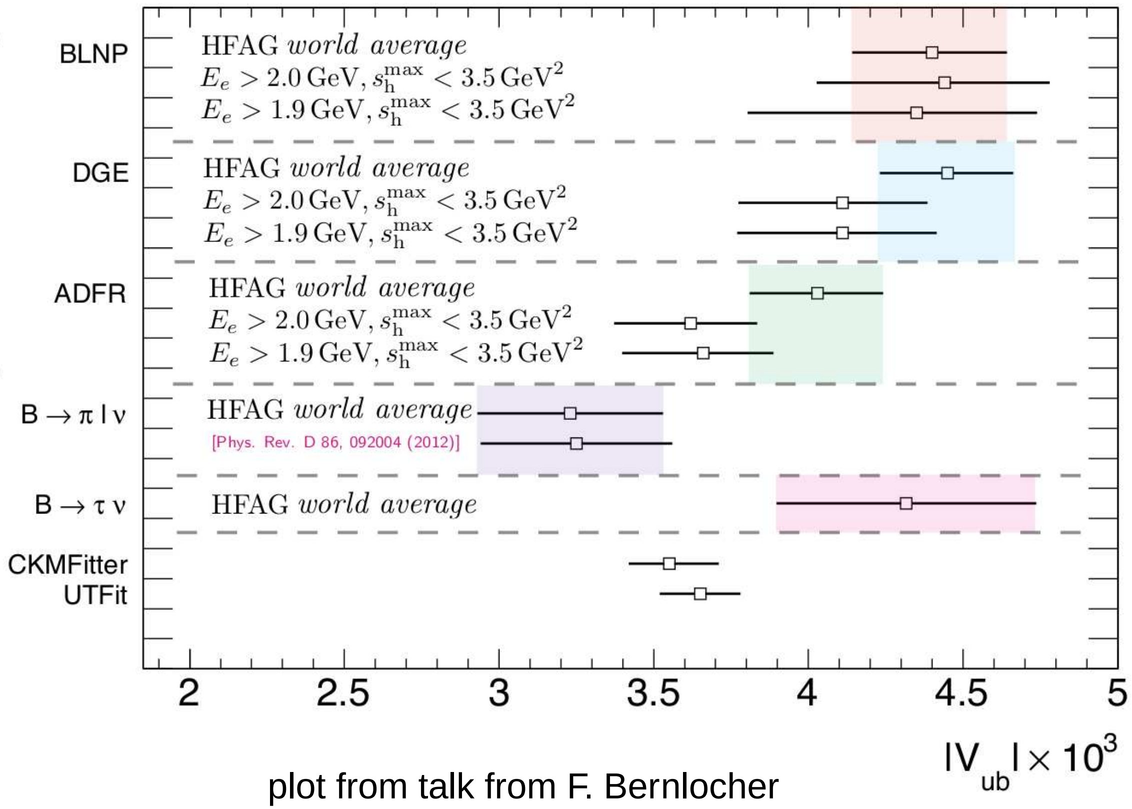
Access to V_{ub} via inclusive semileptonic decays, exclusive semileptonic decays or fit to CKM triangle ($\sin 2\beta$)



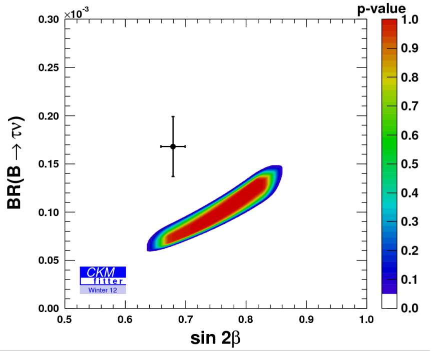
Babar results

Inclusive

new @ EPS2013



plot from talk from F. Bernlocher

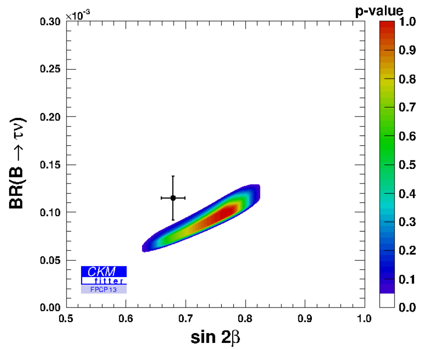


ICHEP 2012

BELLE result

on $BR(B^+ \to \tau\nu)$

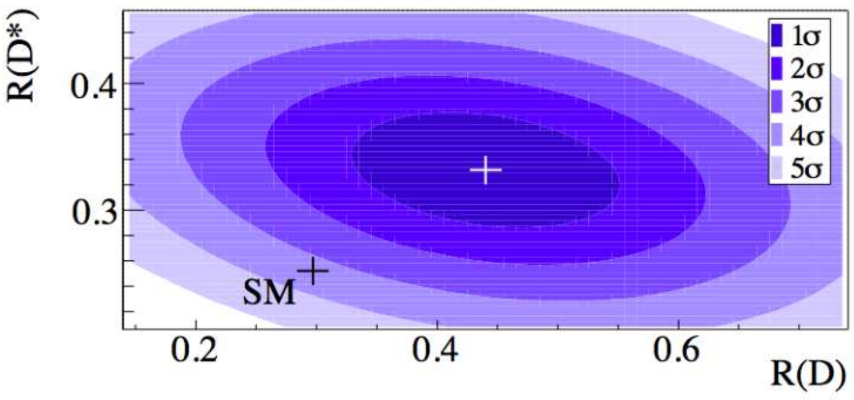
(PRL 110 131801)



tensions decreased with recent data

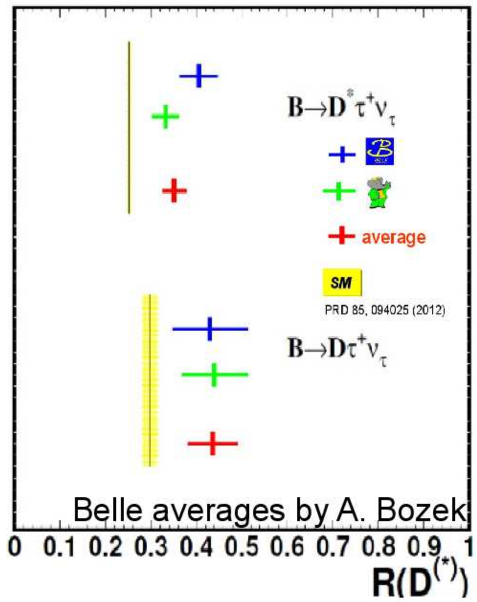
$B \to D^{(*)}\tau\nu$

$$R(D^{(*)}) = \frac{\Gamma(B \to D^{(*)}\tau\nu_\tau)}{\Gamma(B \to D^{(*)}\ell\nu_\ell)_{\ell=e,\mu}}$$



