TeV Physics and Cosmology

中科院高能所
张新民

Talk given at “2014年TeV 工作组学术研讨会”
2014年**5**月**15-18**日
中山大学

报告提纲

I）90’s：粒子物理标准模型精确检验

2012年：发现 **Higgs** 粒子， **2013**年诺贝尔奖

精确**Higgs**测量**------**〉**Higgs Factory**

* Higgs 工厂 和 Electroweak Baryogenesis

i）Anomalous Higgs couplings;

ii) Anomalous Top couplings.

2) **00’s**：精确宇宙学 **(**简单介绍）

2014年：**BICEP2** 发现 **CMB B-mode polarization,**

诺贝尔奖？

* Implications for particle physics?

(Inflation, bounce ………..不讲）

i) Leptogenesis and Quintessential Baryogenesis,

ii) Testing CPT with CMB Polarization, CMB polarization rotation angle;

iii) Comment on “Self calibration” used by BICEP2

3) Discussions

LHC/Higgs: origin of mass

CEPC/SPPC: origin of matter (Why no anti-matter in our universe?)

- **Higgs 工厂科学问题**

精确检验

测量anomalous couplings:

确认标准模型

发现anomalous couplings

------〉 implies new physics

New Physics Scale?

Based on unitarity argu…

理论：calculating loop effects with models

like SUSY …..

Useful: study with Effective Theory

Brief Comments on Effective Theory

1) 要求可重整，局限 **“**等于或小于维数**=4”** 的算子：

由于没有引进右手中微子**====**〉中微子质量为零。

2）标准模型是个有效理论：

i）**SU_L(2) X U_Y(1) nonlinearly realized**

见：**Peccei and Zhang**

Xinmin Zhang （博士论文，**UCLA, 1991**年）

(including a singlet scalar, Higgs-like particle, see C.-P. Yuan , H.J. He, Y.P. Kuang et al)

ii) SU_L(2)XU_Y(1) linearly realized

（**Buchmuller-Wyler**，**1986**年**)**

$$\hat{O}_{\rm dim=5} = \ell^T C \epsilon \varphi \; \varphi^T \epsilon \ell \qquad C = i\gamma_2\gamma_0$$

(Weinberg ’79)

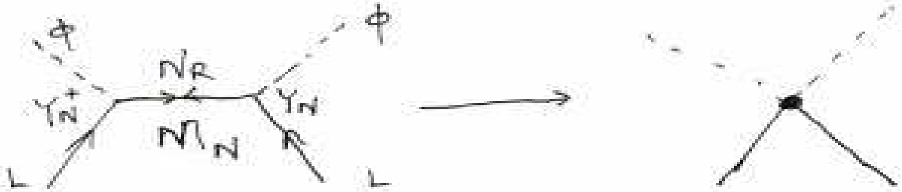
$$\frac{1}{\Lambda}\hat{O}_{\rm dim=5} \xrightarrow{\langle\varphi\rangle = \binom{0}{v}} \frac{v^2}{\Lambda}\nu_L^T C \nu_L$$

$$m_\nu \sim 1\,{\rm eV} \;\rightarrow\; \Lambda \sim 10^{13}\,{\rm GeV}$$

Seesaw 机制

→ dim-5 operator $\frac{1}{\Lambda} L\phi L\phi$

I, 引入右手中微子



$$\Rightarrow m_\nu = Y_N^T \frac{1}{M_N} Y_N v^2$$

II, 引入 triplet 标量场

$$\Rightarrow m_\nu = Y_\Delta \frac{\mu_\Delta}{M_\Delta^2} v^2$$

III, ⋮ 很多小的中微子质量产生模型……

\Lambda ?

- In linear version of effective theory, satisfies the decoupling theorem: when Cut-off goes to infinity, the new physics effects disappear!!

- Any upper limit on \Lambda?

  or are there any arguments for the new physics?

