Fourth Generation

— Towards Effect of Large Yukawa Coupling

George W.S. Hou (侯維恕)
National Taiwan University

June 3, 2010, TOP 2010 @ Bruges, Belgium

臺灣大學
National Taiwan University

3G to 4G

0. Intro: the Four Statements

$\longrightarrow$ Limit Scope to Two Threads

I. CPV4U: from Earth to Heaven

* Earthly Thread
  - $B \to K\pi$ DCPV Difference; $B_s \to J/\psi\phi$ & A_{SL}
* Heavenly Touch — Towards BAU
* Unfinished on Earth

II. Direct Search: Large Yukawa Coupling & EWSB?

* Tevatron Thread
  - Rising Bounds; 1 fb^{-1} @ 7 TeV; Unitarity Bound
* Nambu Legacy: Holdom, Burdman & "Top Condensate"
* Higgs-Yukawa on a Lattice

EW Theory on a Lattice ?

III. Prospects:

* Source of CPV4BAU(?)
* Source of EWSB?

Discussion

0. Intro: the Four Statements

- "Beyond the 3SM generation at the LHC era" workshop, 9/2008 @ CERN
  http://indico.cern.ch/conferenceDisplay.py?confId=33285

  → "**Four Statements about the Fourth Generation**"
  arXiv:0904.4698 [hep-ph] ← 50+ citations within a year
  4G has warmed up

PMC Physics A

PhysMathCentral

Open Access

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]

PMC Physics A 2009, 3:4 doi:10.1186/1754-0410-3-4

Statement 1: The fourth generation is not excluded by EW precision data.

EW precision data CKM unitarity

Statement 2: SM4 addresses some of the currently open questions.

New CPV source for BAU

New perspectives on Higgs naturalness fermion mass hierarchy

Dark Matter

Statement 3: SM4 can accommodate emerging possible hints of new physics.

Hints from B-factories

Tevatron direct search CPV in $B_s \to J/\psi\,\phi$ at Tevatron

Statement 4: LHC has the potential to discover or fully exclude SM4.

ATLAS and CMS discovery prospects Other LHC searches

Impact on Higgs searches LHCb prospects future colliders

0. Intro: the Four Statements

- "Beyond the 3SM generation at the LHC era" workshop, 9/2008 @ CERN
  http://indico.cern.ch/conferenceDisplay.py?confId=33285
  → "Four Statements about the Fourth Generation"
  arXiv:0904.4698 [hep-ph] ← 50+ citations within a year
  4G has warmed up
- 2nd Workshop on "Beyond 3 Generation Standard Model
  — New Fermions at the Crossroads of Tevatron and LHC", 1/2010 in Taipei
  http://indico.cern.ch/conferenceDisplay.py?confId=68036

  Is this why I'm here?

PMC Physics A
PhysMathCentral
Mini-review
Open Access

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]

PMC Physics A 2009, 3:4 doi:10.1186/1754-0410-3-4

Statement 1: The fourth generation is not excluded by EW precision data.

EW precision data   CKM unitarity

Statement 2: SM4 addresses some of the currently open questions.

New CPV source for BAU

New perspectives on Higgs naturalness   fermion mass hierarchy

Dark Matter

Two Threads

Statement 3: SM4 can accommodate emerging possible hints of new physics.

Hints from B-factories

Tevatron direct search   CPV in $B_s \to J/\psi\,\phi$ at Tevatron

Statement 4: LHC has the potential to discover or fully exclude SM4.

ATLAS and CMS discovery prospects   Other LHC searches

Impact on Higgs searches   LHCb prospects   future colliders

I. CPV4U: from Earth to Heaven

Earthly Thread: $B \to K\pi$ Direct CPV Difference

It's personal.

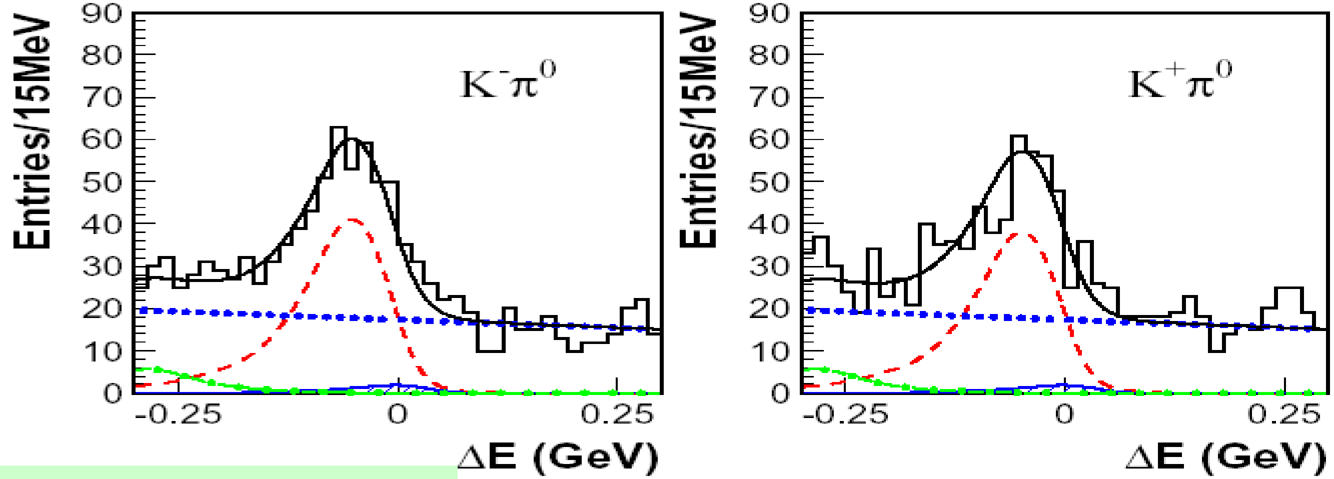
Saga Towards Belle Nature Paper ...

$A_{CP}(B \to K^+\pi^0)$

Sakai

275M $B\bar{B}$
New

$K^\pm\pi^0$: 728 ±53



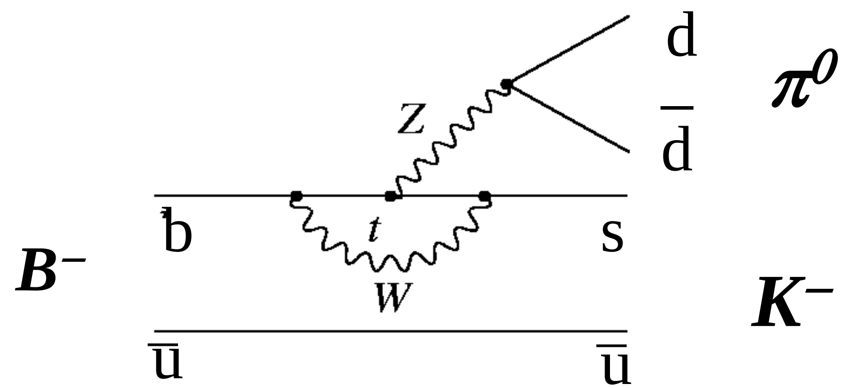
$A_{CP}(K^\pm\pi^0) = 0.04 \pm 0.05 \pm 0.02$

hint that $A_{CP}(K^+\pi^-) \neq A_{CP}(K^\pm\pi^0)$? (2.4σ)

[also seen by BaBar]

Large EW penguin (Z^0) ?

New Physics ?



Belle 2004 PRL: Seed

Y. Chao, P. Chang et al.

BELLE

The partial rate asymmetry $\mathcal{A}_{CP}(K^+\pi^-)$ is found to be $-0.101 \pm 0.025 \pm 0.005$, which is 3.9σ from zero. The significance calculation includes the effects of systematic uncertainties. Our result is consistent with the value reported by *BABAR*, $\mathcal{A}_{CP}(K^+\pi^-) = -0.133 \pm 0.030 \pm 0.009$ [7]. The combined experimental result has a significance greater than 5σ, indicating that direct *CP* violation in the *B* meson system is established. Our measurement of $\mathcal{A}_{CP}(K^+\pi^0)$ is consistent with no asymmetry; the central value is 2.4σ away from $\mathcal{A}_{CP}(K^+\pi^-)$. If this result is confirmed with higher statistics, the difference may be due to the contribution of the electroweak penguin diagram or other mechanisms [16]. No evidence of

by "yours truly"

[16] A. J. Buras, R. Fleischer, S. Recksiegel, and F. Schwab, hep-ph/0402112; V. Barger, C.W. Chiang, P. Langacker, and H. S. Lee, Phys. Lett. B **598**, 218 (2004).

P_{EW}

Z'

My first B (and 4G) paper

WSH, Willey, Soni

VOLUME 58, NUMBER 16 PHYSICAL REVIEW LETTERS 20 APRIL 1987

an by Inami and Lim,[9] and we follow their notation. The effective Lagrangean arising from Fig. 1 is

$$\mathcal{L}_{\rm eff}^{b\bar{s}\to l^+l^-} = 2\sqrt{2}G_F\chi v_i\{\bar{C}_i(\bar{s}\gamma_\mu Lb)(\bar{l}\gamma_\mu Ll) - s_W^2(F_1^i + 2\bar{C}_i^Z)(\bar{s}\gamma_\mu Lb)(\bar{l}\gamma_\mu l) - s_W^4F_2^i[\bar{s}i\sigma_{\mu\nu}(q_\nu/q^2)(m_sL + m_bR)b](\bar{l}\gamma_\mu l)\}, \quad (1)$$

$$\mathcal{L}_{\rm eff}^{b\bar{s}\to\nu\bar{\nu}} = -2\sqrt{2}G_F\chi v_i\bar{D}_i(\bar{s}\gamma_\mu Lb)(\bar{\nu}\gamma_\mu L\nu), \quad (2)$$

where $\chi = g^2/16\pi^2$, $v_i \equiv V_{is}^* V_{ib}$, i is summed from 2 to n (where n is the number of generations),[10] s_W is the sine of the Weinberg angle, and we exhibit[11]

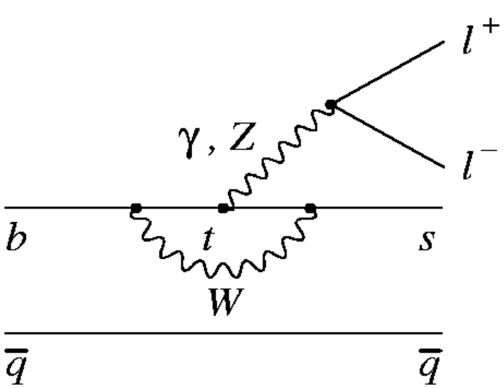
$$\bar{C}_i \equiv \bar{C}_i^Z + \bar{C}_i^{\rm box} = \tfrac{1}{4}x_i + \frac{3}{4}\left(\frac{x_i}{x_i-1}\right)^2\ln x_i - \frac{3}{4}\frac{x_i}{x_i-1}, \quad (3)$$

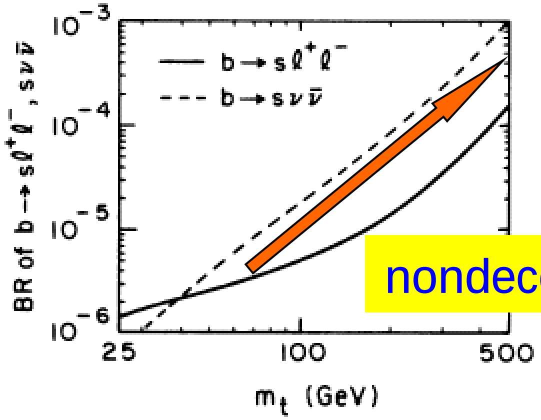
$$\bar{D}_i \equiv \bar{D}_i^Z + \bar{D}_i^{\rm box} = \tfrac{1}{4}x_i + \frac{3}{4}\frac{x_i(x_i-2)}{(x_i-1)^2}\ln x_i + \frac{3}{4}\frac{x_i}{x_i-1}, \quad (4)$$

where $x_i = m_i^2/M_W^2$, and m_i is the internal quark mass. The important feature of Eqs. (3) and (4) is the term $x_i/4$,[8]