3.4 σ deviation from SM

PRL 109, 101802 (2012), arXiv: 1303.0571



private combinations :

3.3 σ deviation from SM

updated result on full data set to come soon

combined BABAR + BELLE: 4.8 σ

More in next talk

Lifetime Measurements

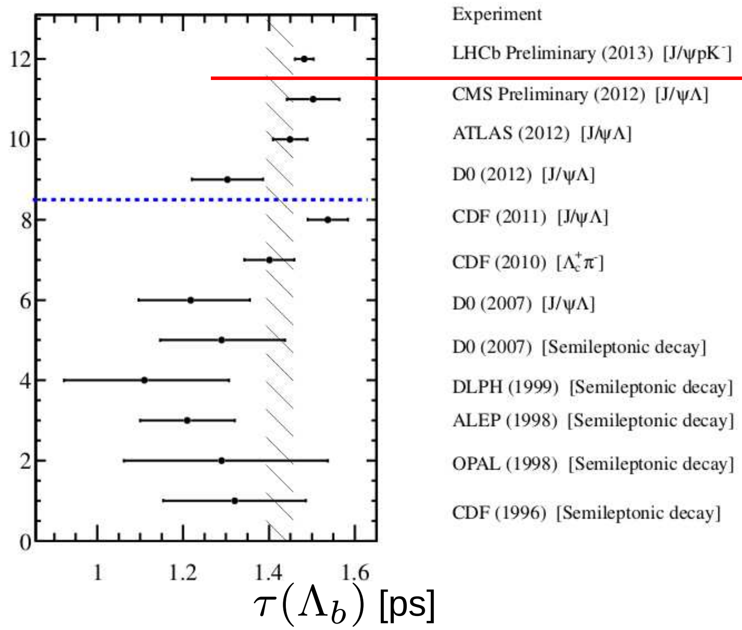
Lifetimes are insensitive to BSM effects

$\longrightarrow$ test of QCD predictions; probe of HQE

theoretical predictions:

$\frac{\tau_{B^+}}{\tau_{B^0}}$ = 1.06$\pm$0.03; $\frac{\tau_{B_s}}{\tau_{B^0}}$ = 1.00$\pm$0.01; $\frac{\tau_{\Lambda_b}}{\tau_{B^0}}$ = 0.88$\pm$0.05

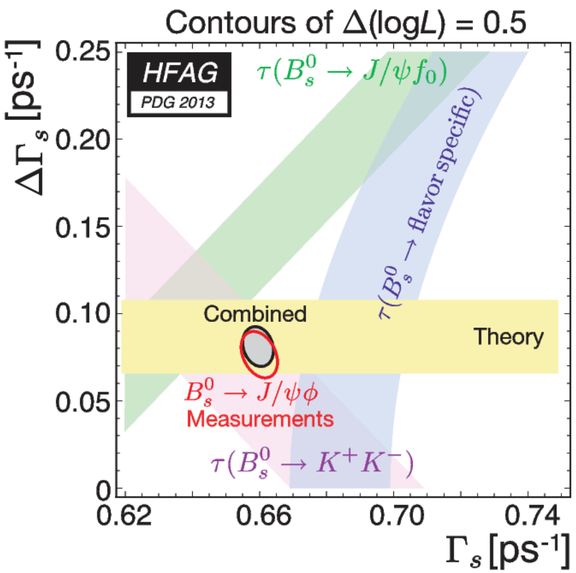
arXiv:1307.2476 - 1fb^{-1}

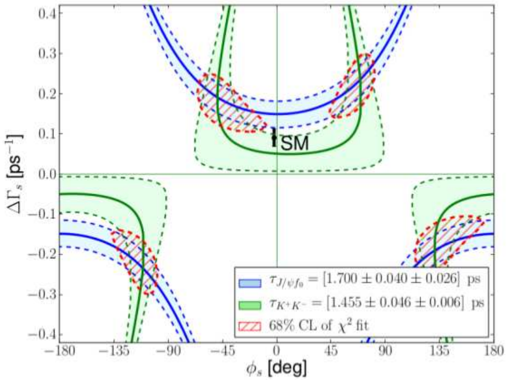


new @ EPS2013

predictions using WA of $\tau(B^0)$

(plot from B. Pal)





$\tau(B_s \to KK)$ = [1.455$\pm$0.046$\pm$0.006] ps

[Phys. Lett. B716 (2012) 393-400]

$\tau(B_s \to J/\Psi f_0)$ = [1.700$\pm$0.040$\pm$0.026] ps

[Phys Rev. Lett. 109.152002 (2012)]

Fleischer, Kneigens [arXiv:1209.3206]

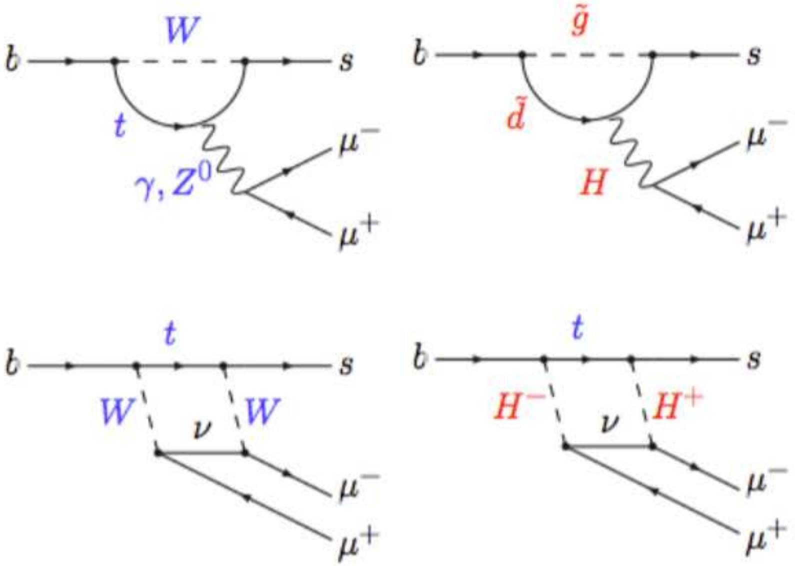
$b \to s$ Transitions

General description of Hamiltonian in operator product expansion:

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \Big[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\substack{\text{right-handed part} \\ \text{suppressed in SM}}} \Big]$$

i = 1,2	Tree
i = 3 – 6,8	Gluon penguin
i = 7	Photon penguin
i = 9,10	Electroweak penguin
i = S	Higgs (scalar) penguin
i = P	Pseudoscalar penguin