  Naturalness

  Cosmology

==========➔ TeV physics and Cosmology

i) Baryogenesis

ii) WIMPs dark matter

Matter Antimatter Asymmetry

1) Our universe is matter antimatter asymmetric

2）能否宇宙本身就是不对称的？？
In the framework of inflation, all of the matter created during or after reheating processes➔dynamical generation of baryon number asymmetry

3）用物理规律来解释？ =➔Baryogenesis
i) Electroweak baryogenesis → Generating matter asymmetry at the TeV scale
ii) Leptogenesis =➔Neutrino physics
iii)Quintessential Electro/Leptogenesis ====➔CMB polarization

baryogenesis
三个条件

Andrei Sakharov （1967年） 三个条件：

i) B violation

ii) C and CP violation

iii)Out of thermo-equilibrium (CPT conserved)

Freezing out of the heavy particles

$$\begin{aligned}\langle B\rangle &= \mathrm{Tr}(\rho B) = \mathrm{Tr}\left((CPT)(CPT)^{-1}\exp(-\beta H)B\right) \\ &= \mathrm{Tr}\left(\exp(-\beta H)(CPT)^{-1}B(CPT)\right) = -\mathrm{Tr}(\rho B) = 0\end{aligned}$$

If CPT is broken, can be generated in thermo-equilibrium

Baryon and Lepton sym in S.M.

$\mathcal{L}^{S.M.} \sim Y_e \bar{l} e \phi + Y_d \bar{q} d \phi + Y_u \bar{q} u \phi$

Global symmetries: 剩余的对称性

$\begin{matrix} q \\ u \\ d \end{matrix} \to e^{iQ\alpha} \begin{matrix} q \\ u \\ d \end{matrix}$ 重子数

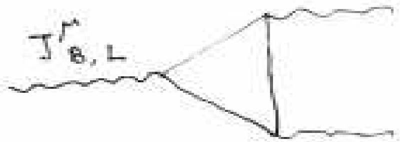
同样: $l_i \to e^{iQ_i \alpha} l_i$ 轻子数对称性

但是: triangle anomaly

$J^\mu_B = \frac{1}{3} \sum_i (\bar{q}_L \gamma^\mu q_L + \bar{u}_R \gamma_\mu u_R + \bar{d}_R \gamma^\mu d_R)$

$J^L_\mu = \sum_i (\bar{l}_L \gamma_\mu l_L + \bar{e}_R \gamma_\mu e_R)$

$\partial^\mu J^B_\mu = \partial^\mu J^L_\mu = \frac{N_f}{32\pi^2}(-g^2 W^a_{\mu\nu} \tilde{W}^{a\mu\nu} + g'^2 B_{\mu\nu} \tilde{B}^{\mu\nu})$



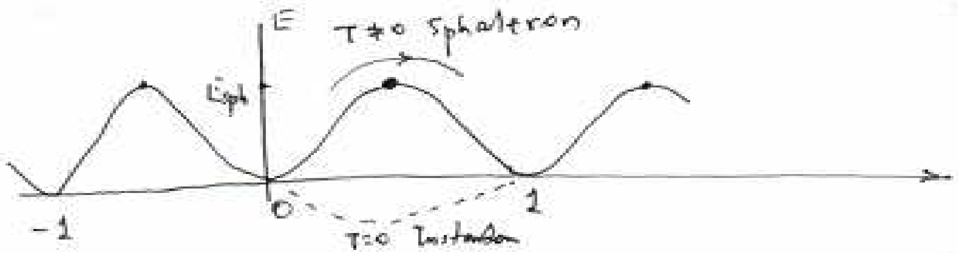
More on Symmetry breaking via anomaly

$$\partial_\mu J^\mu_B = \partial_\mu J^\mu_L \sim W^I_{\mu\nu} \tilde{W}^{I,\mu\nu}$$
$$\oplus \quad B_{\mu\nu} \tilde{B}^{\mu\nu}$$

注意： $B_{\mu\nu}\tilde{B}^{\mu\nu} \sim \partial_\mu K^\mu$
$\quad \hookrightarrow \varepsilon^{\mu\nu\alpha\beta} A_\nu \partial_\alpha A_\beta$

$$\int d^4x \, \partial_\mu K^\mu = ?$$

SU(2)真空：Θ真空



$$N_{CS} = \frac{g^3}{96\pi^2} \int d^3x \, \varepsilon_{ijk} \varepsilon^{IJK} W^{Ii} W^{Jj} W^{Kk}$$

$$\Delta B = \Delta L = 3 \Delta N_{CS}$$

Physics Letters B 266 (1991) 413–418
North-Holland

PHYSICS LETTERS B

Sphalerons in the two-doublet Higgs model

B. Kastening, R.D. Peccei and X. Zhang
Department of Physics, University of California, Los Angeles, CA 90024, USA

$$\mathscr{L} = -\tfrac{1}{4}F^{a}_{\mu\nu}F^{a\mu\nu} - \tfrac{1}{4}f_{\mu\nu}f^{\mu\nu} + (D_\mu\Phi_1)^\dagger(D^\mu\Phi_1) + (D_\mu\Phi_2)^\dagger(D^\mu\Phi_2) - V(\Phi_1, \Phi_2)\,, \qquad (1)$$

where $F^{a}_{\mu\nu}$ are the SU(2) field strength, $f_{\mu\nu}$ the $U_Y(1)$ field strength, $V(\Phi_1, \Phi_2)$ the Higgs potential and $D_\mu\Phi_{(1,2)}$ the covariant derivative. Our Minkowski space metric is $g_{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$.