dimensions

γ		Z
αG_F	<	$G_F^2\, m_t^2$





nondecoupling

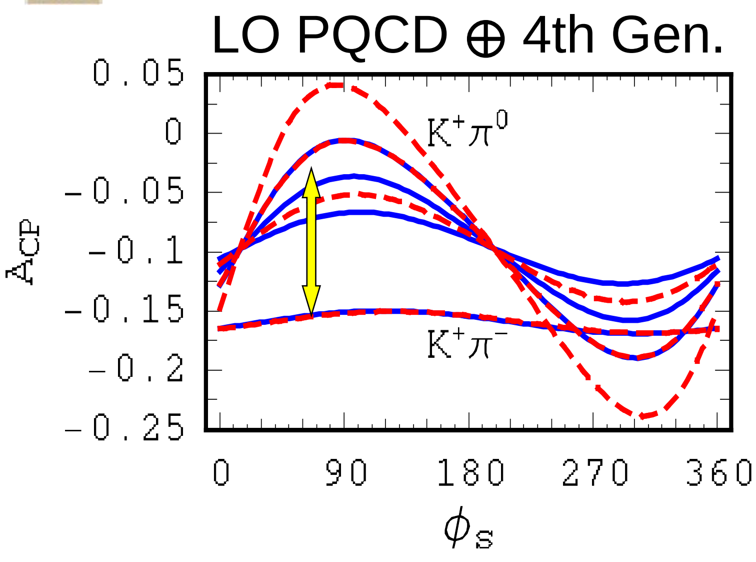
Nondecoupling

Decoupling Thm: Heavy Masses are decoupled in QED/QCD
∵ Appear in Propagator

Nondecoupling: Yukawa Couplings λ_Q Appear in Numerator

Subtlety of Spont. Broken **Chiral** Gauge Theory dynamical

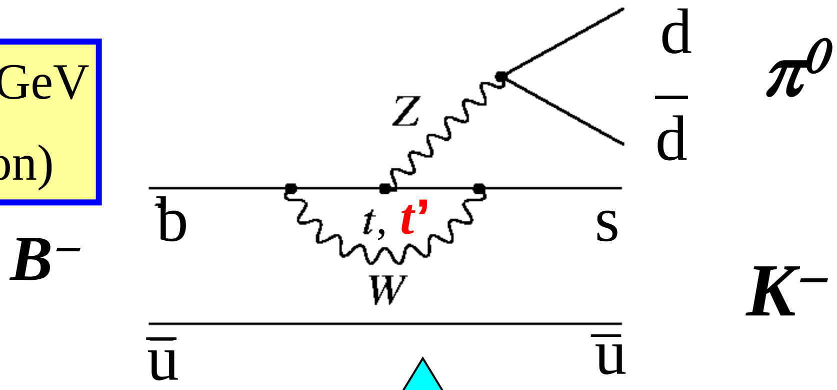
$\Delta\mathcal{A}_{K\pi} = A_{K^+\pi^0} - A_{K^+\pi^-} \sim 15\%$ and $P_{EW}^{b\to s}$

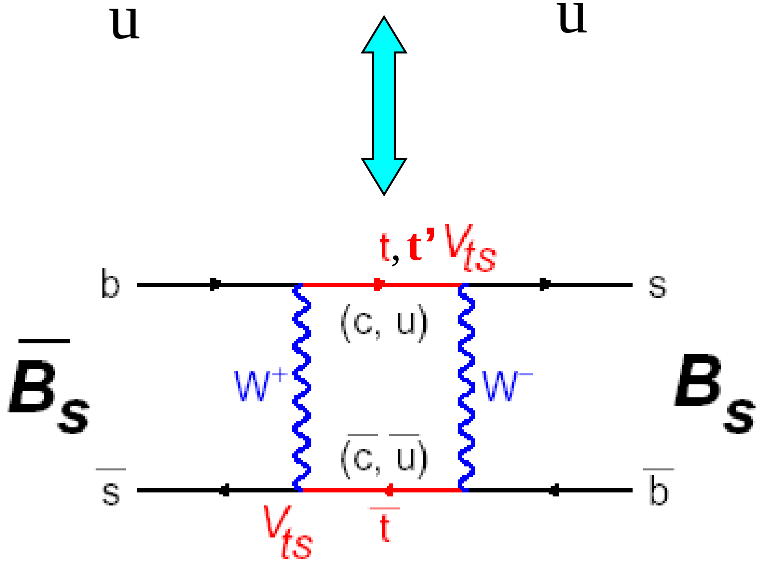


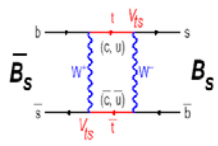
WSH, Nagashima, Soddu, PRL'05

$\Delta\mathcal{A}_{K\pi} \approx 12\%$ vs 15% (data)

$m_{t'} = 300$ GeV (illustration)





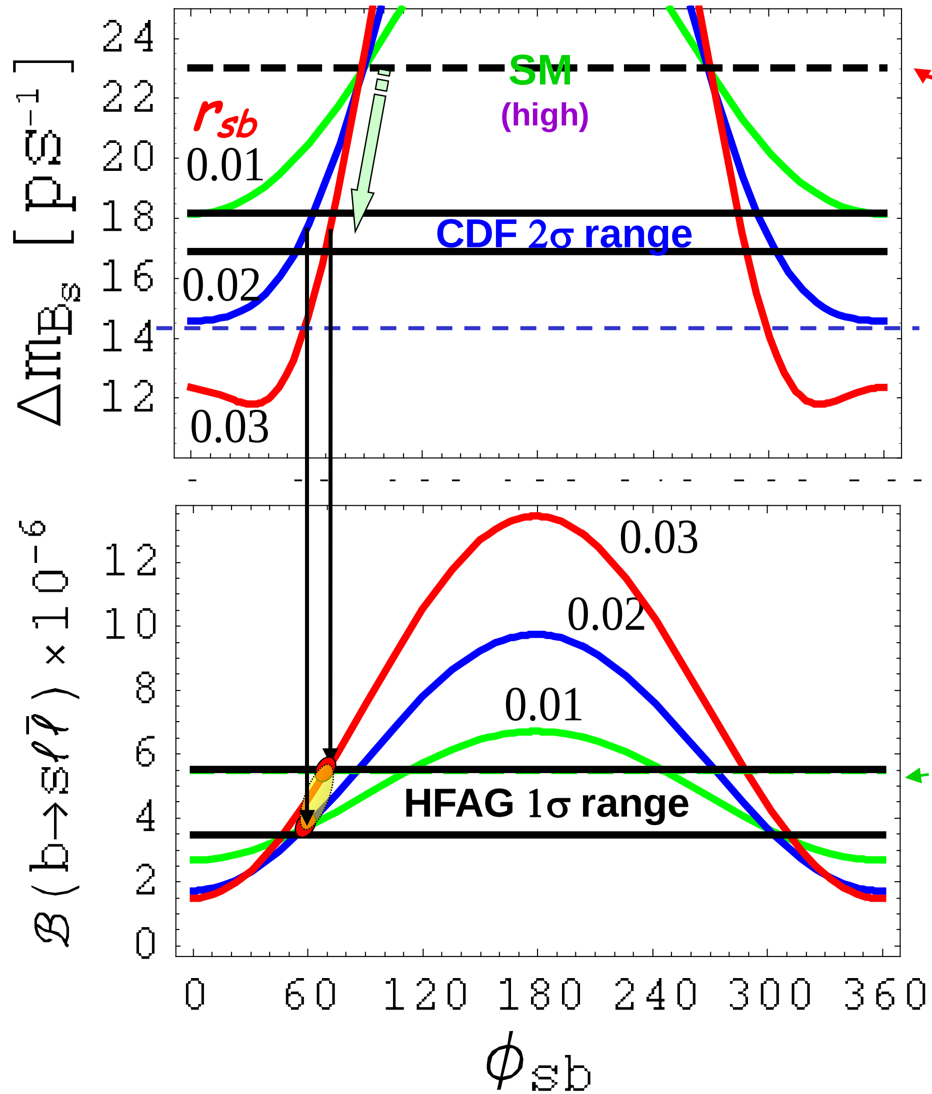


$$\lambda_{t'} \equiv V^*_{t's} V_{t'b} \equiv r_{sb}\, e^{i\phi_{sb}}$$

WSH, Nagashima, Soddu, hep-ph/0610385 (PRD'07)

a walk-thru exercise

$$f_{B_s}\sqrt{B_{B_s}} = 295 \pm 32 \text{ MeV}$$



- Fixed r_{sb} ⇨ Narrow ϕ_{sb} Range
  destructive with top
- For r_{sb} ~ 0.02 – 0.03, [V_{cb} ~ 0.04

ϕ_{sb} Range ~ 60° - 70°

Finite CPV Phase

Consistent w/ $\mathcal{B}(b \to s \ell\ell)$

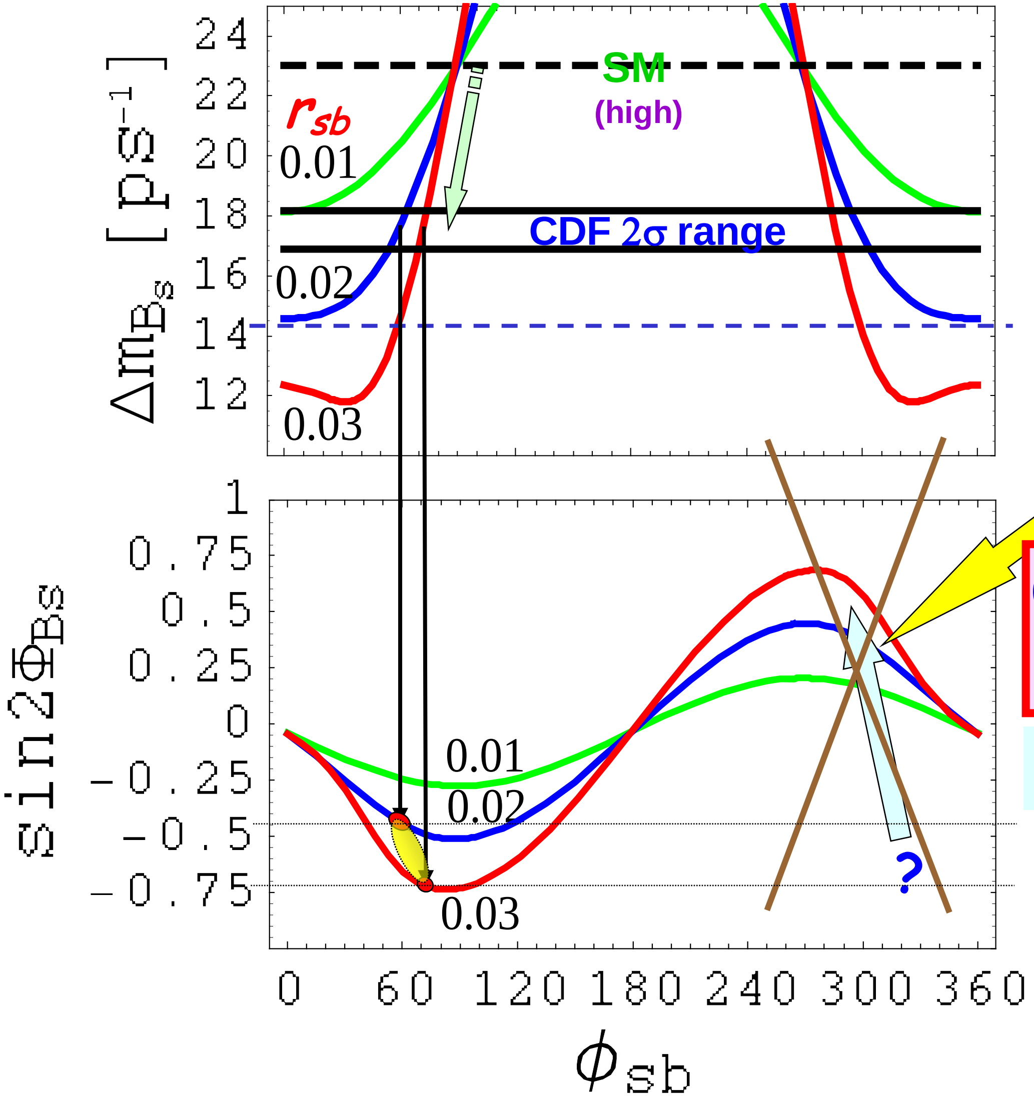
SM-like !

Large CPV Possible !

Despite Δm_{B_s}, $\mathcal{B}(b \to s \ell\ell)$ SM-like

Large CPV in B_s Mixing

WSH, Nagashima, Soddu, hep-ph/0610385 (PRD'07)



$\Delta\mathcal{A}_{K\pi}$, ΔS

Can **Large CPV in B_s Mixing** Be Measured @ Tevatron ?

Sign Predicted !