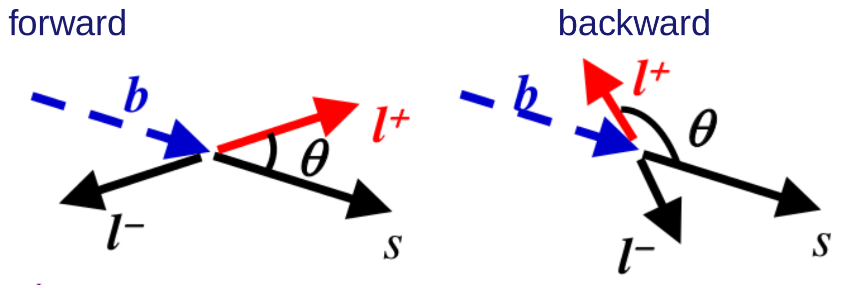
$b \to s$ transitions are sensitive to $O_7^{(\prime)}$, $O_9^{(\prime)}$, $O_{10}^{(\prime)}$



$B^0 \to K^* \ell^+ \ell^-$ is the most prominent (large statistic and flavour specific) candidate

Studies in statistical limited $B_s \to \phi\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$ started ...

Angular analysis



One very famous variable:

$$A_{FB} \propto -Re[(2C_7^{eff} + \frac{q^2}{m_b^2}C_9^{eff})C_{10}]$$

Introduce 3 relative angles to describe angular distribution of final state particles.

Folding $\phi \rightarrow \phi + \pi$ if $\phi < 0$ increase sensitivity for some coefficients.

e.g. $A_{FB} = \frac{3}{4}(1 - F_L)A_T^{Re}$

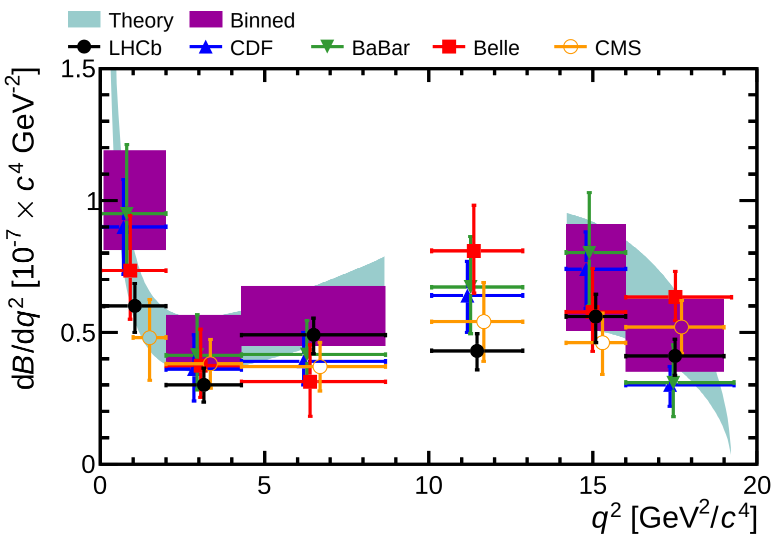
$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$
$$\sqrt{F_L(1-F_L)}P_4'\sin 2\theta_K\sin 2\theta_\ell\cos\phi + \sqrt{F_L(1-F_L)}P_5'\sin 2\theta_K\sin\theta_\ell\cos\phi +$$
$$\frac{1}{2}(1-F_L)A_{Re}^T\sin^2\theta_K\cos\theta_\ell + \sqrt{F_L(1-F_L)}P_6'\sin 2\theta_K\sin\theta_\ell\sin\phi +$$
$$\sqrt{F_L(1-F_L)}P_8'\sin 2\theta_K\sin 2\theta_\ell\sin\phi + (S/A)_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

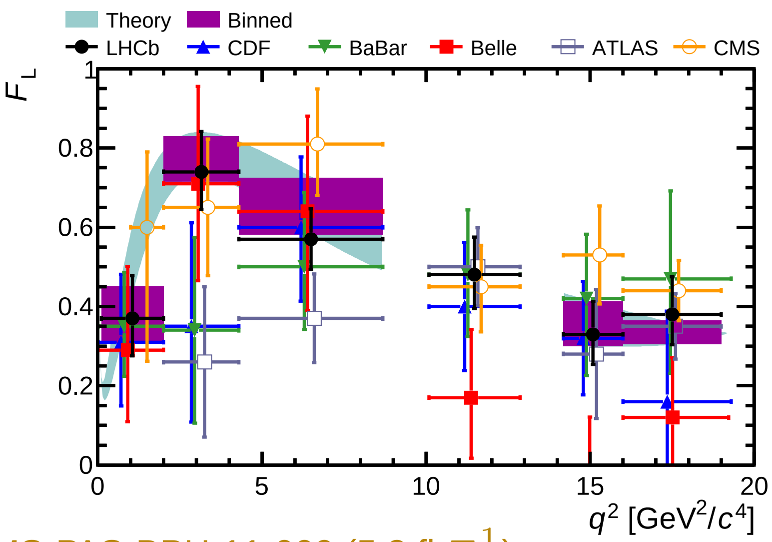
New: alternative folding give access to form factor independent parameters

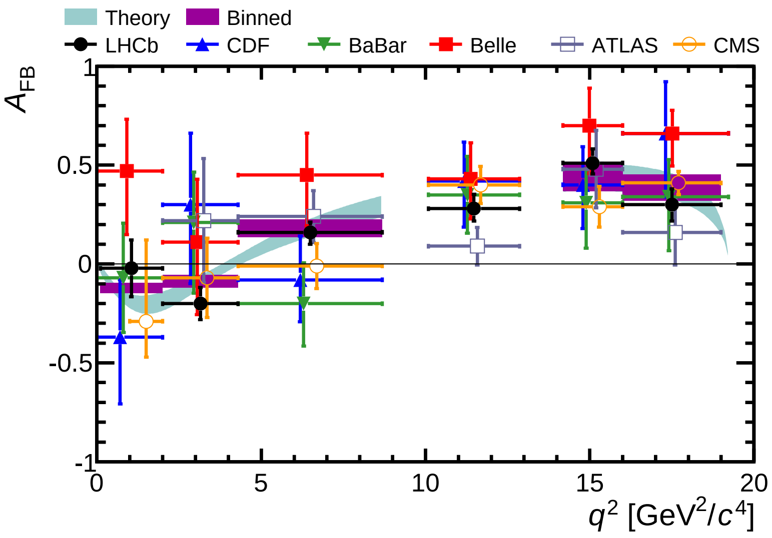
(arXiv:1106.3283, arXiv:1106.3283, arXiv:hep-ph/050206, arXiv:0807.2589, arXiv:1105.0376)