We seek to minimize the energy functional (4) with fields of the general form

$$\boldsymbol{W}_i\cdot\boldsymbol{\tau}\,dx^i = -\frac{2i}{g} f(gvr)\, dU^\infty (U^\infty)^{-1}\,,$$

$$\Phi_1 = \frac{v_1}{\sqrt{2}} h_1(gvr) U^\infty \begin{pmatrix}0\\1\end{pmatrix},$$

$$\Phi_2 = \frac{v_2}{\sqrt{2}} h_2(gvr) U^\infty \begin{pmatrix}0\\1\end{pmatrix} e^{i\rho}\,, \qquad (5)$$

where

$$U^\infty = \frac{1}{r}\begin{pmatrix} z & x+iy \\ -x+iy & z \end{pmatrix}. \qquad (6)$$

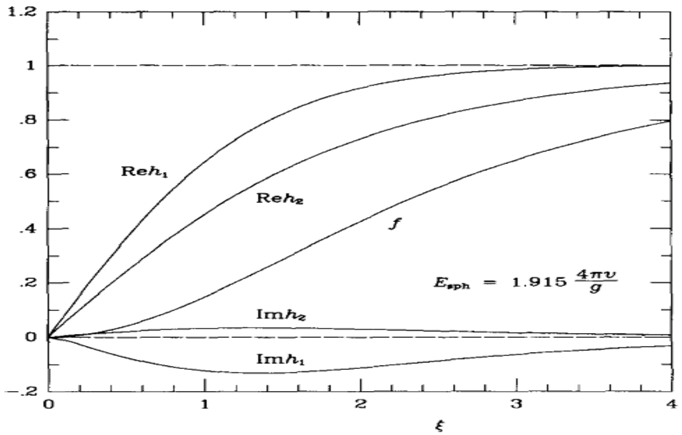


Fig. 1. Radial functions f, h_1 and h_2 for $\lambda_1/g^2 = 4$, $\lambda_2/g^2 = 0.1$, $\lambda_3/g^2 = 0.04$, $\lambda_5/g^2 = 0.3$, $\lambda_6/g^2 = 5$, $\cos^2\beta = 0.2$ and $\rho = 30°$.

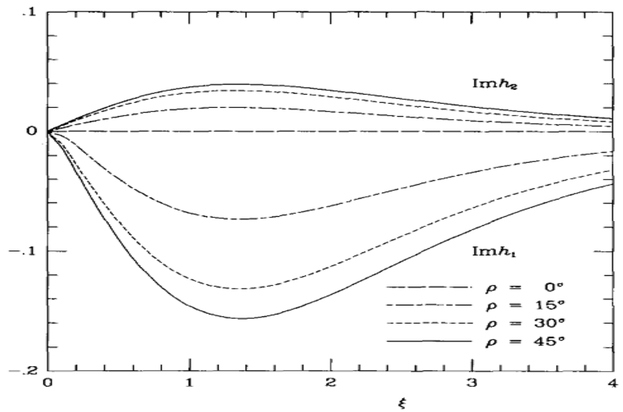
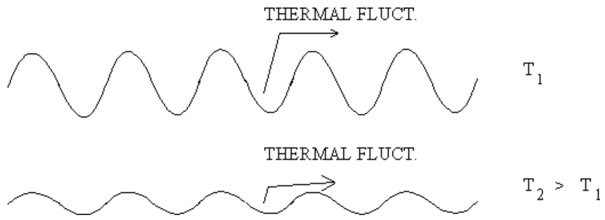


Fig. 2. Imaginary parts of h_1 and h_2 for different ρ, with the other parameters being the same as in fig. 1.