Sure thing by LHCb ca. 2008

$\sin 2\Phi_{B_s} \sim \pm 0.5 - \pm 0.7$

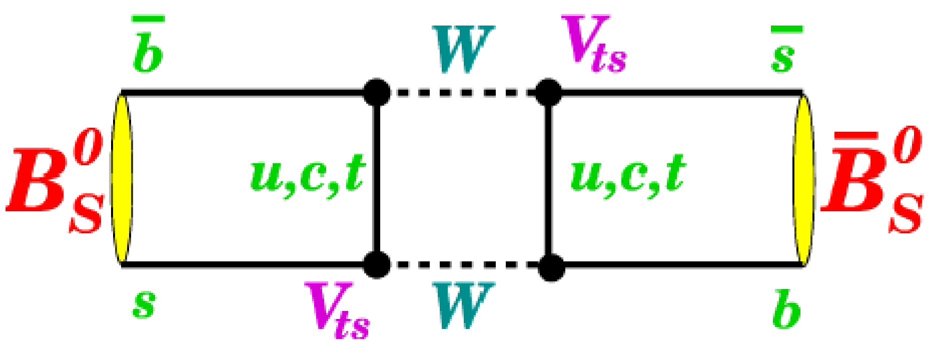
Despite Δm_{B_s}, $\mathcal{B}(b \to s \ell\ell)$ SM-like

An Updated Measurement of the CP Violating Phase $\beta_s^{J/\psi\phi}$

The CDF Collaboration[1]

CDF/ANAL/BOTTOM/PUBLIC/9458
Version 1.0
August 7, 2008

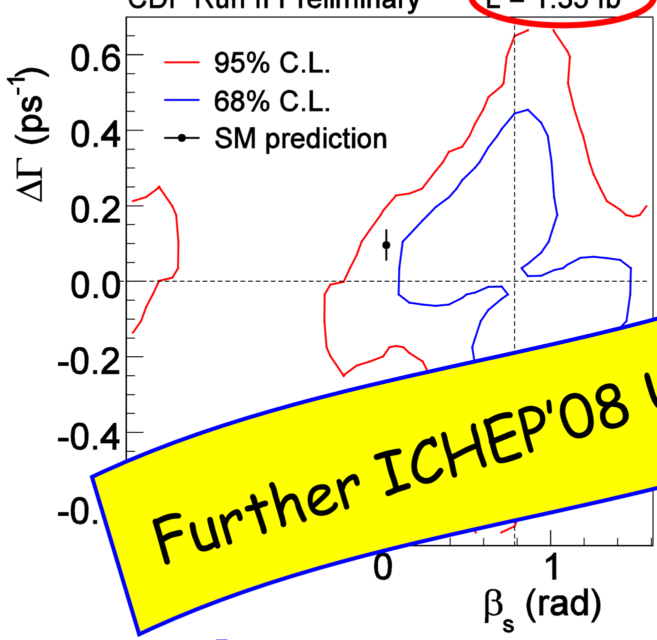
It is interesting to note that the Belle and *BABAR* collaborations have observed an asymmetry between direct CP asymmetries of charged and neutral $B \to K\pi$ decays with 5σ significance [5, 6]. In the absence of an under-estimation of the contribution from color-suppressed tree decays, it is difficult to explain this discrepancy without some source of new physics contributing to the electroweak penguin which governs the $b \to s$ transition.In the standard model, this isospin-violating diagram should be highly suppressed, but if a new source of physics is indeed present in these transitions it may be enough to cause the different CP asymmetries that have been observed.. In the $B_s^0 \to J/\psi\,\phi$ decay, the $b \to s$ transition occurs through the mixing box diagram shown in Fig. 1. It is possible that new particles could enter this transition through the $b \to s$ quark transition. While there are surely a number of possible sources of new physics that might give rise to such discrepancies, George Hou predicted the presence of a t' quark with mass between ~ 300 and 1,000 GeV/c^2 in order to explain the Belle result and predicted *a priori* the observation of a large CP-violating phase in $B_s^0 \to J/\psi\,\phi$ decays [7, 8]. Another result of interest in the context of these measurements is the excess observed at ~ 350 GeV/c^2 in the recent t' search at CDF using 2.3 fb^{-1} of data [9]. In this direct search for a fourth generation up-type quark, a significance of less than 2σ is obtained for the discrepancy between the data and the predicted backgrounds, so that the effect, while intriguing, is presently consistent with a statistical fluctuation. A updated search with more data would also clearly be of interest, particularly if a large value of $\beta_s^{J/\psi\phi}$ persists with the addition of more data.



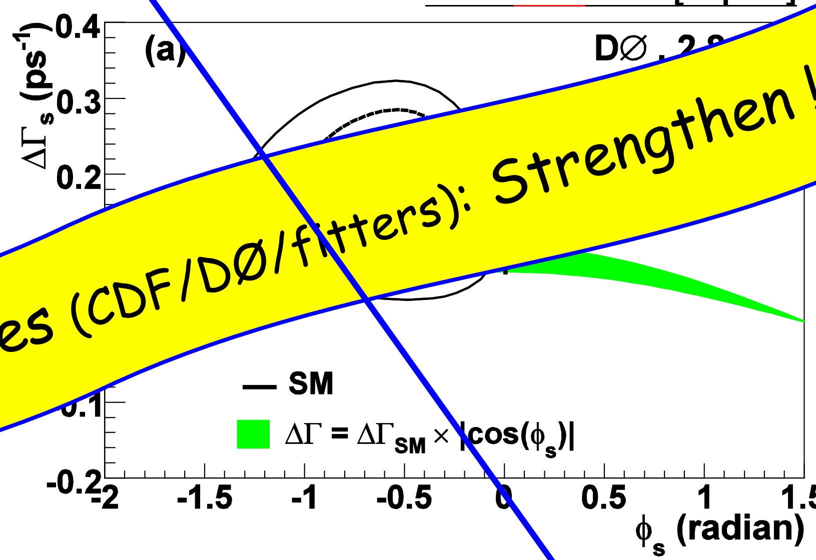
$\sin 2\Phi_{B_s} \sim -0.5$ - -0.7

WSH, Nagashima, Soddu, PRD'07 (already in 05)

PRL'08
arXiv:0712.2397 [hep.ex]



PRL'08
arXiv:0802.2255 [hep.ex]



Further ICHEP'08 Updates (CDF/DØ/fitters): Strengthen !

Summer '09

Observable	68% Prob.	95% Prob.
ϕ_{B_s} [°]	-19.9 ± 5.6	~~[-30.45, -9.29]~~
	-68.2 ± 4.9	[-78.45,-58.2]

UT*fit*

arXiv:0803.0659 [hep.ph]

$\sin 2\Phi_{B_s} = -0.64 \pm ?$

~~~2.8σ~~ 2.1

Incredible !!!
~~~

From Fermilab, a New Clue to Explain Human Existence? - NYTimes.com http://www.nytimes.com/2010/05/18/science/space/18cosmos.html?pa...

The New York Times Reprints

May 17, 2010

A New Clue to Explain Existence

By DENNIS OVERBYE

Physicists at the Fermi National Accelerator Laboratory are reporting that they have discovered a new clue that could help unravel one of the biggest mysteries of cosmology: why the universe is composed of matter and not its evil-twin opposite, antimatter. If confirmed, the finding portends fundamental discoveries at the new Large Hadron Collider outside Geneva, as well as a possible explanation for our own existence.

Matter: The next generation - physics-math - 01 June 2010 - New Scientist http://www.newscientist.com/article/mg20627622.700-matter-the-next-...

Matter: The next generation

01 June 2010 by David Shiga
Magazine issue 2762. Subscribe and save
For similar stories, visit the Quantum World Topic Guide

Hints of a new quark have turned up in the decay products of the Tevatron particle smasher

A fourth generation of particles could explain how matter survived to form stars and galaxies

Evidence for an anomalous like-sign dimuon charge asymmetry

arXiv:1005.2757 [hep-ex]