$B^0 \to K^* \ell^+ \ell^-$ angular analysis

Some example distributions:







CMS: CMS-PAS-BPH-11-009 (5.2 fb^{-1})

ATLAS: ATLAS-CONF-2013-038 (4.9 fb^{-1})

BELLE: Phys. Rev. Lett. 103 (2009) 171801 (605 fb^{-1})

BABAR: Phys. Rev. D73 (2006) 092001 (208 fb^{-1})

CDF: Phys. Rev. Lett 108 (2012) 081807 (6.8 fb^{-1})

(results from CDF Public Note 10894 (9.6 fb^{-1}) not included)

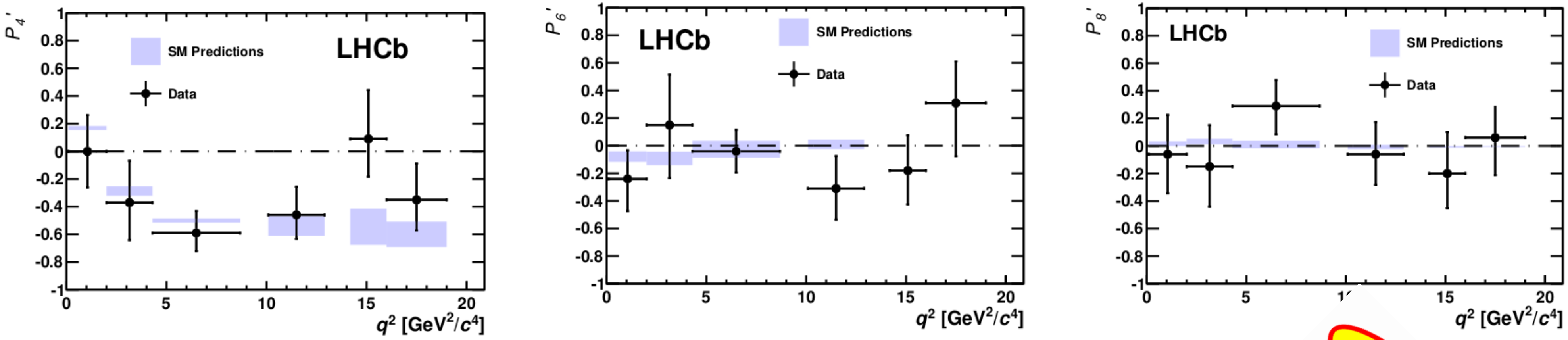
LHCb: arXiv:1304.6325 (1 fb^{-1})

Very good agreement with theory predictions!

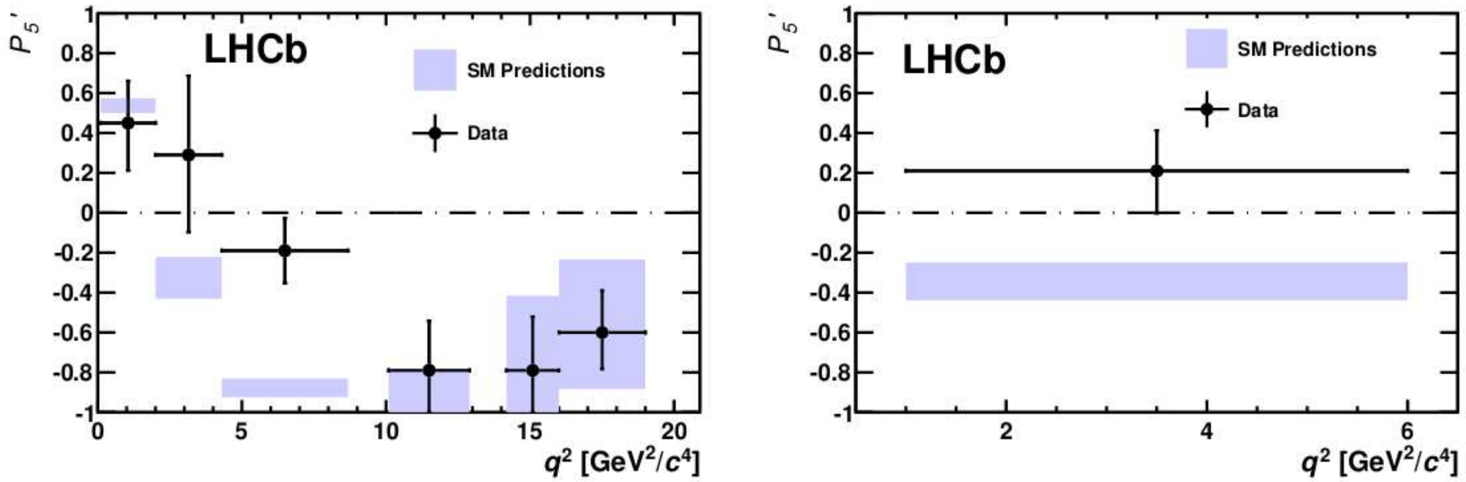
New Observables in $B^0 \to K^*\mu^+\mu^-$

LHCb-PAPER-2013-037

Very good agreement in P_4', P_6', P_8'



some tension in P_5' (3.7 σ):



new @ EPS2013

Discussion at EPS resulted in an article: Descotes, Matias, Virto arXiv:1307.5683

0.5% probability to see such a deviation with 24 independent measurements.