Electroweak baryogenesis

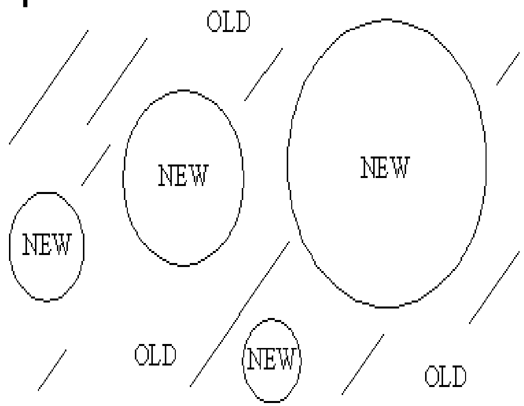
i) B violation ←----anomaly, non-trivial vacuum, sphaleron



ii) C and CP violation ←-----CKM mechanism

(however, too small-→new physics)

iii) First order phase transition



Need Higgs mass < 35 GeV!

重要预言：

Higgs质量

新物理

弱电相变

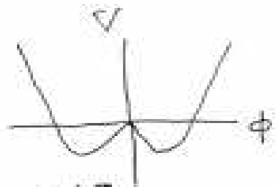
$$SU(2)\times U_Y(1) \xrightarrow[\langle\phi\rangle = v]{} U_{em}(1)$$

$T > T_c \quad \langle\phi\rangle \neq 0$

$T < T_c \quad \langle\phi\rangle = 0$

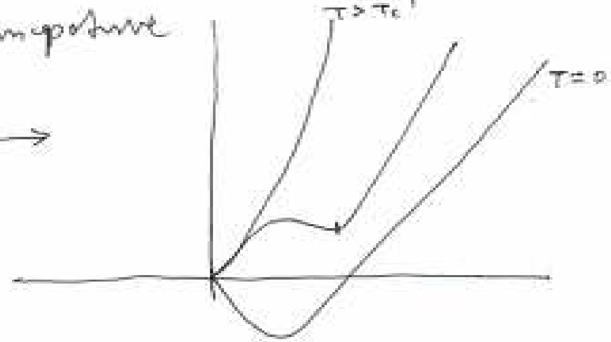
I, potential at tree level

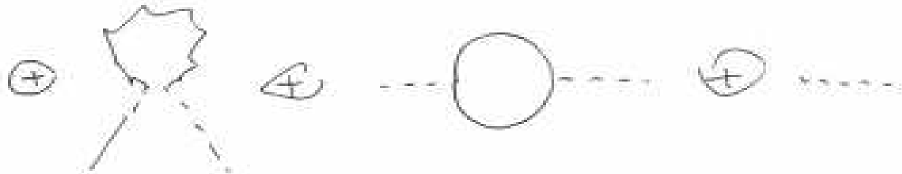
$$V(\phi) = \lambda\left(\phi^{+}\phi - \frac{v^2}{2}\right)^2$$



II, At finite temperature

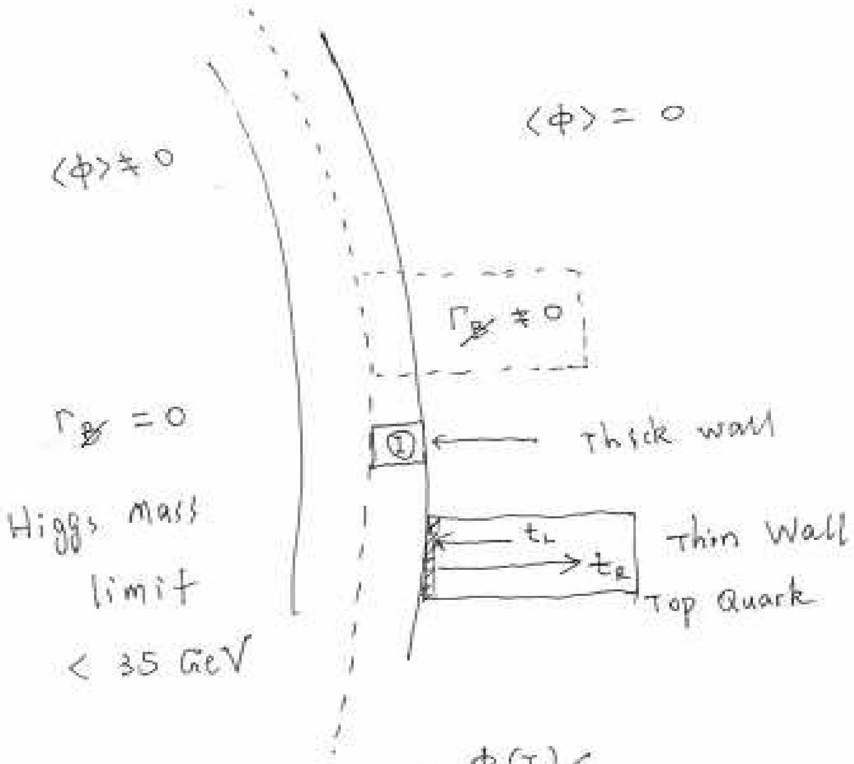
$\longrightarrow$





Electroweak Baryogenesis

机制



$$\Gamma_{\not B} \sim e^{-\phi(T)/T}$$

Electroweak Baryogenesis and New Physics

i) Early 90's and later on, many studies with new physics models like 2- Higgs，L-R symmetry, SUSY