G.Borissov

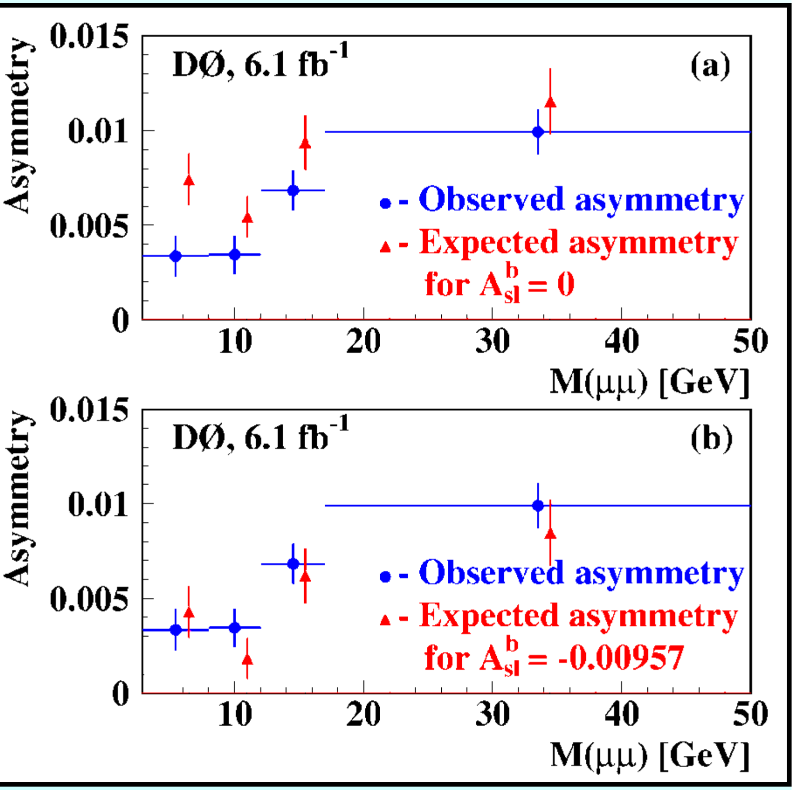
Lancaster University, UK

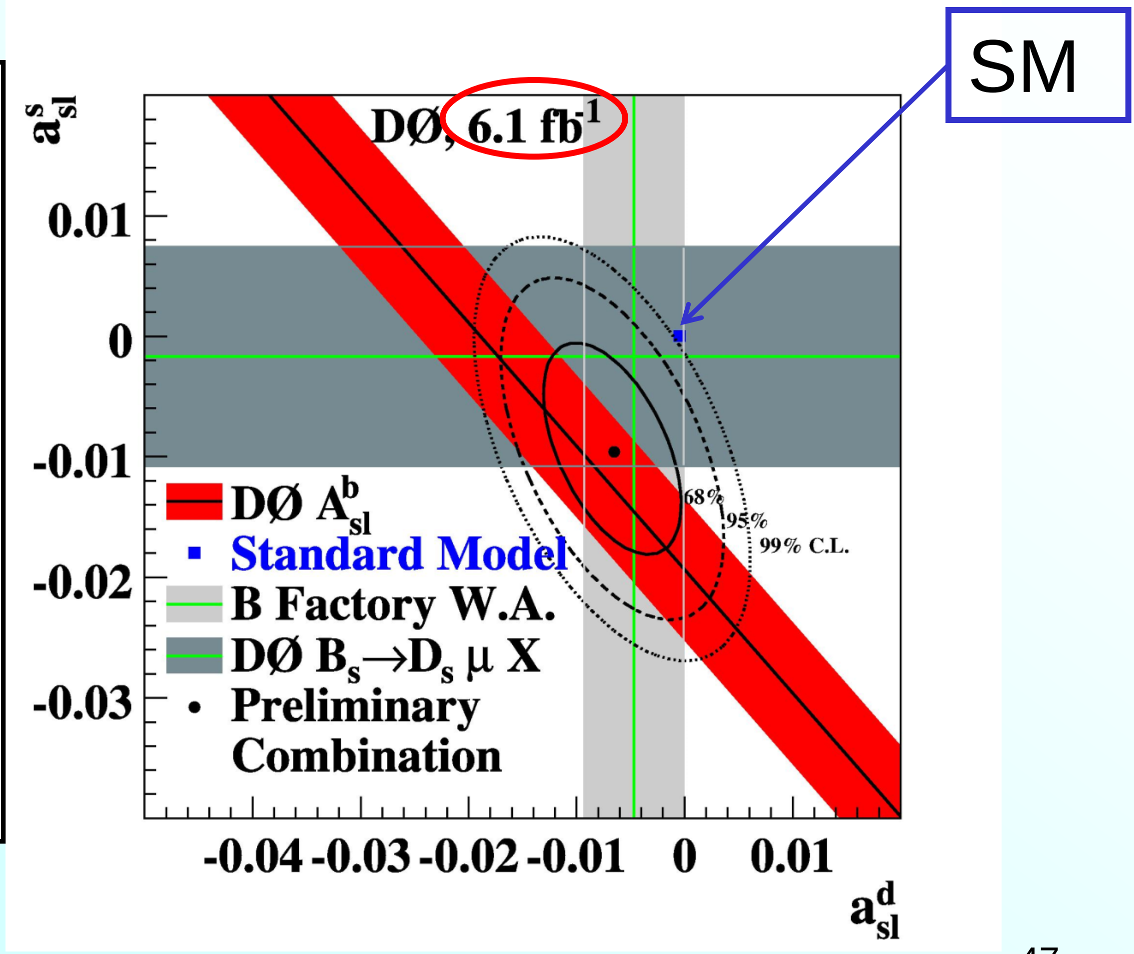
Result is ~3.2 σ from SM

$$A_{sl}^{b} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

preliminary combination

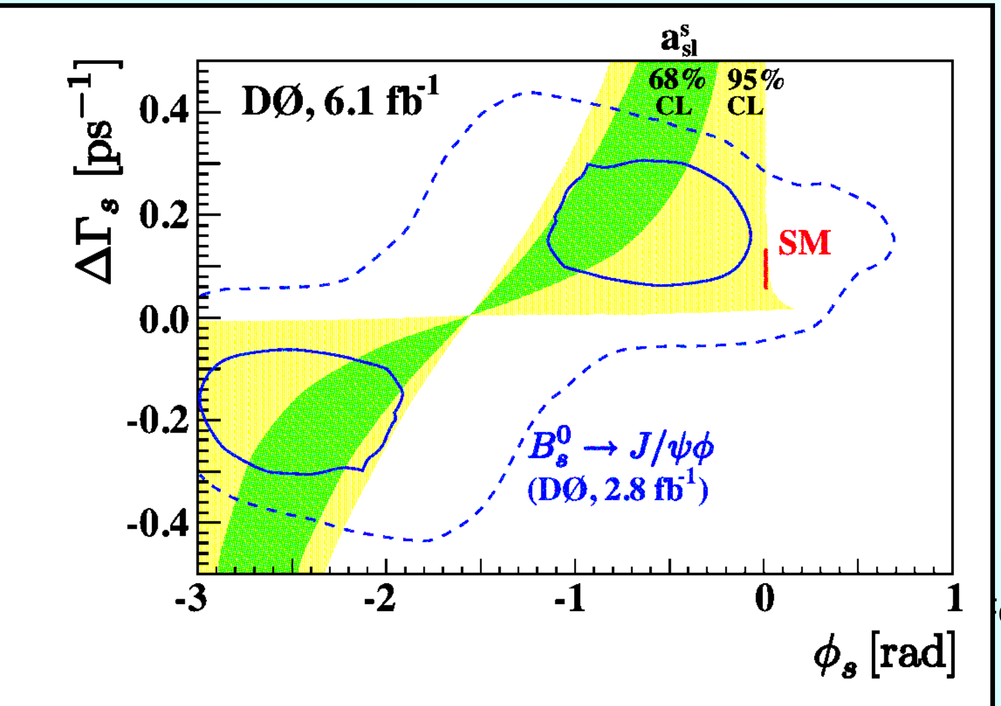
- Our (preliminary) combination of all measurements of semileptonic charge asymmetry shows a similar deviation from the SM.

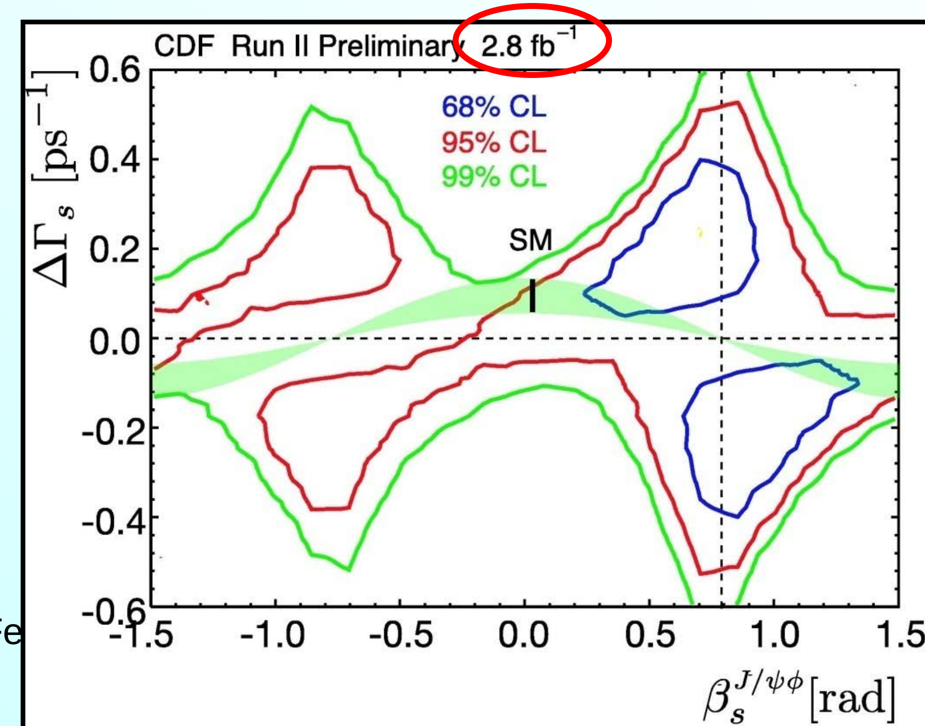




Comparison with other measurements

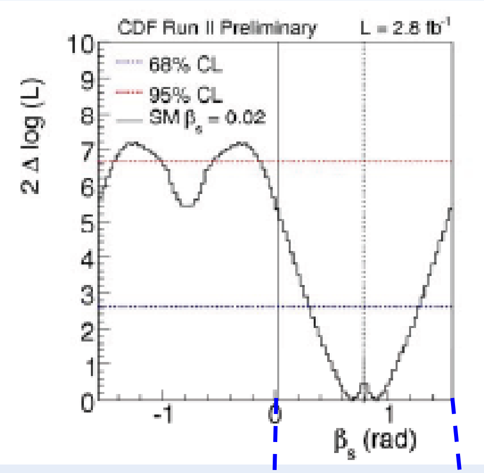
- Obtained value of a^s_{sl} can be translated into the measurement of the CP violating phase ϕ_s and $\Delta\Gamma_s$
- This constraint is in excellent agreement with an independent measurement of ϕ_s and $\Delta\Gamma_s$ in $B_s \rightarrow J/\psi\phi$ decay
- This result is also consistent with the CDF measurement in this channel



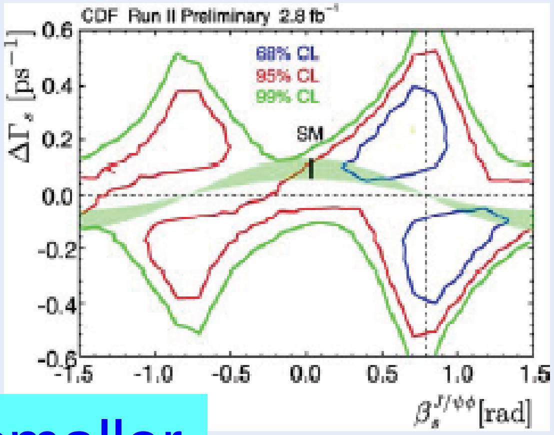


Comparisons

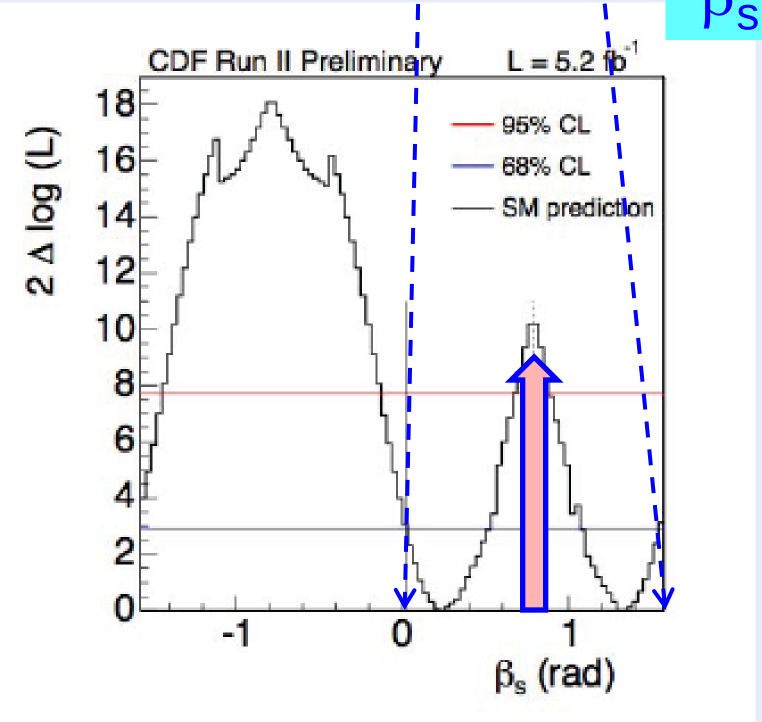
CDF Update at FPCP last week

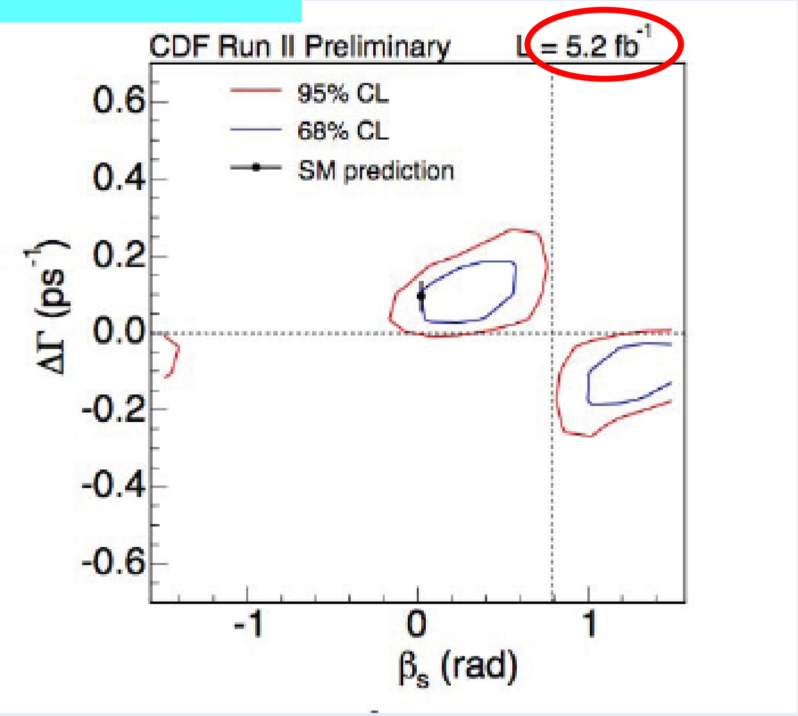


ICHEP 2008 results



β_s seems smaller





Comparison with other measurements

Can One Comprehend This ?

$\sin 2\Phi_{B_s} = -\sin 2\beta_s = \sin\phi_s$

- Obtained value of a^s_{sl} can be translated into the measurement of the CP violating phase … and $\Delta\Gamma_s$
- This constraint is in excellent agreement with an independent mea… decay
- This result is also consist… me… channel

● Dzero & CDF consistent, but $\sin 2\Phi_{B_s}$ "smaller" than before.

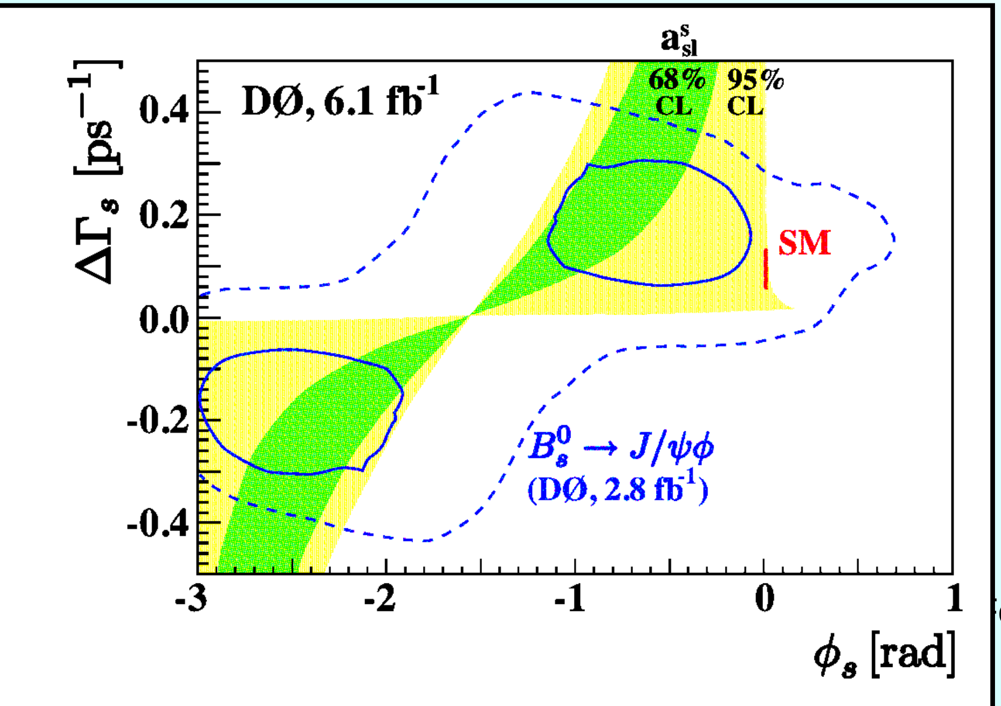
● If Dzero result stays, $\Delta\Gamma_s^{SM}$ probably larger than Lenz-Nierste.