Inclusive $B \to X_s \ell\ell$ Decays

Less theoretical uncertainties for inclusive $B \to X_s \ell\ell$ analysis,

statistical uncertainties comparable

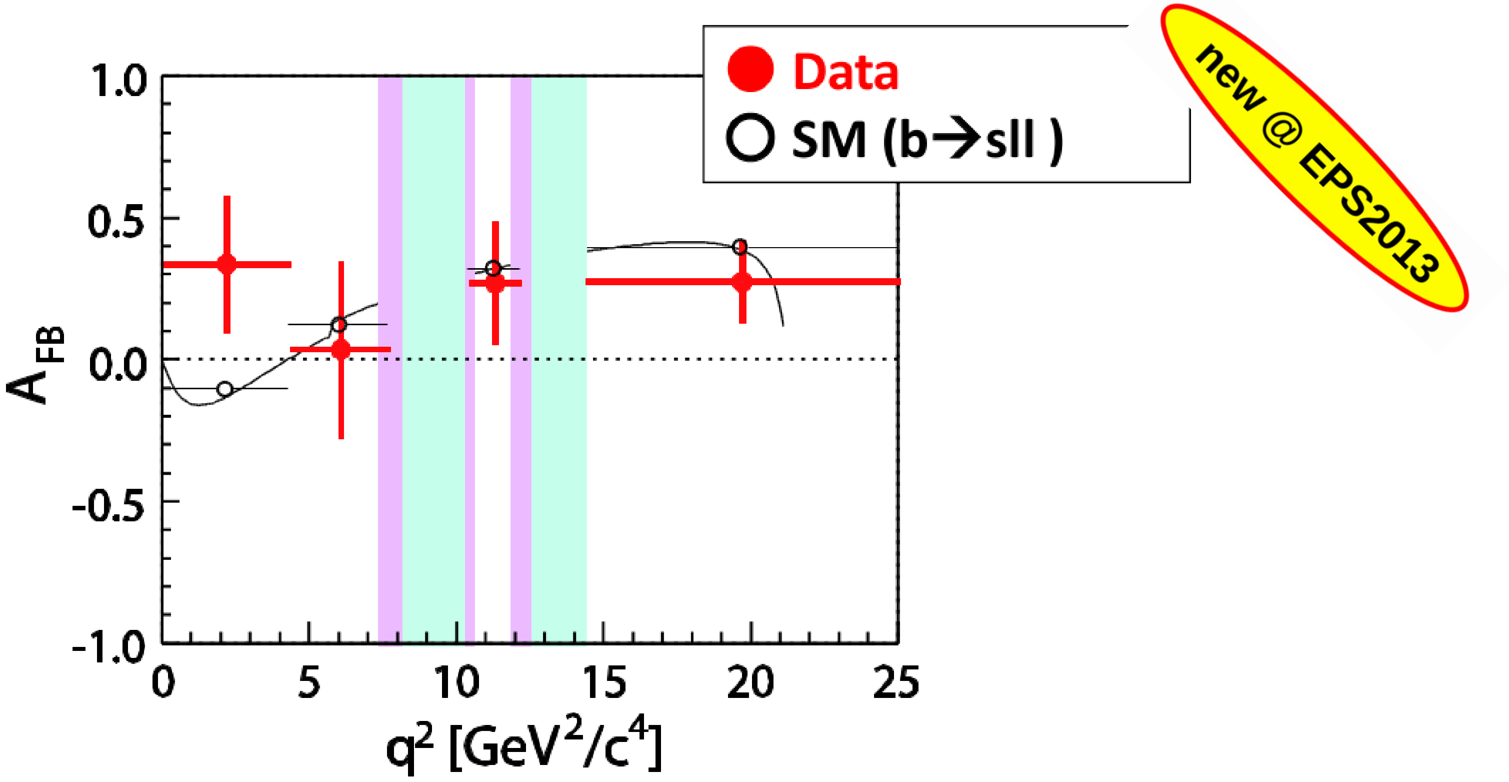
36 (18 $\times$ 2) modes studied

20 (10 $\times$ 2) modes used for final result

$\equiv$ 50% of all X_s

$\sim$ 140 $B \to X_s e^+ e^-$ +

$\sim$ 160 $B \to X_s \mu^+ \mu^-$ candidates



Quest for $B^0_{(s)} \to \mu^+\mu^-$

Start in 1984 by the CLEO experiment ...

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1

Two-body decays of *B* mesons

B. Search for exclusive $\bar{B}^0$ decays into two charged leptons

Our search for the $\pi^+\pi^-$ final state is not sensitive to the mass of the final-state particles, provided that they are light, since the mass enters only in the energy constraint. Therefore, the upper limit of 0.05% applies for any final-state particles with a pion mass or less. When the final-state particles are leptons the limits are improved by using the lepton identification capabilities of the CLEO detector.[14] For the decay $\bar{B}^0 \to \mu^+\mu^-$, we improve our limit by requiring that both muons penetrate the iron and produce signals in drift chambers. We find no such events. After correcting for detection efficiency (33%), we set an upper limit of 0.02% at 90% confidence for this decay. We im-

SM expectations (FCNC and helicity suppressed):

BR($B_s \to \mu^+\mu^-$) = 3.34 $\pm$ 0.27 $\times$ 10^{-9}

BR($B^0 \to \mu^+\mu^-$) = 1.07 $\pm$ 0.10 $\times$ 10^{-10}

Buras, Girrbach, Guadagnoli, Isodori, Fleischer, Kengjens

Eur Phy J. C72 (2012), 2172 + arXiv: 1303.3820

time integrated BR taking into account $\Delta\Gamma_s \neq 0$ (to be compared to experimental results)

BR($B_s \to \mu^+\mu^-$) = 3.56 $\pm$ 0.29 $\times$ 10^{-9}

Quest for $B^0_{(s)} \to \mu^+\mu^-$

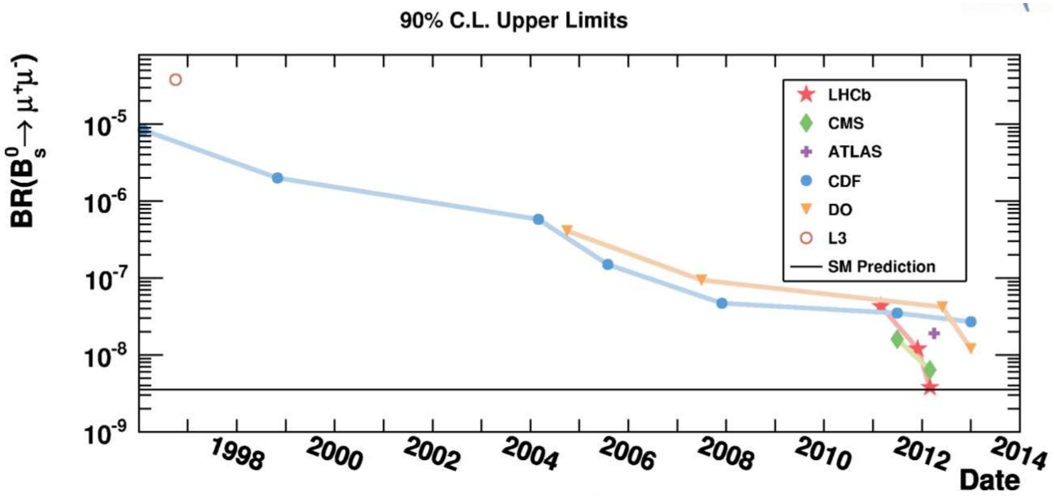
LHCb: Phys Rev Lett 110 (2013) 021801 (2.1 fb^{-1})