ii) Effective Lagrangian Method

1) Xinmin Zhang, Phys. Rev. D47, (1993) 3065 (**hep-ph/9301277** **)**
"**Operator Analysis for the Higgs Potential and Cosmological Bound on the Higgs-Boson Mass"**

2) Bing-Lin Young and Xinmin Zhang, PRD49 (1994) 563 (**hep-ph/9309269**)
"Effective Lagrangian Approach to Electroweak Baryogenesis: Higgs mass limit and Electric dipole moments of fermion "

3) Xinmin Zhang, S.K. Lee, K. Whisnant and B.-L. Young Phys.Rev. D50 (1994) 7042-7047 (hep-ph/9407259)
"Phenomenology of a non-standard top quark Yukawa coupling "

$$\mathcal{L}^{\text{new}} = \sum_i \frac{c_i}{\Lambda^{d_i-4}} O^i ,$$

Operator relevant to Higgs mass limit

$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} ,$$

Effective potential:

$$V_T^{\text{eff}} = D(T^2 - T_0^2)\phi^2 - ET\phi^3 + \tfrac{1}{4}\lambda_T \phi^4 ,$$

where

$$D = \frac{1}{8v^2}(2M_W^2 + 2m_t^2 + M_Z^2) ,$$

$$T_0^2 = \frac{1}{D}\left[\frac{m_H^2}{4} - 2Bv^2\right] ,$$

$$B = \frac{3}{64\pi^2 v^4}(2M_W^4 + M_Z^4 - 4m_t^4) ,$$

$$E = \frac{1}{6\pi v^3}(2M_W^3 + M_Z^3) ,$$

$$\lambda_T = \lambda - \frac{3}{16\pi^2 v^4}\left[2M_W^4 \ln\frac{M_W^2}{\alpha_B T^2} + M_Z^4 \ln\frac{M_Z^2}{\alpha_B T^2} - 4m_t^4 \ln\frac{m_t^2}{\alpha_F T^2}\right] ,$$

where $\ln\alpha_B = 2\ln 4\pi - 2\gamma \simeq 3.91$ and $\ln\alpha_F = 2\ln\pi - 2\gamma \simeq 1.14$.

$$V_3^{(r)} = \alpha \frac{v^2}{\Lambda^2}\phi^2 \left[-\phi^2 + v^2 + \frac{1}{3}\frac{\phi^4}{v^2}\right] .$$

$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} \quad \Longrightarrow \quad m_H^2 < (35\ GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$$

Prediction for a light Higgs !!!

重要预言：

Higgs质量：

115 GeV ~ 132 GeV

Xinmin Zhang PRD47, 3065 (1993)

Cedric Delaunay, Christophe Grojean, James D. Wells

JHEP 0804:029,2008

PHYSICAL REVIEW D, VOLUME 70, 093007

Electroweak phase transition in the standard model with a dimension-six Higgs operator at the one-loop level

S.W. Ham[1] and S. K. Oh[1,2]

[1]*Center for High Energy Physics, Kyungpook National University, Daegu 702-701, Korea*

[2]*Department of Physics, Konkuk University, Seoul 143-701, Korea*

(Received 29 August 2004; published 11 November 2004)

The possibility of a strongly first-order electroweak phase transition by means of a dimension-six Higgs operator in the Higgs potential of the standard model is studied at finite temperature at the one-loop level. Exact calculation of the one-loop effective Higgs potential at finite temperature suggests that for the Higgs boson with its mass between 115 and 132 GeV the strongly first-order electroweak phase transition is possible if a dimension-six operator is present.

DOI: 10.1103/PhysR...

I. INTRO...

comparable to 1 for $115 \leq m_H \leq 132$ GeV. Thus, our study suggests that the SM Higgs potential at the one-loop level with a dimension-six operator allows a strongly first-order electroweak phase transition, for the Higgs boson mass between 115 and 132 GeV. A Higgs boson with this mass range might easily be searched in future high energy experiments.

... in the Higgs

ACKNOWLEDGMENTS

This work was supported by Korea Research Foundation Grant No. 2001-050-D00005.