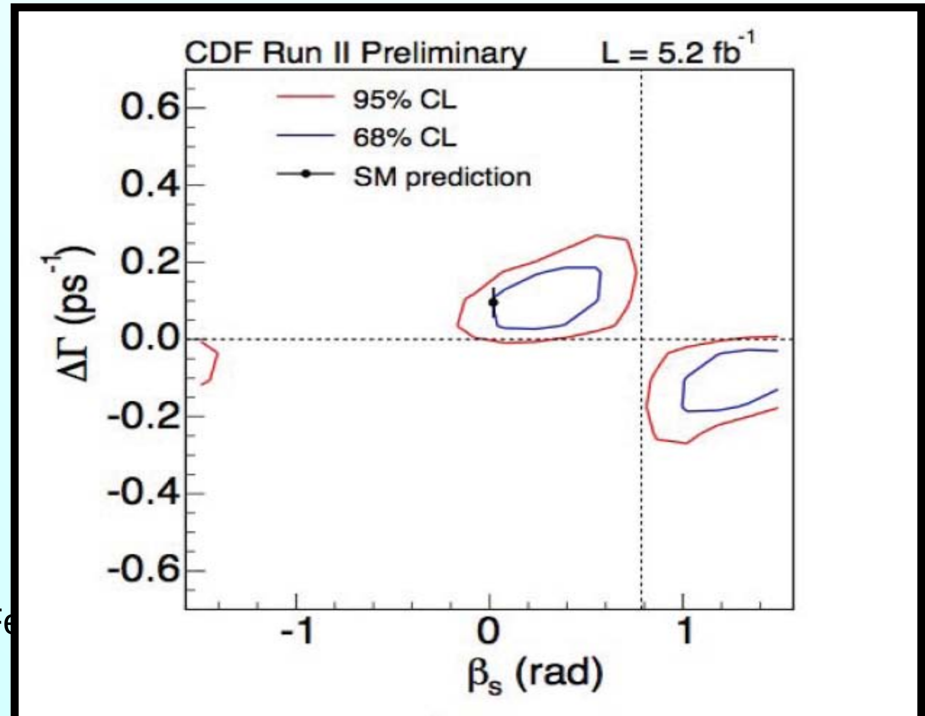
$$A^s_{SL} = \mathrm{Im}\,\frac{\Gamma^s_{12}}{M^s_{12}} = \left|\frac{\Gamma^s_{12}}{M^s_{12}}\right| \sin\phi_s = \frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$$

$$\Delta\Gamma_s = \Delta\Gamma_s^{SM}\cos\phi_s$$

$$|A^s_{SL}| < \frac{\Delta\Gamma_s^{SM}}{\Delta m_s^{CDF}} \lesssim 0.008$$

see WSH & Mahajan, PRD'07
also: Grossman, PLB'96
Dunietz, Fleischer, Nierste, PRD'01





$\sin 2\Phi_{B_s} \sim -0.5 - -0.7$

$m_{t'} = 300$ GeV

WSH, Nagashima, Soddu, PRD'07 (already in 05)

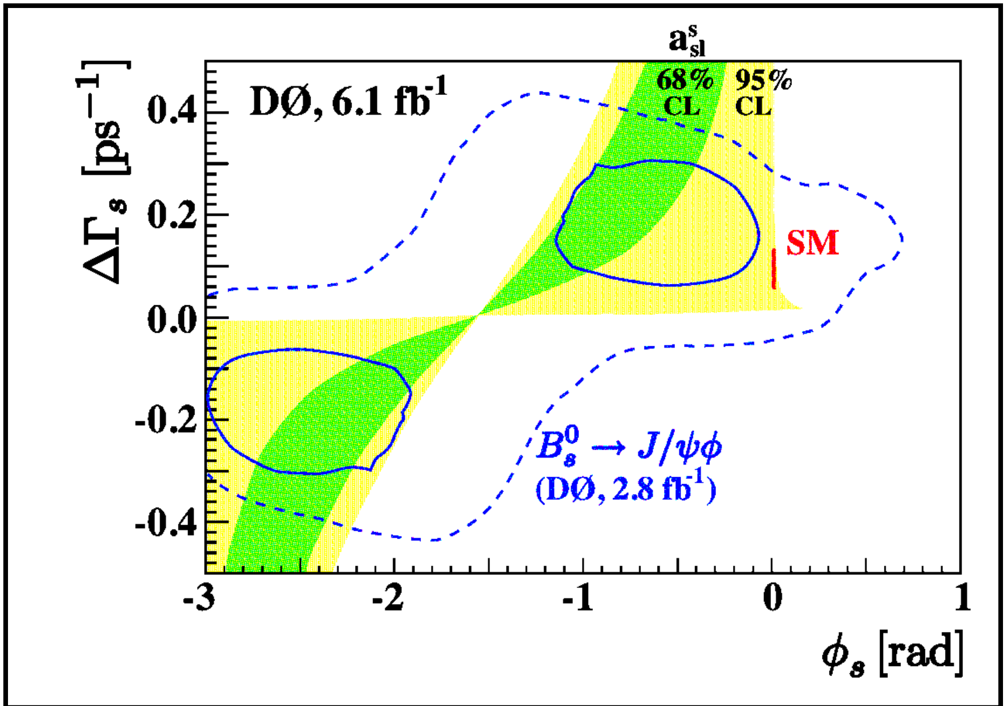
$\sin 2\Phi_{B_s} \sim -0.33$

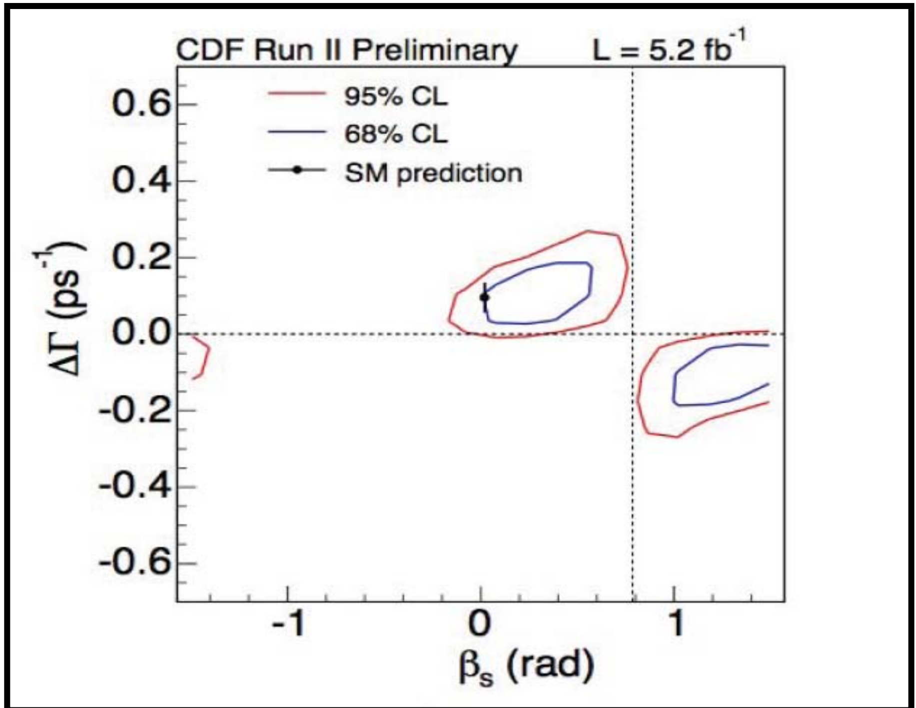
$m_{t'} = 500$ GeV

WSH, Ma, arXiv:1004.2186 [hep-ph]

Also, Soni et al., arXiv:1002.0595 [hep-ph]
Buras et al. arXiv:1002.2126 [hep-ph]
Lenz et al., arXiv:1005.3505 [hep-ph]

4th generation "prediction" still robust, but needs LHCb to verify.





Heavenly Touch — Towards BAU

Kobayashi's Nobel slides

Present Status of CP Violation

B-factory results show that quark mixing is the dominant source of CP violation

B-factory results allow room for additional source from new physics

Matter dominance of the Universe seems requiring new source of CP violation

CPV so far only observed in KM ...

- Nontrivial CPV Phase

  Nontrivial $V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$

- All like-charge quark pairs nondegenerate,

  Otherwise → Back to 2-gen. and CPV vanish.

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)\, A$$

Jarlskog Invariant for **CPV**

$$\mathrm{Im}\,\det\left[m_u m_u^{\dagger},\ \ m_d m_d^{\dagger}\right]$$

Kobayashi's Nobel slides

Present Status of CP Violation

B-factory results show that quark mixing is the dominant source of CP violation

B-factory results allow room for additional source from new physics

Matter dominance of the Universe seems requiring new source of CP violation

J seems short by at least 10^{-10}

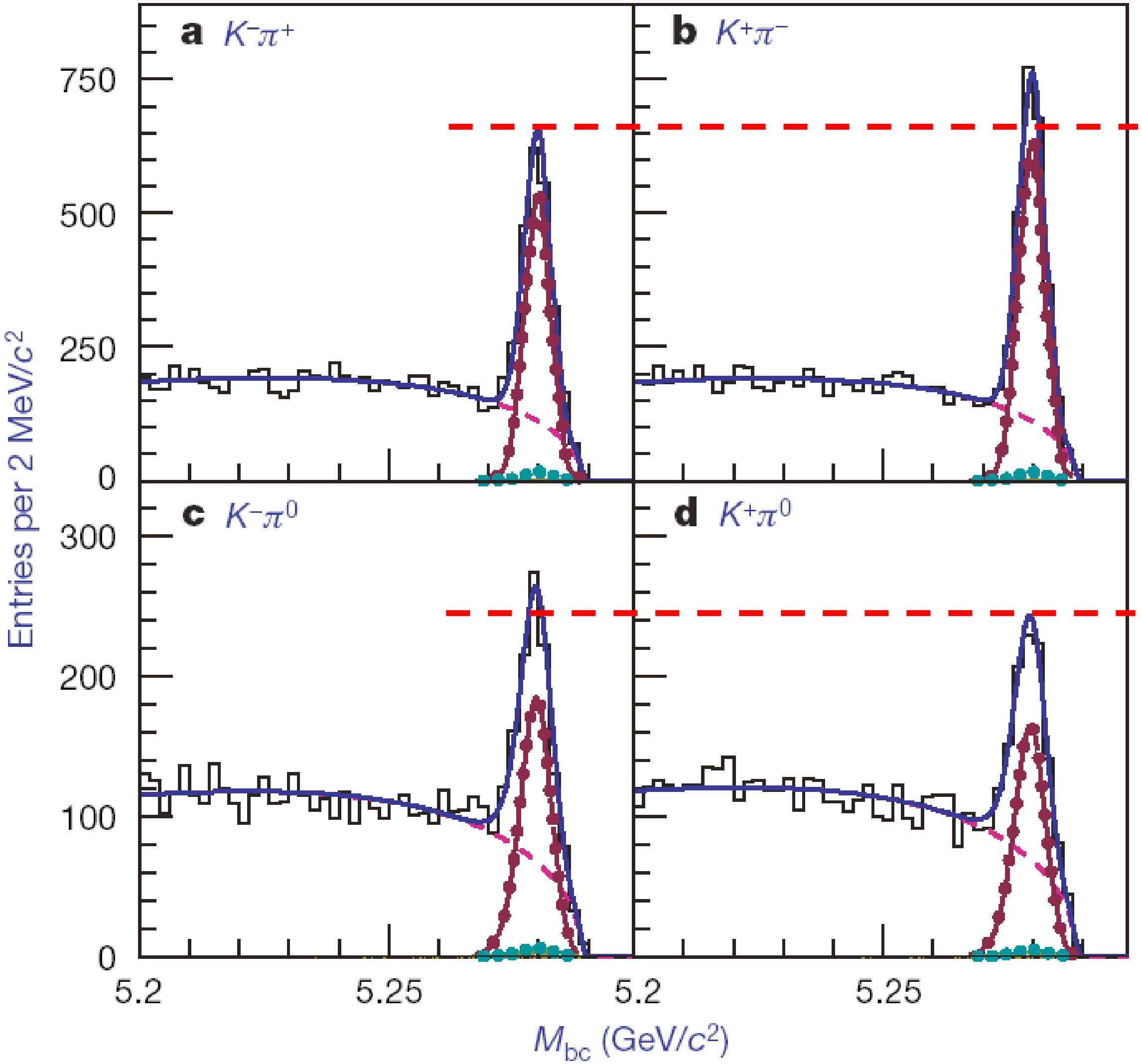
Belle 2008 ⟨Nature⟩: Simple Bean Count

$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} = +0.164 \pm 0.037 \quad 4.4\sigma$

$+0.07 \pm 0.03$ vs -0.094 ± 0.020

LETTERS

NATURE | Vol 452 | 20 March 2008



b → s CPV

Difference Is Large !