CMS: J. High Energy Phys 04 (2012) 033 (5.0 fb^{-1})

ATLAS: ATLAS-CONF-2013-076 (5.0 fb^{-1})

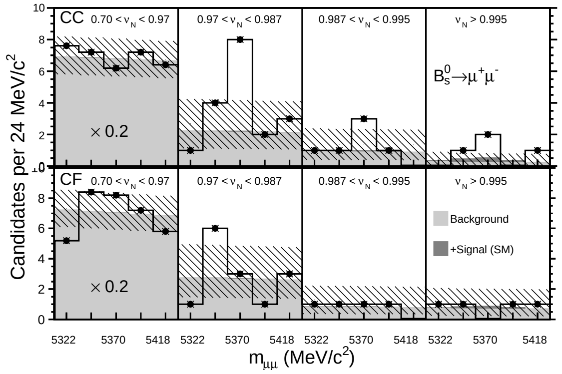
CDF: Phys. Rev. D 87, 072003 (2013) (9.7 fb^{-1})

D0: Phys. Rev. D87 07.2006 (2013) (10.4 fb^{-1})



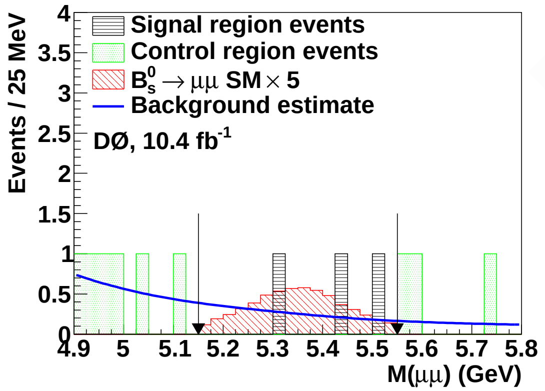
CC: two central muons

CF: one forward muon



95% CL:

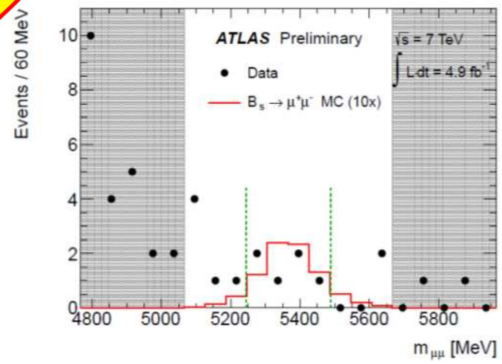
BR($B_s \to \mu^+\mu^-$) < 3.1 × 10^{-8}



95% CL:

BR($B_s \to \mu^+\mu^-$) < 1.5 × 10^{-8}

new @ EPS2013



95% CL:

BR($B_s \to \mu^+\mu^-$) < 1.5 × 10^{-8}

Updated Results

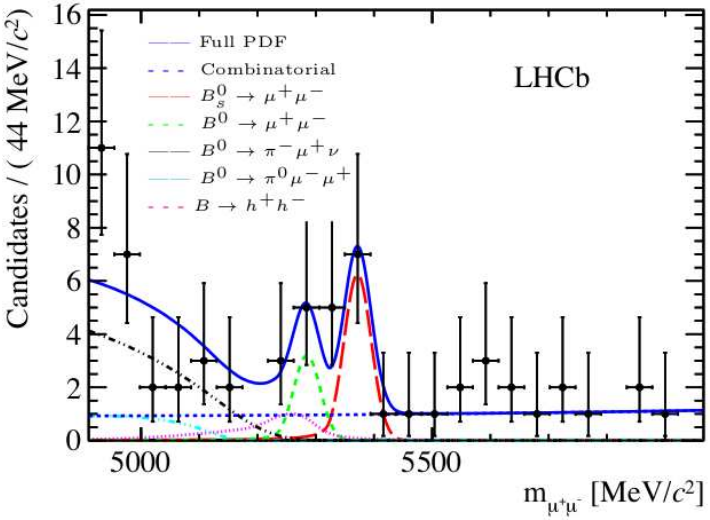
- 2.1 $\rightarrow$ 3.0 fb^{-1}
- more variables in BDT

- 5.0 $\rightarrow$ 25 fb^{-1}
- cut base selection $\rightarrow$ BDT
- new & improved variables (PID)

expected sensitivity: 3.7 $\rightarrow$ 5.0 σ

new @ EPS2013

arXiv:1307.5024



BR($B_s \rightarrow \mu^+\mu^-$) = (2.9 $^{+1.1}_{-1.0}$(stat)$^{+0.3}_{-0.1}$(syst))$\times$ 10^{-9}

$\rightarrow$ 4 σ

BR($B^0 \rightarrow \mu^+\mu^-$) < 7.4 $\times$ 10^{-10} at 95% CL

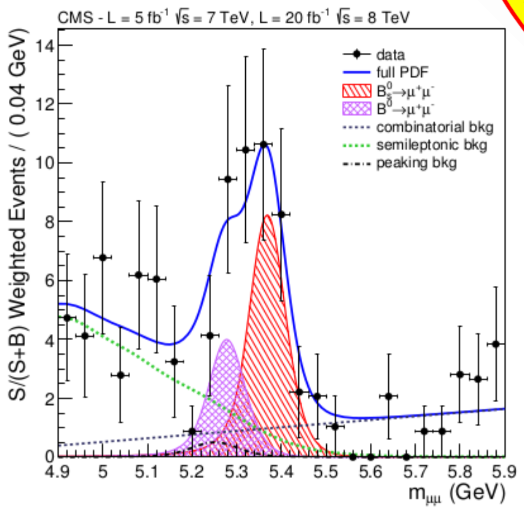
BR($B^0 \rightarrow \mu^+\mu^-$) = (3.7 $^{+2.4}_{-2.1}$(stat)$^{+0.6}_{-0.4}$(syst))$\times$ 10^{-10}