Anomalous Higgs self couplings

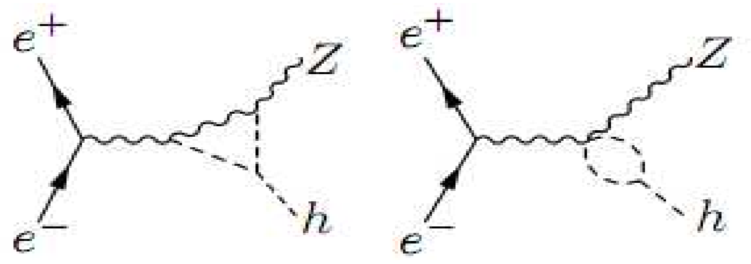
$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} \, ,$$

My result in 1993: $m_H^2 < (35 \; GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$

taking Higgs mass 125 GeV, I obtain \Lambda should be
no more than 1.5 TeV for \alpha ~ O(1)
which gives a correct to the triplet Higgs coupling about 90%

My result is consistent with the recent analysis (C. Grojean, G. Servant, J. Wells; S. W. Ham, S. K. Oh; Dietrich Bodeker, Lars Fromme, Stephan J. Huber, Michael Seniuch ; Daniel J. H. Chung, Andrew J. Long, Lian-Tao Wang ……)

The anomalous Higgs self coupling is claimed to be measured with
precision O (30 %) at TLEP in Matthew McCullough arXiv:1312.3322



Implication for 125 GeV Higgs and BICEP2

"Probable or Improbable Universe? Correlating Electroweak Vacuum Instability with the Scale of Inflation" arXiv:1404.5953

Anson Hook, John Kearney, Bibhushan Shakya, Kathryn M. Zurek

" we examine the effects of generic Planck-suppressed corrections to the Higgs potential, which can be sufficient to stabilize the electroweak vacuum during inflation."

==

ELSEVIER

26 September 1996

Physics Letters B 385 (1996) 225–230

PHYSICS LETTERS B

Implications of a non-standard light Higgs boson

A. Datta, B.L. Young, X. Zhang

Department of Physics and Astronomy, Iowa State University, Ames, IA 50011, USA

Received 14 April 1996; revised manuscript received 12 June 1996

Abstract

Analyses of the vacuum stability of the electroweak theory indicate that new physics occur at a scale of the order of 1 TeV if a light Higgs is discovered at LEP II. In this paper, we parameterize the effects of new physics in the effective Lagrangian approach and examine its implication on the Higgs boson production at LEP II. We consider the effect of a higher dimension operator on the Higgs potential and calculate the lower bound on the Higgs boson mass from the requirement of vacuum stability. We show that if a Higgs boson is seen at LEP II, then under favourable conditions the deviation of the production cross section from the standard model value could be significant and therefore the presence of the new physics is detectable at LEP II.

$$
\begin{aligned}
\mathcal{L}^{\rm new} = & \frac{1}{\Lambda^2} c_{\Phi,3} (\Phi^+\Phi - \tfrac{1}{2}v^2)^3 \\
& + \frac{1}{\Lambda^2} \Big[c_{\Phi,1} (D_\mu \Phi)^+ \Phi\Phi^+ (D^\mu \Phi) \\
& + \tfrac{1}{2} c_{\Phi,2} \partial_\mu (\Phi^+\Phi) \partial^\mu (\Phi^+\Phi) \Big] \\
& + \frac{1}{\Lambda^2} \Big[c_{BW} \Phi^+ \widehat{B}_{\mu\nu} \widehat{W}^{\mu\nu} \Phi \\
& + c_W (D_\mu \Phi)^+ \widehat{W}^{\mu\nu} (D_\nu \Phi) \Big] \\
& + \frac{1}{\Lambda^2} \Big[c_B (D_\mu \Phi)^+ \widehat{B}^{\mu\nu} (D_\nu \Phi) \\
& + c_{WW} \Phi^+ \widehat{W}_{\mu\nu} \widehat{W}^{\mu\nu} \Phi \Big] \\
& + \frac{1}{\Lambda^2} c_{BB} \Phi^+ \widehat{B}_{\mu\nu} \widehat{B}^{\mu\nu} \Phi .
\end{aligned}
$$

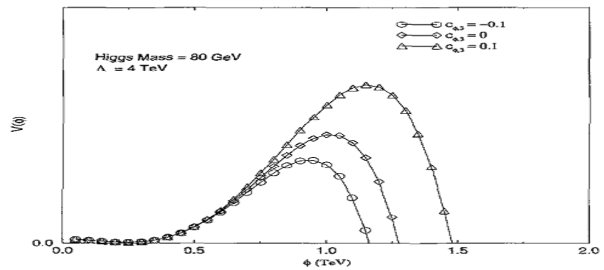


Fig. 1. The effective potential for various values of $c_{\phi,3}$. The Higgs mass is taken as 80 GeV and the scale of new physics $\Lambda = 4$ TeV. The curve with $c_{\phi,3} = 0$ corresponds to the standard model.