Exp. Established

Belle + BaBar (+ CDF)

And Not Predicted !

"Nature" writing : Explaining CPV to "biologists"

You get "out of your mind".

B.A.U. from CPV in KM

$$\frac{n_{\bar{\mathcal{B}}}}{n_\gamma} \cong 0$$

$$\frac{n_{\mathcal{B}}}{n_\gamma} = (6.2 \pm 0.2) \times 10^{-10}$$

WMAP

KM ~ Enough CPV?

~~Too Small in SM~~

If shift by One Generation in SM4 (need 3 generation in KM)

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)\,A$$

Providence

WSH, arXiv:0803.1234 [hep-ph]

CJP'09

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\,A^{sb}_{234}$$

$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\,\frac{A^{sb}_{234}}{A}\,J$$

~ 10^{+15} Gain

Order 1 ~ 30

Gain mostly in Large Yukawa Couplings !

Nature would likely use this !?

Matter: The next generation - physics-math - 01 June 2010 - New Scientist http://www.newscientist.com/article/mg20627622.700-matter-the-next-...

Matter: The next generation

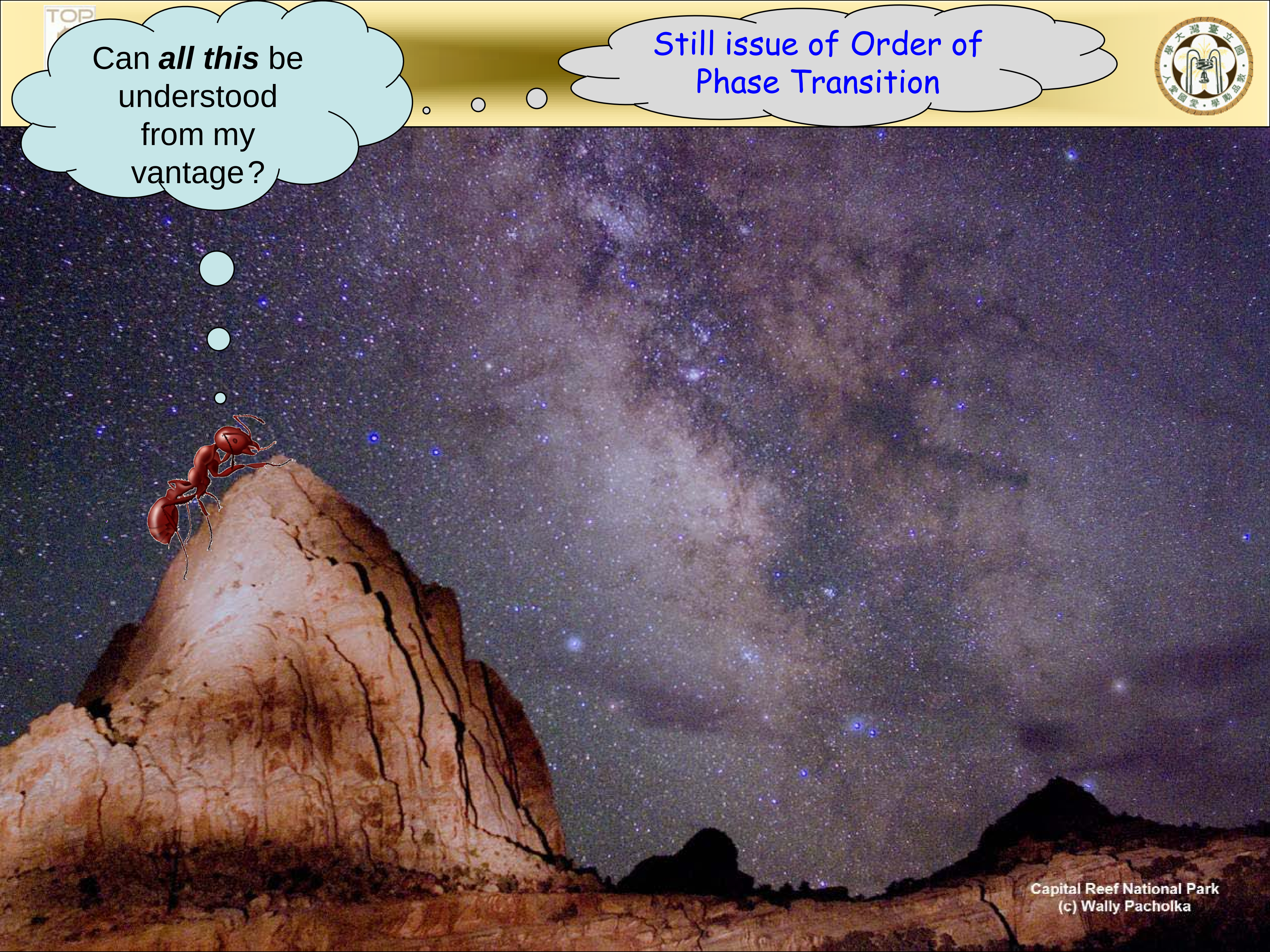
01 June 2010 by David Shiga
Magazine issue 2762. Subscribe and save
For similar stories, visit the Quantum World Topic Guide

Hints of a new quark have turned up in the decay products of the Tevatron particle smasher

A fourth generation of particles could explain how matter survived to form stars and galaxies

If fourth-generation quarks are responsible for upsetting this balance, then we would not exist without them. "To me, this is the single most important motivation for the existence of [the fourth generation]," says George Hou of the National Taiwan University in Taipei. By a mere extension from three to four generations, he adds, we may have enough asymmetry to explain how matter survived annihilation in the early universe.

Still issue of Order of Phase Transition



Unfinished on Earth

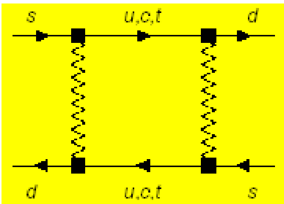
$A_{FB}(B \to K^* l^+ l^-)$ and Other Predictions

sent to Backup

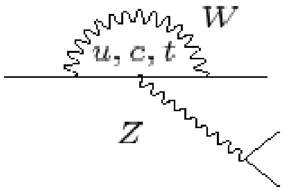
On Boxes and Z Penguins

Nondecoupling

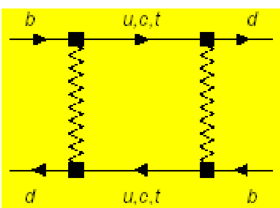
∵ Large Yukawa!



GIM, charm, ε_K

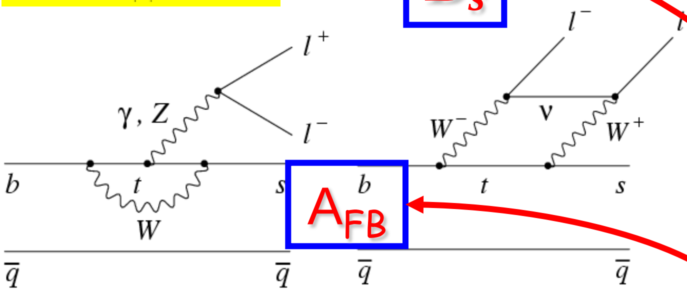


small ε'/ε, K $\to$ $\pi\nu\nu$ (still waiting)



heavy top, sin$2\phi_1/\beta$

B_s



A_{FB}

Z dominance for heavy top

1986 $\to$ 2002

All w/ 3-generations,
Just wait if there's a 4th

D !

b', t' @ (Tevatron/)LHC

II. Direct Search: Large Yukawa Coupling & EWSB?

Tevatron Thread

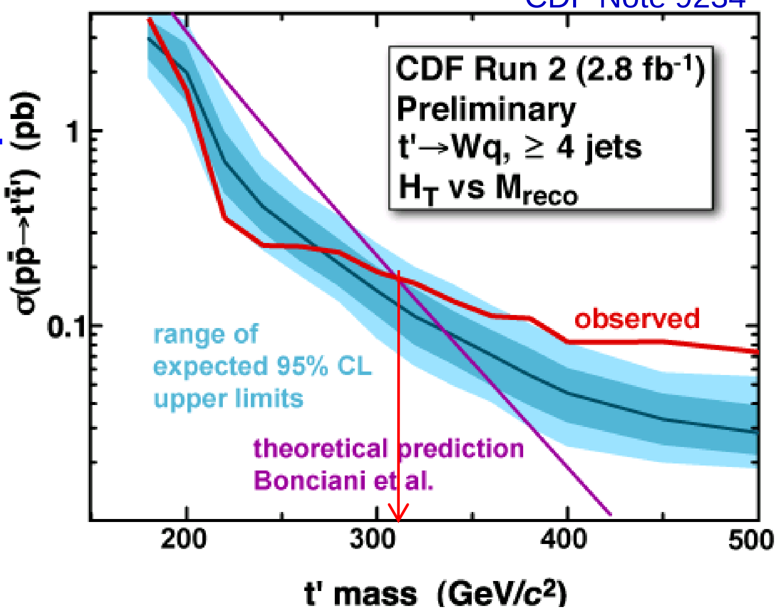
Nambu Legacy

Higgs-Yukawa on ...