$\rightarrow$ 2.0 σ

expected sensitivity: 4.8 σ

new @ EPS2013

arXiv:1307.5025



BR($B_s \rightarrow \mu^+\mu^-$) = 3.0 $^{+1.0}_{-0.9}$ $\times$ 10^{-9}

$\rightarrow$ 4.3 σ

BR($B^0 \rightarrow \mu^+\mu^-$) < 1.1 $\times$ 10^{-9} at 95% CL

BR($B^0 \rightarrow \mu^+\mu^-$) = 3.5 $^{+2.1}_{-1.8}$ $\times$ 10^{-10}

$\rightarrow$ 2.0 σ

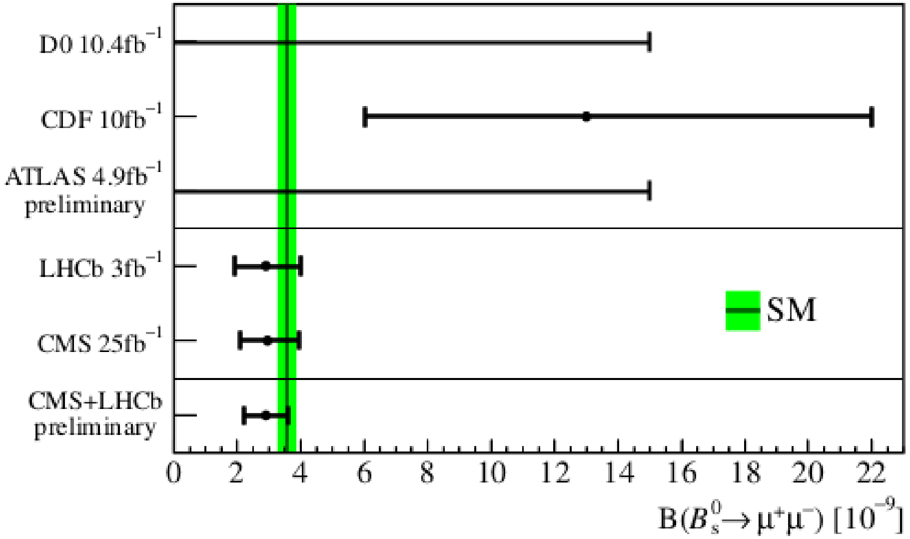
Combined LHCb + CMS Result

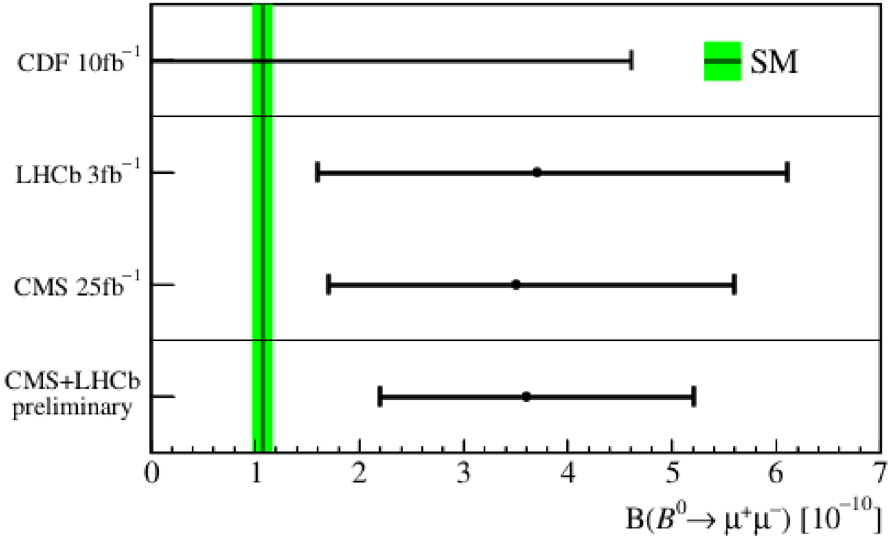
new @ EPS2013

Observation:

BR($B_s \to \mu^+\mu^-$) = $(2.9 \pm 0.7) \times 10^{-9}$

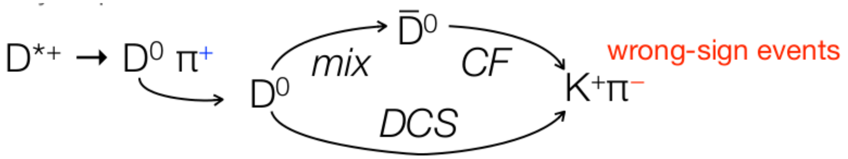
BR($B^0 \to \mu^+\mu^-$) = $3.6^{+1.6}_{-1.4} \times 10^{-10}$

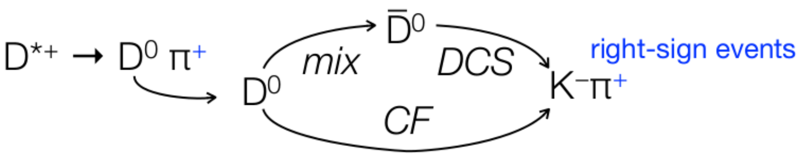




LHCb-CONF-2013-012, CMS-PAS-BPH-13-007

Charm Mixing

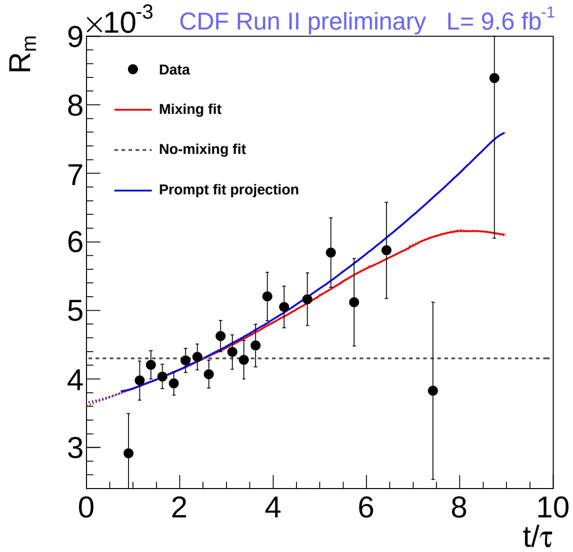


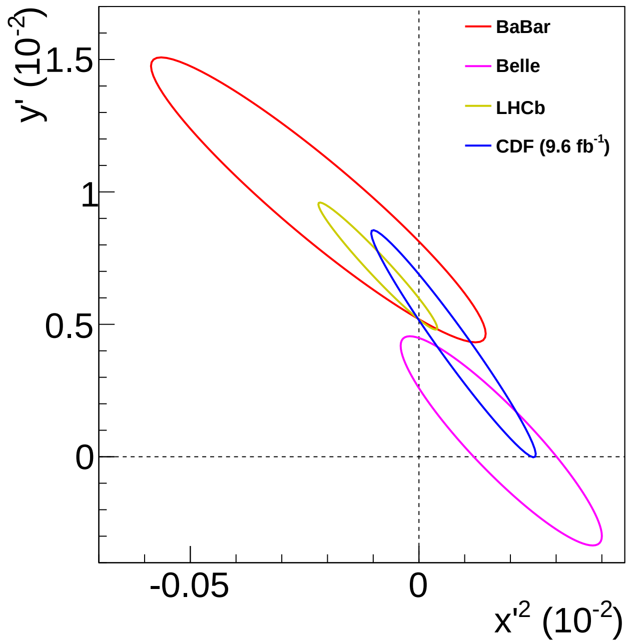


$$R_m(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}\, y' \, t + \frac{y'^2 + x'^2}{4}\, t^2$$

decay interference mixing

no mixing: $x' = 0, y' = 0$





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

ΔA_{CP} in $D \to h^+h^-$ decays

$$A_{CP} = \frac{\Gamma(D^0 \to h^+h^-) - \Gamma(\overline{D^0} \to h^+h^-)}{\Gamma(D^0 \to h^+h^-) + \Gamma(\overline{D^0} \to h^+h^-)}$$

