Measuring CKM4 at LHC

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Jan. 19-20, 2012

Focus Workshop on Heavy Quarks at LHC

(Based on W.-S. Hou, M. Kohda and F. Xu, PRD 84, 094027 (2011))

Outline

Introduction

famous
(100 ~ 499 cites)

- Why SM4

Mini-review

Four statements about the fourth generation

Bob Holdom[1], WS Hou[2], Tobias Hurth[3], Michelangelo L Mangano*[3], Saleh Sultansoy[4] and Gokhan Ünel[5]

Published: 28 September 2009
PMC Physics A 2009, **3**:4 doi:10.1186/1754-0410-3-4
Received: 19 August 2009
Accepted: 28 September 2009

Abstract

This summary of the Workshop "Beyond the 3-generation SM in the LHC era" presents a brief discussion of the following four statements about the fourth generation: 1) It is not excluded by EW precision data; 2) It addresses some of the currently open questions; 3) It can accommodate emerging possible hints of new physics; 4) LHC has the potential to discover or fully exclude it.

- Prof. Yuan's talk ("From Top to Heavy Quark") in the morning

Introduction

- Direct search at LHC – Prof. Chen's talk
  - t' quark
    $m_{t'} > 450\text{GeV}$ @95%CL, "CMS PAS EXO-11-051", 2011/07/22
    $m_{t'} > 490\text{GeV}$ @95%CL, $1.1 fb^{-1}$, "CMS PAS EXO-11-054", 2011/10/04
  - b' quark
    $m_{b'} > 495\text{GeV}$ @95%CL, $1.14 fb^{-1}$ "CMS PAS EXO-11-036", 2011/08/27

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  - b' quark
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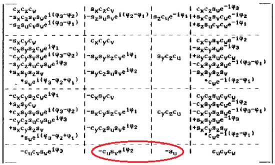
- "Indirect search" in flavor physics
  –constraints of flavor mixing matrix from FCNC processes
  - $\mathcal{B}(B_s \to \mu^+\mu^-)$
  - $\sin 2\Phi_{B_s}$ from $B_s \to J/\psi\,\phi$
  - A_{FB} of $B_d \to K^*\mu^+\mu^-$



Hou-Soni-Steger 1987

3 New Measurements

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

PRL **107,** 191801 (2011) PHYSICAL REVIEW LETTERS week ending 4 NOVEMBER 2011

Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ Decays with CDF II

(CDF Collaboration)

(Received 10 July 2011; published 1 November 2011; corrected 17 November 2011)

A search has been performed for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays using 7 fb^{-1} of integrated luminosity collected by the CDF II detector at the Fermilab Tevatron collider. The observed number of B^0 candidates is consistent with background-only expectations and yields an upper limit on the branching fraction of $\mathcal{B}(B^0 \to \mu^+\mu^-) < 6.0 \times 10^{-9}$ at 95% confidence level. We observe an excess of B_s^0 candidates. The probability that the background processes alone could produce such an excess or larger is 0.27%. The probability that the combination of background and the expected standard model rate of $B_s^0 \to \mu^+\mu^-$ could produce such an excess or larger is 1.9%. These data are used to determine $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$ and provide an upper limit of $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.0 \times 10^{-8}$ at 95% confidence level.

$$\mathcal{B}^{SM}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

A.J. Buras 1012.1447

PRL **107,** 191802 (2011) PHYSICAL REVIEW LETTERS week ending 4 NOVEMBER 2011

Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ Decays in pp Collisions at $\sqrt{s} = 7$ TeV

S. Chatrchyan *et al.**
(CMS Collaboration)
(Received 29 July 2011; published 1 November 2011)

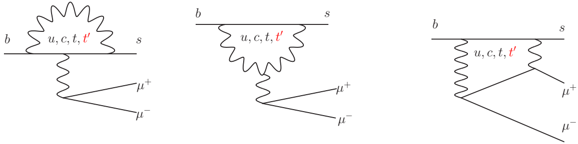
A search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ is performed in pp collisions at $\sqrt{s} =$ 7 TeV, with a data sample corresponding to an integrated luminosity of 1.14 fb^{-1}, collected by the CMS experiment at the LHC. In both cases, the number of events observed after all selection requirements is consistent with expectations from background and standard-model signal predictions. The resulting upper limits on the branching fractions are $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.9 \times 10^{-8}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9}$, at 95% confidence level.