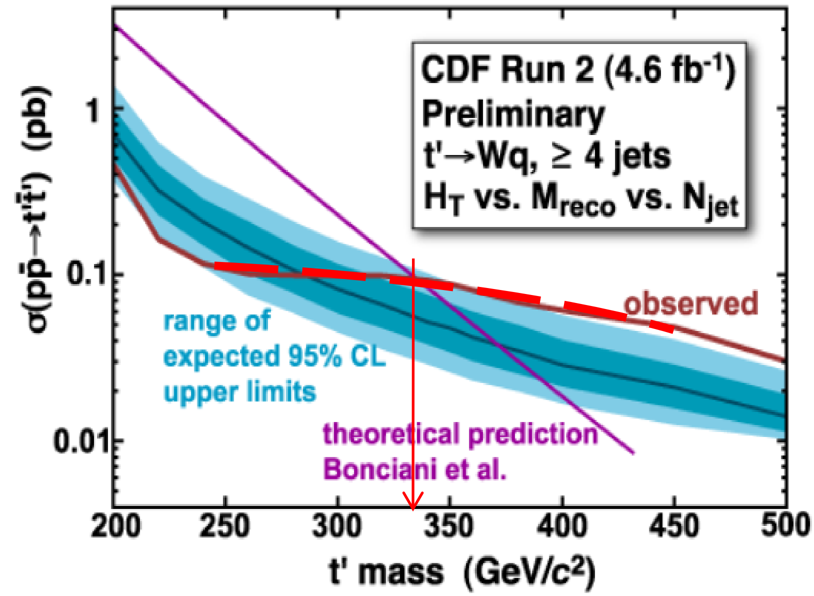
Tevatron t' and b' Search Status

$t' \to Wq$

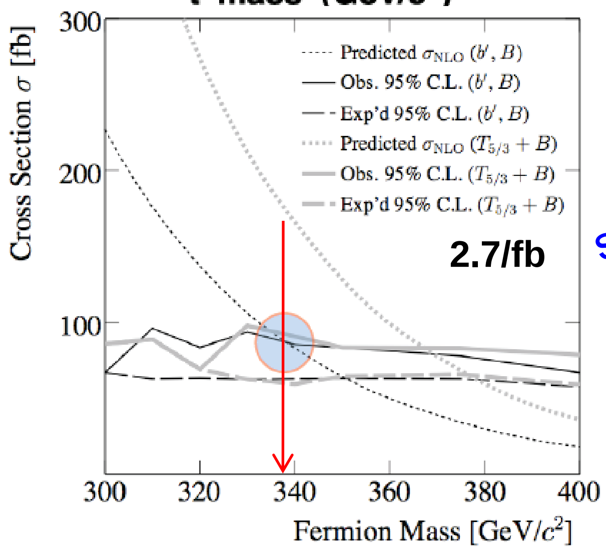
CDF Note 9234



CDF/PUB/TOP/PUBLIC/10110

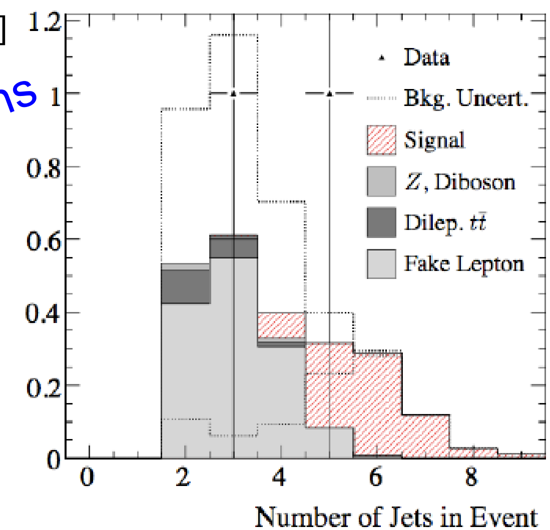


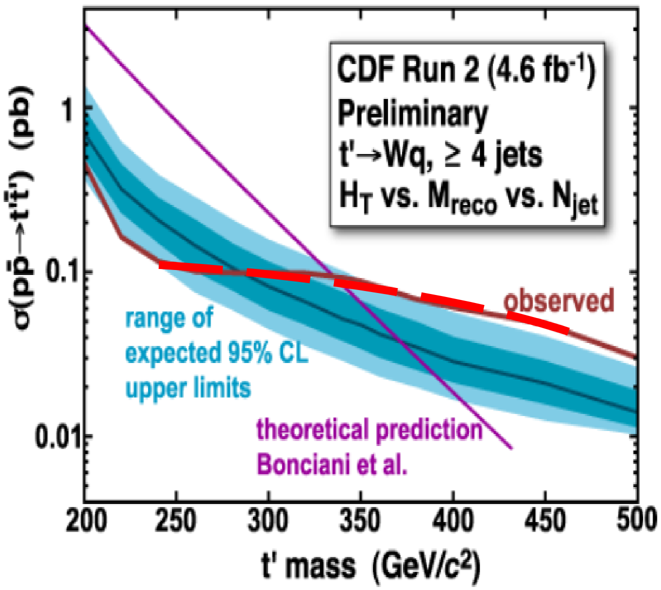
$b' \to Wt$

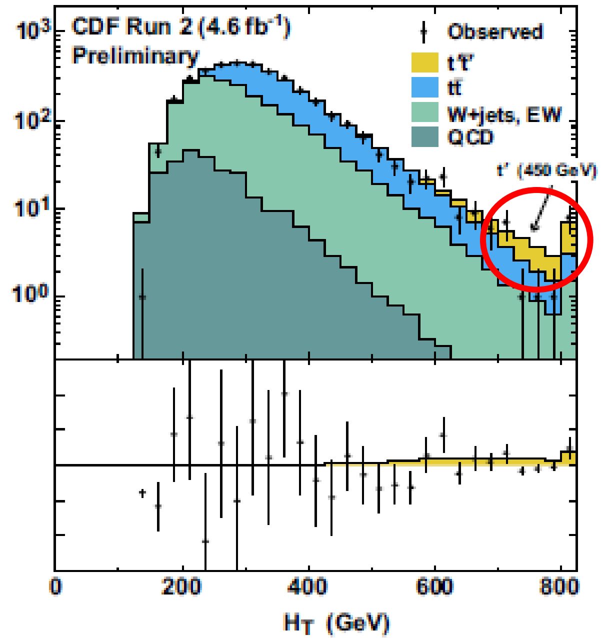


arXiv:0912.1057 [hep-ex]
PRL2010

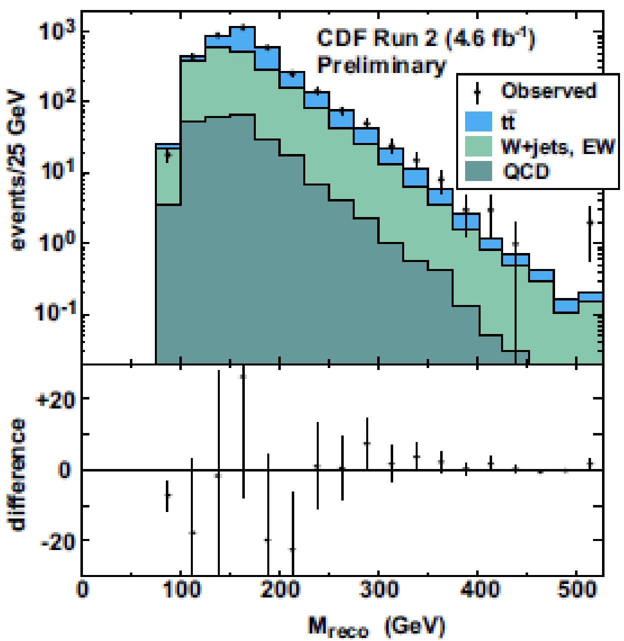
same sign dileptons

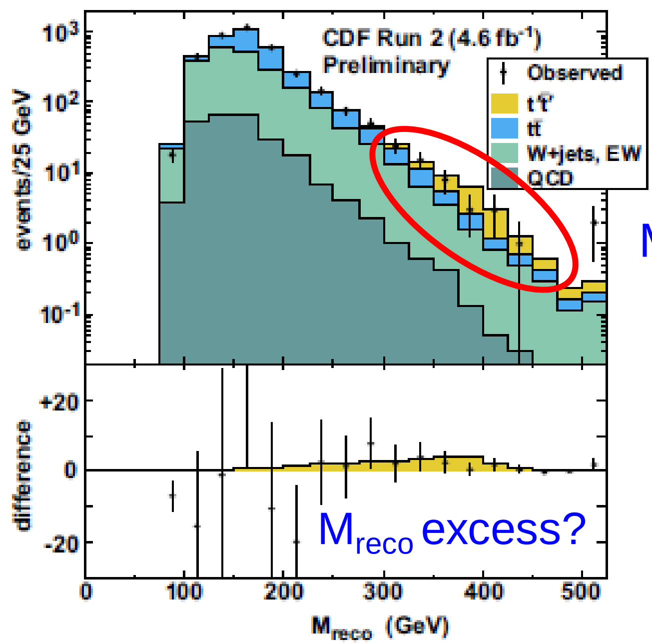






High H_T





$M_{b'} \sim 450$ GeV?

Cross Section
too large

Matter: The next generation

01 June 2010 by David Shiga
Magazine issue 2762. Subscribe and save
For similar stories, visit the Quantum World Topic Guide

Hints of a new quark have turned up in the decay products of the Tevatron particle smasher

The excess is small enough to be a statistical fluke, so the team is not claiming to have seen signs of a fourth generation. "Extraordinary claims require extraordinary evidence, and we definitely don't have that," admits John Conway of the University of California at Davis, one of the study's authors.

A fourth generation of particles could explain how matter survived to form stars and galaxies

If fourth-generation quarks are responsible for upsetting this balance, then we would not exist without them. "To me, this is the single most important motivation for the existence of [the fourth generation]," says George Hou of the National Taiwan University in Taipei. By a mere extension from three to four generations, he adds, we may have enough asymmetry to explain how matter survived annihilation in the early universe.

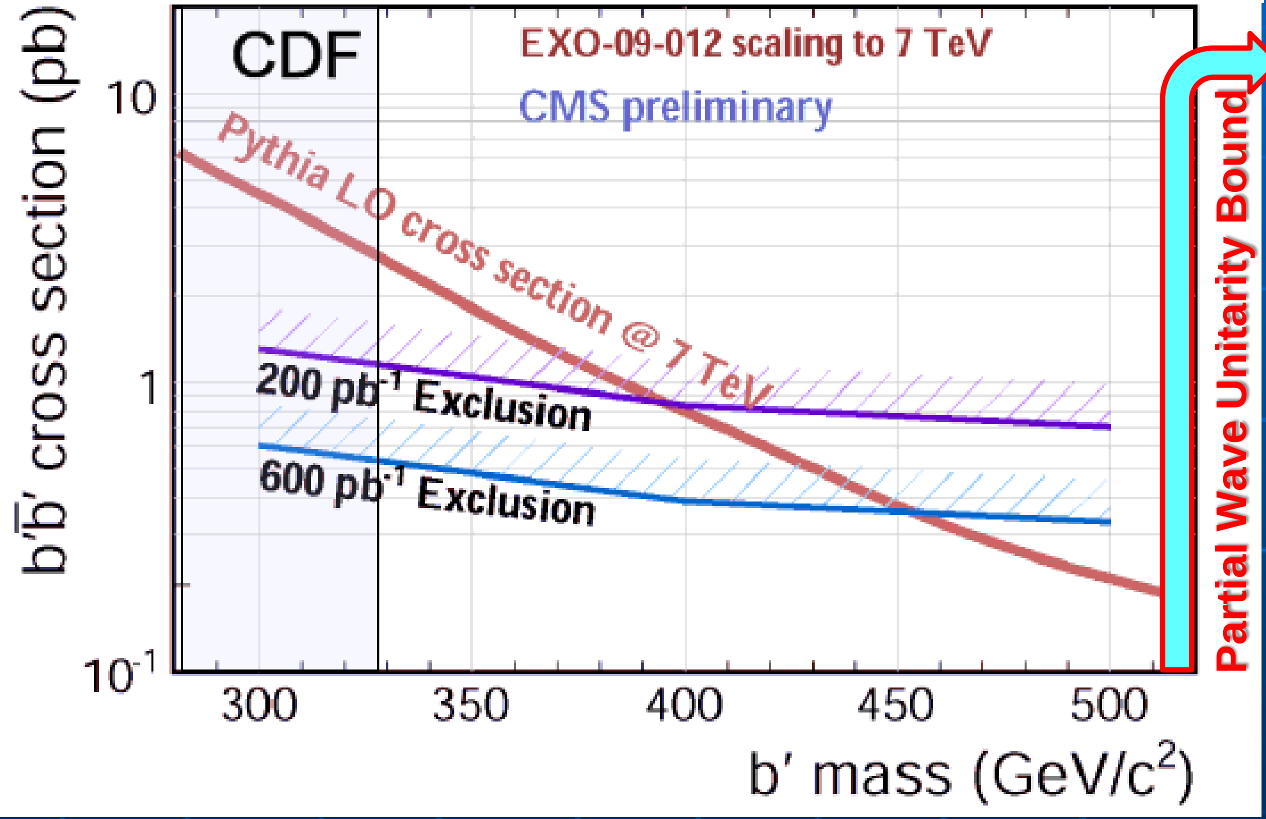
b' Search

same sign dileptons

- b‘ → Wt
- Scale using **LO** PYTHIA cross section for signal and background
- Our sensitivity is expected to surpass the current Tevatron lower b‘ mass limit of 325 GeV (CL 95%)

With ~100 pb^{-1}

CMS NOTE -2010/008



SSB

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

b. 1921
(in Tokyo, Japan)

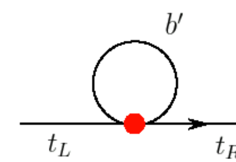
$\langle \bar{Q}Q \rangle$ can Condense

by Large Yukawa !

Could EWSB be
due to b’ and t’
above unitarity bound ~ 500-600 GeV ?

Bob Holdom: N–J-L

[Bardeen, Hill, Lindner



Gustavo Burdman: “Holographic” 4th gen.

Nambu's comment

Y. Nambu, preliminary Notes for the Nobel Lecture

In hindsight I regret that I should have explored in more detail the general mechanism of mass generation for the gauge field. But I thought the plasma and the Meissner effect had already established it. I also should have paid more attention to the Ginzburg-Landau theory which was a forerunner of the present Higgs description.

Other examples of BCS type SSB

- ^3He superfluidity
- Nuleon pairing in nuclei
- Fermion mass generation in the electro-weak sector of the standard model

Nambu calls the last entry

my biased opinion, there being other interpretations as to the nature of the Higgs field

Let's re-learn from Nambu

Forum: Higgs-Yukawa Model on a Lattice

1/2010

http://indico.cern.ch/conferenceDisplay.py?confId=68036

Content :

Presentation given by Philipp Gerhold (20')

Primary authors :

Co-authors :

Presenter : LIN, David (NCTU) ; KIKUKAWA, Yoshio (Tokyo) ; GERHOLD, Philipp (Humboldt) ; SONI, Amarjit (BNL)

Introduction and motivation
The lattice Higgs-Yukawa model
Higgs boson mass bounds
Summary and Outlook

The chiral Higgs-fermion coupling on the lattice
Simulation algorithm
Phase diagram

Coupling structure on the lattice

- Introduce finite, discrete space-time lattice with $V = L_s^3 \times L_t$ sites.
- Lattice model, obeying global $SU(2)_L \times U(1)_Y$ symmetry:

$$S = \sum_{x,\mu} \frac{1}{2} \nabla^f_\mu \varphi^\dagger_x \nabla^f_\mu \varphi_x + \sum_x \frac{1}{2} m_0^2 \varphi^\dagger_x \varphi_x + \sum_x \lambda \left(\varphi^\dagger_x \varphi_x\right)^2$$

$$+ \sum_{x,y} \bar{t}_x \mathcal{D}^{(ov)}_{x,y} t_y + \sum_{x,y} \bar{b}_x \mathcal{D}^{(ov)}_{x,y} b_y + \sum_x y_b \cdot (\bar{t}_{L,x}, \bar{b}_{L,x}) \varphi_x b_{R,x} + y_t \cdot (\bar{t}_{L,x}, \bar{b}_{L,x}) \tilde{\varphi}_x t_{R,x} + h.c.$$

Some lattice details...