Two ways to tag flavour of D^0 with complementary systematics:

soft pion tag: $D^{*+} \to D^0 \pi^+$

muon tag: $B^- \to D^0 \mu^- X$

Detector and production asymmetries hard to control at that level, thus use trick:

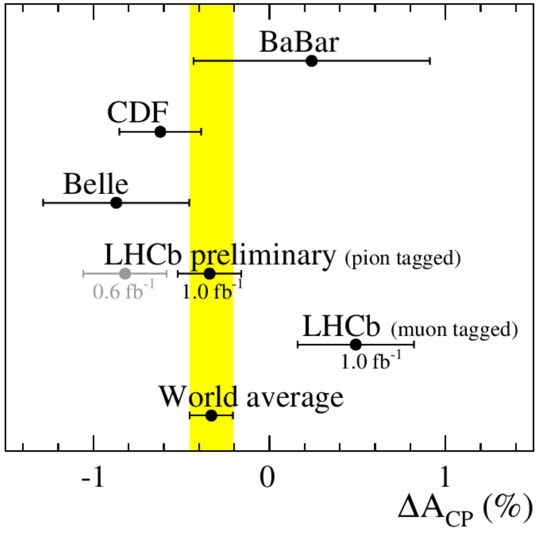
$$A_{raw} = A_{CP} + A_{reco\,tag} + A_{prod}$$

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = A_{raw}(K^+K^-) - A_{raw}(\pi^+\pi^-)$$

LHCb: ΔA_{CP} = (-0.15 $\pm$ 0.16)%

(LHCB-CONF-2012-003, Phys. Lett B 723 (2013) 33)

WA: ΔA_{CP} = (-0.33 $\pm$ 0.12)%



Further Direct CPV in Charm decays

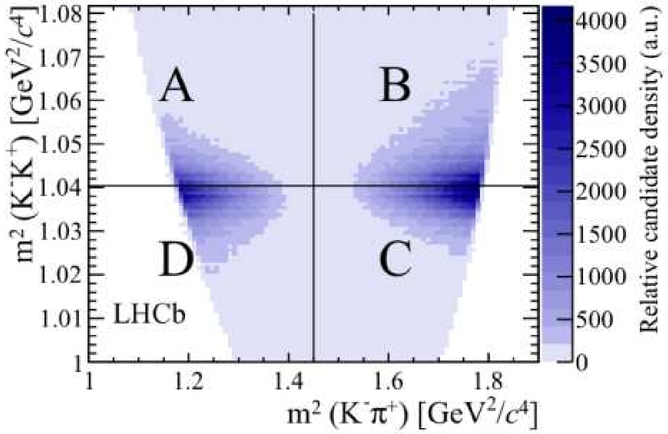
$$A|_S = \frac{1}{2}(A^A_{raw} + A^C_{raw} - A^B_{raw} - A^D_{raw})$$

LHCb (arXiv: 1303.4906v2):

$A(D^+ \to \phi\pi^+)$ = (-0.04 $\pm$ 0.14 $\pm$ 0.13)%

$A|_S(D^+ \to \phi\pi^+)$ = (-0.18 $\pm$ 0.17 $\pm$ 0.18)%

$A(D_s^+ \to K_s^0\pi^+)$ = (+0.61 $\pm$ 0.83 $\pm$ 0.13)%

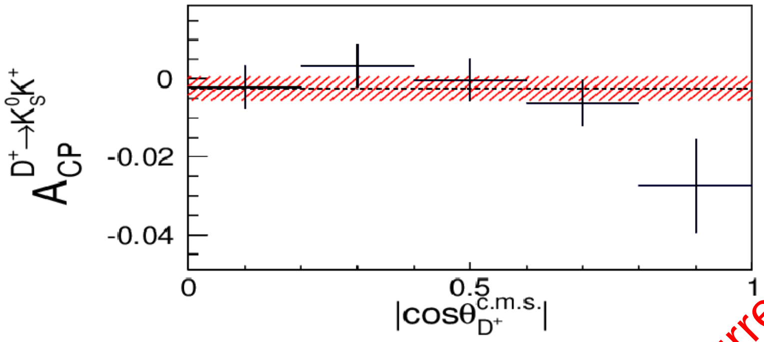


Babar (Phys Rev D87 (2012) 052010)

$A(D^+ \to \phi\pi^+)$ = (-0.3 $\pm$ 0.3 $\pm$ 0.5)%

Belle (Phys Rev Lett 108 (2012) 071801)

$A(D^+ \to \phi\pi^+)$ = (0.51 $\pm$ 0.28 $\pm$ 0.05)%



new @ EPS2013

Further studies (LHCb-PAPER-2013-037):

$D^0 \to K^-K^+\pi^-\pi^+$ & $D^0 \to \pi^-\pi^+\pi^+\pi^-$

no evidence for asymmetry found

With current sensitivity no CPV established

Belle (JHEP 02 (2013) 098)

$A(D^+ \to K_s K^+)$ = (-0.25 $\pm$ 0.28 $\pm$ 0.14)%

Summary

- Flavour physics plays an important role in the search for New Physics!

  despite or due to no unambiguous New Physics signal has shown up yet

- LHC is a flavour factory!

  A lot of world best results: $B^0_{(s)} \rightarrow \mu^+\mu^+$ new @ EPS2013, γ, Δm_s, ϕ_s

- Many competitive results still coming in from Tevatron, Babar & Belle

- No striking hint yet, but some tensions exist

  new @ EPS2013

  - P_5' from $K^*\mu^+\mu^-$ analysis (LHCb)
  - rate of $B \rightarrow D^{(*)}\tau\nu$ (Babar & Belle)
  - A_{sl} (D0)
  - CPV in charm

- Lot's of more data and results ahead of us!

- Lot's of additionally new @ EPS2013 results not shown in this talk