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 1.2(1.5) \times 10^{-8} @90(95)\%CL$$

$300pb^{-1}$, LHCb@EPS-HEP2011

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

$bs \to \ell^+\ell^-$



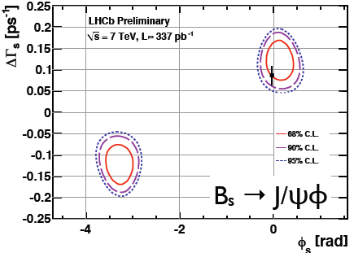
- large uncertainty: $\mathcal{B}(B_s \to \mu^+\mu^-) \propto f_{B_s}^2$
- note $\Delta m_{B_s} \propto f_{B_s}^2 \hat{B}_{B_s}$
- reduce the uncertainty to bag parameter: $\frac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\Delta m_{B_s}|^{th.} / \Delta m_{B_s}|^{exp.}}$

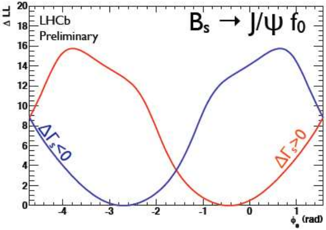
$$\mathcal{B}(B_s \to \mu^+\mu^-) = C \frac{\tau_{B_s}\eta_Y^2}{\hat{B}_{B_s}\eta_B} \frac{|\lambda_t^{SM} Y_0(x_t) + \lambda_{t'} \Delta Y_0|^2}{|\Delta_{12}^s| / \Delta m_{B_s}|^{exp}}$$

with $\boxed{\lambda_{t'} = V_{t'b} V_{t's}^*}$

$B_s^0 \to J/\psi\phi(f_0)$

- LHCb@LP2011 (G. Raven)





$\phi_s = 0.13 \pm 0.18 \pm 0.07$ rad $(337pb^{-1})$

$\phi_s = -0.44 \pm 0.44 \pm 0.02$ rad $(378pb^{-1})$

$\Downarrow$

$$\phi_s = 0.03 \pm 0.16 \pm 0.07 \text{ rad}$$

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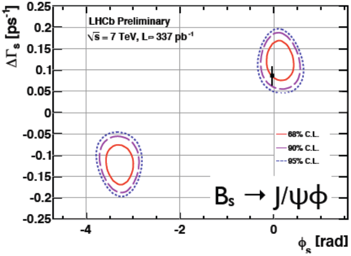

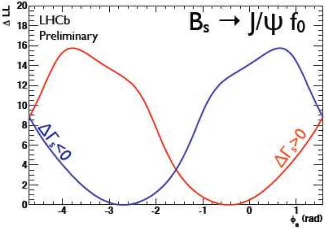

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- SM

$\phi_s = -2\Phi_{B_s} = 0.0038 \pm 0.0010$ (A. Lenz 1102.4274v1) Consistent

$\sin 2\Phi_{B_s}$

- The time-dependent CPV (TCPV) asymmetry for $B_s \to J/\psi\,\phi(f_0)$

$$A(\Delta t) = -(\mathcal{S}_{J/\psi\,\phi}\sin(\Delta M_{B_s}\Delta t) + \mathcal{A}_{J/\psi\,\phi}\cos(\Delta M_{B_s}\Delta t))$$

$\mathcal{S}_{J/\psi\,\phi} \cong \sin 2\Phi_{B_s}$ free of hadronic uncertainty

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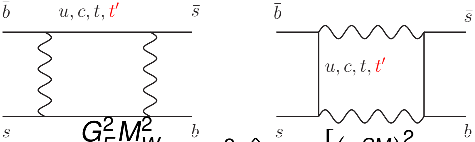
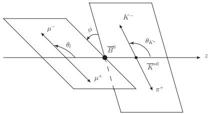
- $2\Phi_{B_s} = Arg(M_{12}^s)$



$$M_{12}^s = \frac{G_F^2 M_W^2}{12\pi^2} m_{B_s} f_{B_s}^2 \hat{B}_{B_s} \eta_B \left[\left(\lambda_t^{SM}\right)^2 S_0 + 2\lambda_t^{SM}\lambda_{t'}\Delta S_0^{(1)} + \lambda_{t'}^2 \Delta S_0^{(2)}\right]$$

with $\lambda_t^{SM} = V_{ts}^* V_{tb}$, $\lambda_{t'} = V_{t's}^* V_{t'b}$

A_{FB} of $B \to K^*\mu^+\mu^-$

- 

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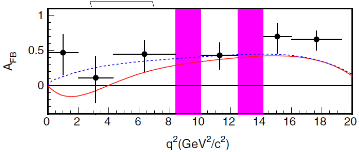
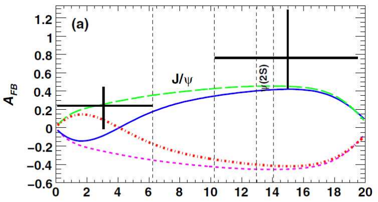
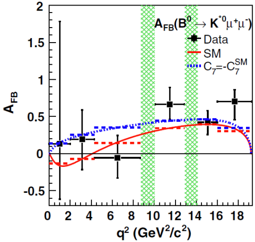