Forum: Higgs-Yukawa Model on a Lattice

If $\langle \overline{Q} Q \rangle$ can Condense by Large Yukawa,

then, Who Needs the Higgs for v.e.v.?

ceDisplay.py?confId=68036

Co

F

Primary authors :

Co-authors :

Presenter : LIN, David (NCTU) ; KIKUKAWA, Yoshio (Tokyo) ; GERHOLD, Philipp (Humboldt) ; SONI, Amarjit (BNL)

Intend to Embark on Lattice Study

Introduction and motivation
The lattice Higgs-Yukawa model
Higgs boson mass bounds
Summary and Outlook

The chiral Higgs-fermion coupling on the lattice
Simulation algorithm
Phase diagram

Coupling structure on the lattice

- Introduce finite, discrete space-time lattice with $V = L_s^3 \times L_t$ sites.
- Lattice model, obeying global $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ symmetry:

$$\begin{aligned} S &= \sum_{x,\mu} \frac{1}{2} \nabla^f_\mu \varphi^\dagger_x \nabla^f_\mu \varphi_x + \sum_x \frac{1}{2} m_0^2 \varphi^\dagger_x \varphi_x + \sum_x \lambda \left(\varphi^\dagger_x \varphi_x \right)^2 \\ &+ \sum_{x,y} \bar{t}_x \mathcal{D}^{(ov)}_{x,y} t_y + \sum_{x,y} \bar{b}_x \mathcal{D}^{(ov)}_{x,y} b_y + \sum_x y_b \cdot (\bar{t}_{L,x}, \bar{b}_{L,x}) \varphi_x b_{R,x} + y_t \cdot (\bar{t}_{L,x}, \bar{b}_{L,x}) \tilde{\varphi}_x t_{R,x} + h.c. \end{aligned}$$

Some lattice details...

EW Theory on a Lattice ?

No Higgs !

- SU(2)$_L$ x U(1): (chiral) gauge symmetry experimentally established
- SSB also experimentally established: Massive W and Z (Massive Fermions, Too)
- Renormalizability depend only on Ward Identities (unaffected by SSB)

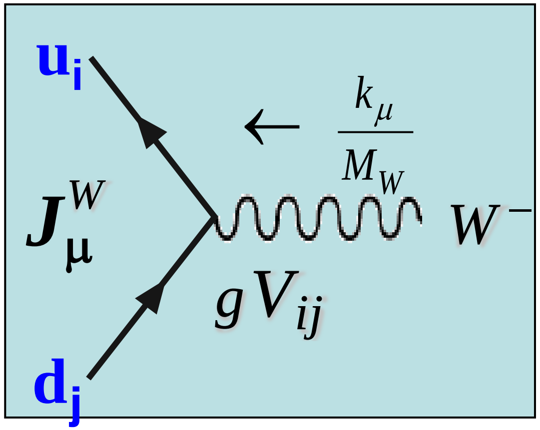
- In Physical Gauge: No would-be-Goldstone, or unphysical, scalars
  - But **Longitudinal W** ($k_\mu k_\nu$ part of propagator) "couple" to Fermion Mass

⇒ Effective Yukawa Coupling ➡ Generate $\langle \bar{Q}Q \rangle \neq 0$ also ?

How to Formulate ?

On a Lattice ?

Intriguing



$$g\gamma_\mu L \;\Rightarrow\; g\not{k} L \;\Rightarrow\; g(\not{p}_i - \not{p}_j)L \;\Rightarrow\; g(m_i L - m_j R) \Big/ M_W$$

$$g\frac{m_i}{M_W} = g\frac{m_i}{gV} = \frac{m_i}{V}$$

$$\lambda_Q \equiv \frac{m_Q}{V}$$

Prospects

From a thread in the "Direct CPV difference" in charged vs neutral B -> K pi decays observed at the B factories, a possible large and negative mixing-dependent CPV in Bs -> J/psi phi is predicted, if the former arises at least partially from 4th generation t' effect in the Z-penguin. Surprisingly, there is some standing hint at the Tevatron. Whether or not these flavor and CPV effects bear up, a 4th generation would help us soar to the heavens: there seems to be enough CPV for the baryon asymmetry of the Universe.

A separate thread is the ever increasing bounds on t' and b' at the Tevatron, implying large Yukawa coupling. Direct search can only be settled at the LHC, and the partial wave unitarity bound is only a glass ceiling. What is intriguing is the possibility of EW symmetry breaking due to the NJL-type condensation of very heavy 4th generation quarks, where we outline two scenarios that can be pursued on the lattice: Higgs-Yukawa Lagrangian, and the electrweak theory as we know it, without ever mentioning the Higgs boson.

Conclusion

If the pursuit of 4th generation quark search at the LHC bears fruit, we may simultaneously touch upon two of the greatest problems in particle physics, and even cosmology: source of EW symmetry breaking (raison d'etre for LHC); and source of CPV for BAU (raison d'etre for ourselves). There would be further Implications for flavor and other physics.

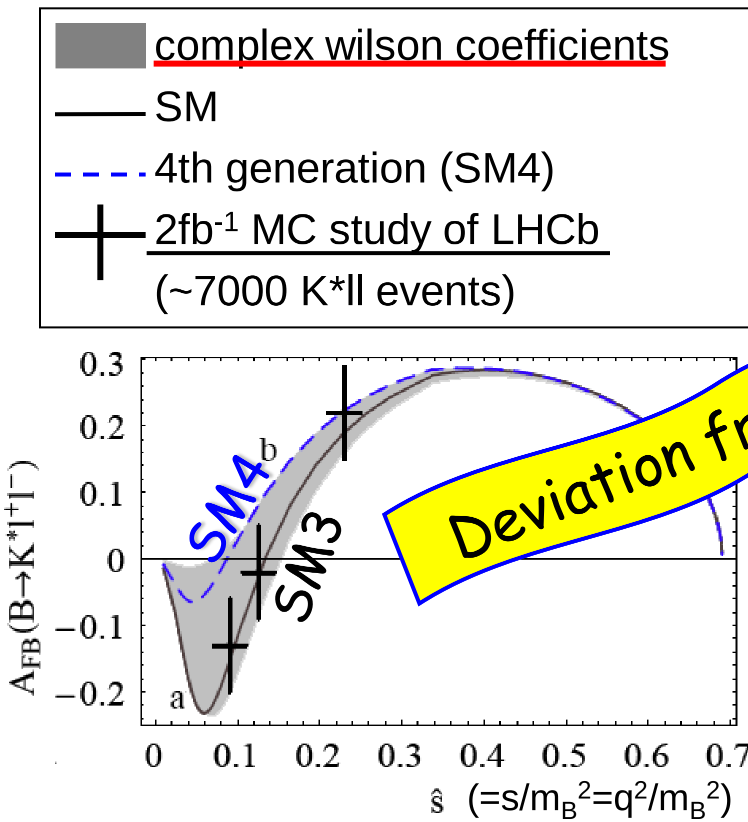
* Source of CPV4BAU ?
* Source of EWSB ?

Discussion

Instead flipped C_7 ...

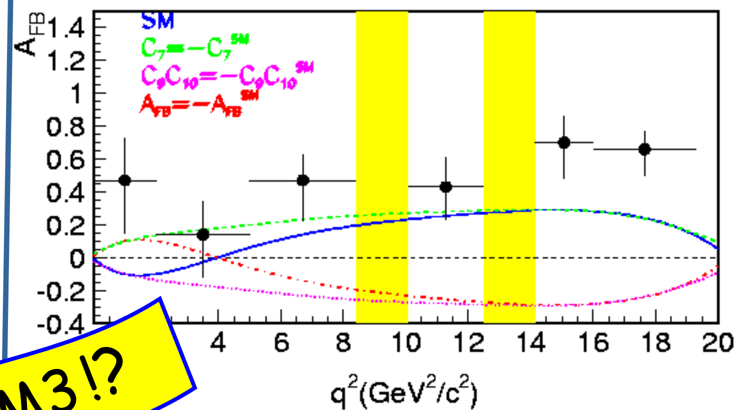
$$\frac{dA_{FB}}{d\hat{s}} \propto -\left\{ \mathrm{Re}(C_9^{eff} C_{10}) VA_1 + \frac{\hat{m}_b}{\hat{s}} \mathrm{Re}(C_7^{eff} C_{10}) \left[VT_2 (1-\hat{m}_{K^*}) + A_1 T_1 (1+\hat{m}_{K^*}) \right] \right\}$$

W.-S. Hou, A. Hovhannisyan, and N. Mahajan, PRD 77, 014016 (2008)

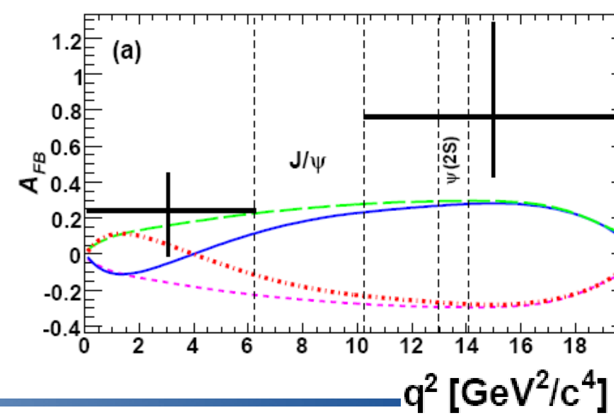


Deviation from SM3!?

Belle 657M arXiv:0904.0770



BABAR, arXiv:0804.4412 386M



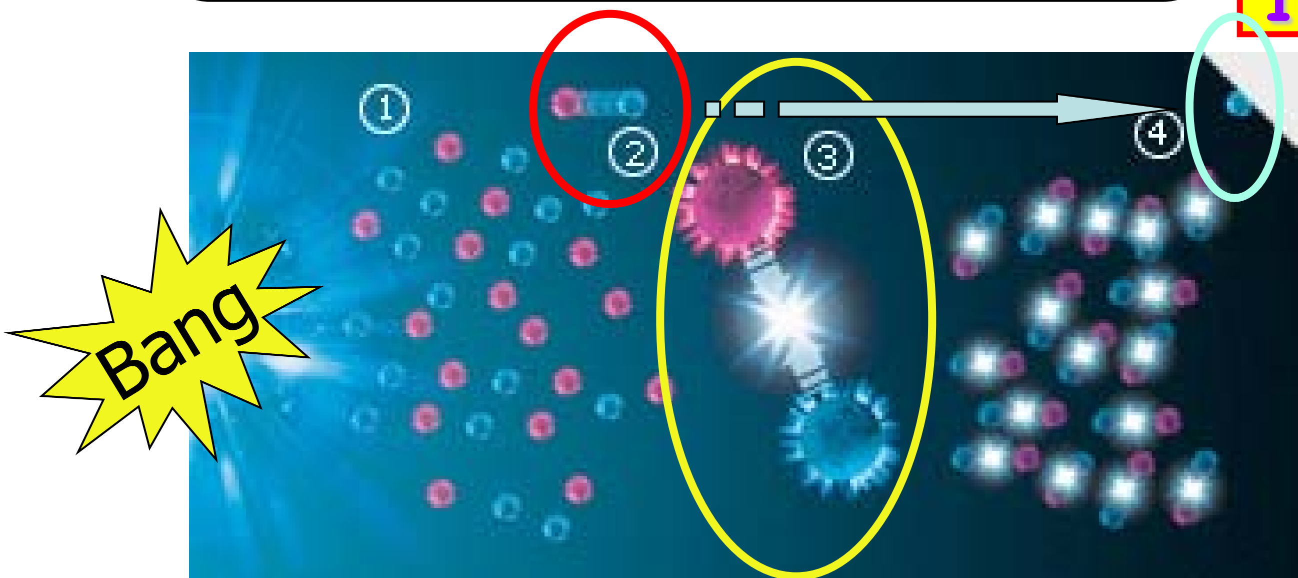
CPV & BAU: The Sakharov View

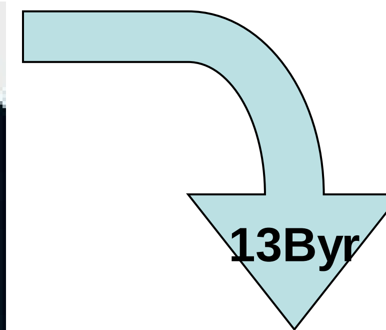
aryon symmetry niverse

(1967)

- *Baryon Number Violation*
- *CP Violation*
- Deviation from Equilibrium

10^{-9} Matter left !





Us

Equal Matter
-Antimatter

Pair
Annihilation