$\mathcal{L}^{eff}$ 方法

① 注意

$$\Delta B \sim \Delta N_{CS} \sim \frac{\alpha_W}{4\pi}\int_{t_c}^{\infty} d^4x \, W_{\mu\nu}\widetilde{W}^{\mu\nu}$$

↑ 相变开始

$$\widetilde{W}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\alpha\beta} W^{\alpha\beta}$$

$$\Delta\mathcal{L}^{\text{new phys}} = C_W \frac{g^2}{8\pi^2}\frac{\phi^2}{\Lambda^2} \underline{\mathrm{Tr}\, W_{\mu\nu}\widetilde{W}^{\mu\nu}}$$

↓ $\partial_\mu K^\mu$

$$n_B = 3\int \frac{\Gamma_{\not B}}{T}\frac{d}{dt}\left(C_W\frac{\phi^2}{\Lambda^2}\right)dt = 3\int\frac{\Gamma_{\not B}}{T}d\left(C_W\frac{\phi^2}{\Lambda^2}\right)$$

$$\Gamma_{\not B} = K(\alpha_W T)^4 \qquad K \simeq 0.1 \sim 1$$

$$\frac{n_B}{S} \sim 4\times 10^{-2} K C_W \alpha_W^4 (T/\Lambda)^2$$

$$\sim (0.4 - 1.4)\times 10^{-10}$$

要求： $\Lambda \sim 1\ \text{TeV} \qquad C_W \gtrsim 0.1 - 1$

$$\Delta \mathcal{L}^{\text{New phys}} \longrightarrow C_W \frac{\alpha_{em}}{32\pi} \frac{H}{v} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$H \rightarrow \gamma\gamma$$

Higgs mass limit:

$$m_H^2 < (35\,\text{GeV})^2 + 8\alpha \frac{v^4}{\Lambda^2}$$

$$\downarrow$$

$$\alpha \frac{\phi^6}{\Lambda^2}$$

$$\langle\phi\rangle \sim \frac{1}{\sqrt{2}} v \sim \frac{1}{\sqrt{2}}\, 250\,\text{GeV}$$

$\Longrightarrow$ i) light Higgs $\sim$ 125 GeV

ii) New $H \rightarrow \gamma\gamma$

$$\mathcal{O}^{\text{New}} \sim \frac{\phi^2}{\Lambda^2} F_{\mu\nu} F^{\mu\nu}$$

PHYSICAL REVIEW D VOLUME 49, NUMBER 1 1 JANUARY 1994

Effective Lagrangian approach to electroweak baryogenesis: Higgs boson mass limit and electric dipole moments of fermions

X. Zhang
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

B.-L. Young
Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011

(Received 7 June 1993)

A natural solution to the hierarchy problem of the standard model is to assume new physics to appear at the TeV scale. We parametrize the effects of this new physics in terms of an effective Lagrangian and examine its impact on electroweak baryogenesis. We point out that with such an effective Langrangian successful electroweak baryogenesis implies (i) the Higgs boson lies within the reach of CERN LEP II; and (ii) electric dipole moments of the electron and neutron are detectable in the near future.

PACS number(s): 12.60.−i, 11.15.Ex, 13.40.Em, 98.80.Cq

$$c_{W} \geq 0.1-1 \ , \tag{10}$$

which is not an unreasonable value to expect.