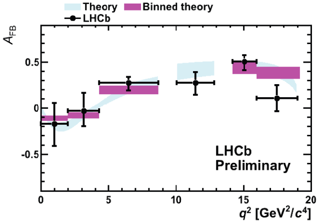


Belle, PRL 103, 171801 (2009)

BaBar, PRD 79, 031102(R) (2009)



CDF, PRL 106, 161801(2011)



$309pb^{-1}$ data, M. Patel, LHCb@EPS-HEP2011

A_{FB} of $B \to K^*\mu^+\mu^-$

Summary of Theoretical status

- The contribution of heavy quark to $b \to s\ell^+\ell^-$

  W.-S. Hou, R.S. Willey and A. Soni, Phys. Rev. Lett. 58, 1608 (1987)

- $B \to K^*\ell^+\ell^-$ @ NLL , naive factorization

  A. Ali, P. Ball, L. T. Handoko,and G. Hiller, PRD 61, 074024 (2000)

  A. J. Buras, M. Münz, PRD 52, 186 (1995), $\cdots$

- $B \to K^*\ell^+\ell^-$ @ NNLL , QCDF/SCET
  - Formulation

    U. Egede, T. Hurth, J. Matias, M. Ramon, W. Reece, JHEP11 (2008) 032

  - Wilson coefficient

    C. Bobeth, M. Misiak, J. Urban, NPB 574 (2000) 291;

    C. Bobeth, P. Gambino, M. Gorbahn and U. Haisch, JHEP 04 (2004) 071

    H. Asatryan, H. Asatrian, C. Greub, M. Walker, PLB 507 (2001) 162

  - Form factor:

    M. Beneke, Th. Feldmann, NPB 592 (2001) 3

A_{FB} of $B \to K^*\mu^+\mu^-$

- Decay amplitude

$$\mathcal{M}_{b\to s\ell^+\ell^-} = -\frac{G_F\alpha}{\sqrt{2}\pi}\lambda_t\Big[\widetilde{C}_9^{eff}(\bar{s}\gamma_\mu\mathbb{P}_L b)(\bar{\ell}\gamma^\mu\ell) + \widetilde{C}_{10}^{eff}(\bar{s}\gamma_\mu\mathbb{P}_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell) - 2\frac{m_b}{q^2}\widetilde{C}_7^{eff}(\bar{s}i\sigma^{\mu\nu}q_\nu\mathbb{P}_R b)(\bar{\ell}\gamma^\mu\ell)\Big]$$

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- take naive factorization as the example

$$\frac{dA_{FB}}{dq^2} \propto Re(\widetilde{C}_9^{eff}\widetilde{C}_{10}^*) + F\ Re(\widetilde{C}_7^{eff}\widetilde{C}_{10}^*)$$

with $\widetilde{C}_i = \widetilde{C}_i^t + \frac{\lambda_{t'}}{\lambda_t}\Delta C_i$ in SM4.

A_{FB} of $B \to K^*\mu^+\mu^-$

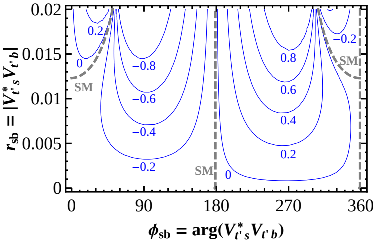
Some remarks

- C_{10} is general complex
- In realistic calculation, NLO Wilson coefficients, $\mathcal{O}(\alpha_s)$ order soft form factors, and non-factorization contribution are included
- QCDF/SCET approach is applicable only at $q^2 < 6GeV^2$
- The A_{FB} zero crossing point s_0 is free of hadronic uncertainty
- Fourth generation information: $\lambda_{t'} = V^*_{t's}V_{tb}$ and $m_{t'}$ can be read from A_{FB} and s_0

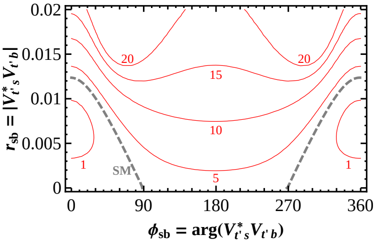
Constraint of $V_{t'b}V^*_{t's}$

Contours in (r_{sb}, ϕ_{sb})

$$\lambda_{t'} = V^*_{t'b} V_{t's} = r_{sb} e^{i\phi_{sb}},\ m_{t'} = 550 GeV$$



$\sin 2\Phi_{B_s}$



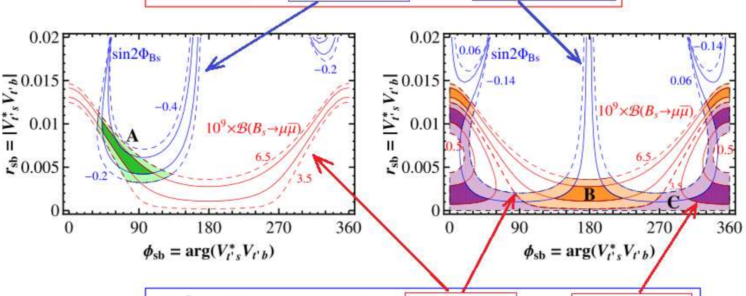
$10^9 \times \mathcal{B}(B_s \to \mu^+\mu^-)$

$\sin 2\Phi_{B_s}$ and $\mathcal{B}(B_s \to \mu^+\mu^-)$ contours are combined to determine the possible regions.

Allowed (r_{sb}, ϕ_{sb}) region

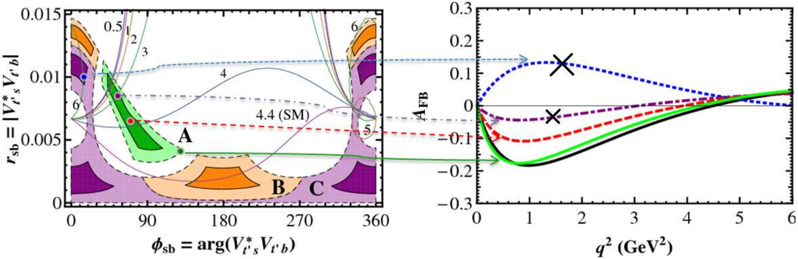
$m_{t'} = 550 GeV$, LHCb $> 1 fb^{-1}$ (2012)

$\sin 2\Phi_{B_s} = -0.3 \pm 0.1$; -0.04 ± 0.1



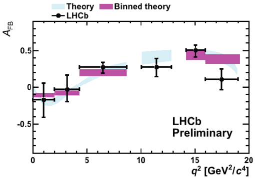
$10^9 \mathcal{B}(B_s \to \mu^+\mu^-) = 5.0 \pm 1.5$; 2.0 ± 1.5

Allowed region and A_{FB}

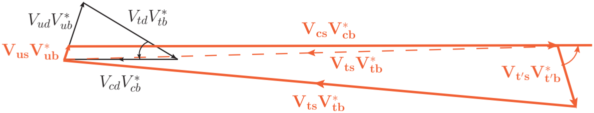


- further discrimination from A_{FB} and s_0
- different behaviors of A_{FB}
- some parameter space can be excluded by LHCb

$|V_{t'b} V^*_{t's}| \leq 0.008$ for $m_{t'} = 550 GeV$



$b \to s$ quadrangle

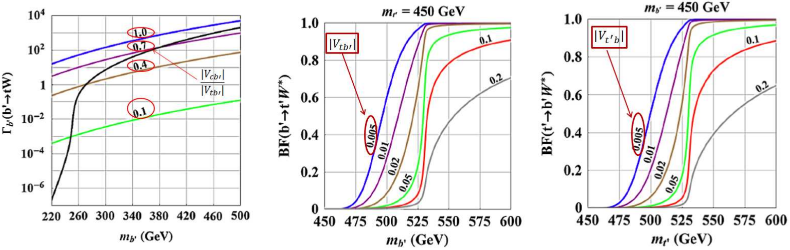


- "$b \to d$" triangle has been examined a lot
- $b \to s$ relevant to BAU
- once $m_{t'}$ is known, $b \to s$ quadrangle can be determined

Constraint of $|V_{t'b}|$ and $|V_{tb'}|$

The decay of b' and t'

More than $b' \to tW$ Y. Chao, K. Chen, S. Chen, W. Hou, B. Huang, Y. Lei, PRD 84, 014029 (2011)



$b' \to cW$

- When $\left|\frac{V_{cb'}}{V_{tb'}}\right| > 0.7$, $b' \to cW$ will dominate.
- Assuming $b' \to t'W^*$ and $b' \to tW$ to be two dominant modes, $\mathcal{B}(b' \to t'W^*)$ is ploted above, which depends on $V_{tb'}$.
- Once $m_{b'}$ and relevant branching ratios are measured,mixing matrix can be determined.

Future constraint of $V_{t'b}V^*_{t'd}$

$b \to d$

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- Experimentally, $B \to \pi\ell^+\ell^-$ has been measured

$$\mathcal{B}(B \to \pi\ell^+\ell^-) < 9.1 \times 10^{-8} \text{ @90\%} \quad \text{(BaBar 2007)}$$
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- How about $\mathcal{B}(B \to \rho\ell^+\ell^-)$ and A_{FB}?

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- How about $\mathcal{B}(B \to \rho\ell^+\ell^-)$ and A_{FB}?
- In progress $\cdots$

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- $b \to d \cdots$