Let us calculate the electric dipole moments of electron and neutron induced by O_{W}. At zero temperature,

$$\phi = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 \\ v+H \end{bmatrix} ,$$

with H being the standard Higgs particle. After diagonalizing the mass matrix of W^3_μ and B_μ, one can see that an effective Higgs-photon-photon vertex is induced by Eq. (4):

$$\mathcal{L}_{H\gamma\gamma} \sim c_W \frac{\alpha_{\rm em}}{32\pi} \frac{H}{v} F_{\mu\nu} \tilde{F}^{\mu\nu} , \tag{11}$$

Operator relevant to baryon number generation

$$\mathcal{O}^t = c_t e^{i\xi}\frac{\phi^2 - v^2/2}{\Lambda^2}\Gamma_t \bar{\Psi}_L \tilde{\Phi} t_R, \qquad \Longrightarrow \qquad \Gamma_t^{\text{eff}} = \Gamma_t\left\{1 + c_t e^{i\xi}\frac{\phi^2 - v^2/2}{\Lambda^2}\right\}.$$

$$\frac{n_B}{s} \sim \kappa c_t \sin\xi \times 10^{-9}.$$

Anomalous top-Higgs couplings:

$$\mathcal{L}^{\text{eff}} \sim \frac{m_t}{t}\bar{t}\left\{\left[1 + \left(\frac{c_t}{16}\right)\cos\xi\right] + i\left(\frac{c_t}{16}\right)\sin\xi\gamma_5\right\}tH,$$

For \Lambda ~ 1 TeV.

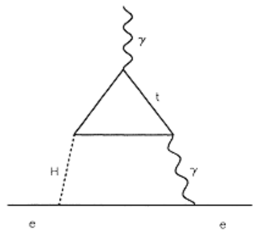
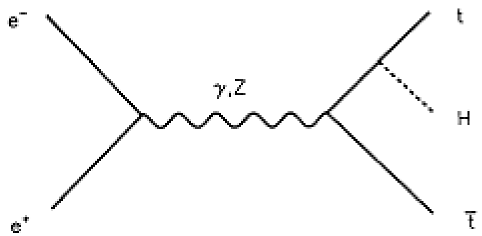


FIG. 1. Dominant contribution to d_e, the electric dipole moment of the electron.



X. Zhang et al, PRD 50, 7042 (1994)
Lars Fromme, Stephan J. Huber, JHEP 0703:049,2007
Lianyou Shan et al (In preparation)

Note: Non-universal couplings induce FCNC couplings

t t\bar h (\gamma, Z) --→ t\bar c h (\gamma, Z)
T. Han, R. Peccei, X. Zhang et al…..
C.-P., Yuan et al

At Higgs factory: single top production e^+e^- --→ Z (or gamma) -→ t \bar c

Comments

I) Electroweak baryogenesis predict

anomalous Higgs couplings

anomalous htt couplings

FCNC top couplings

(with and without CP violation)

II) Large enough to be measured experimentally;

If not, rule out electroweak baryogenesis

General argument ---→ circular collider, a machine

for electroweak baryogenesis (origin of matter !)

CEPC/SPPC: discovering the anomalous couplings at CEPC or

new particles which contribute to the anomalous couplings at SPPC

III) Other possibilities for baryogenesis

two examples

UCB-PTH-14/06, IPMU14-0082

What do precision Higgs measurements buy us?

Brian Henning,[1,2,*] Xiaochuan Lu,[1,2,†] and Hitoshi Murayama[1,2,3,‡]

[1] *Department of Physics, University of California, Berkeley, California 94720, USA*
[2] *Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[3] *Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institutes for Advanced Study, University of Tokyo, Kashiwa 277-8583, Japan*

We study the sensitivities of future precision Higgs measurements and electroweak observables in probing physics beyond the Standard Model. Using effective field theory—appropriate since precision measurements are indirect probes of new physics—we examine two well-motivated test cases. One is a tree-level example due to a singlet scalar field that enables the first-order electroweak phase transition for baryogenesis. The other is a one-loop example due to scalar top in the MSSM. We find both Higgs and electroweak measurements are sensitive probes of these cases.

For decades, experimental efforts have chased the Higgs boson like the *holy grail* while, at the same time, theoretical pursuits have tried to make sense of all of its unnatural and mysterious features. Having discovered a "Higgs boson" [1, 2], these unnatural and mysterious features immediately become pressing questions. Models of new physics

THE STANDARD MODEL EFFECTIVE FIELD THEORY

Precision physics programs offer *indirect* probes of new physics, thereby neccesitating a model-independent framework to analyze potential patterns of deviation from known physics. This framework is most naturally formulated in the

$\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^a_{\mu\nu} G^{a,\mu\nu}$	$\mathcal{O}_H = \frac{1}{2}\left(\partial_\mu \lvert H\rvert^2\right)^2$
$\mathcal{O}_{WW} = g^2 \lvert H\rvert^2 W^a_{\mu\nu} W^{a,\mu\nu}$	$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$
$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_R = \lvert H\rvert^2 \lvert D_\mu H\rvert^2$
$\mathcal{O}_{WB} = 2gg' H^\dagger t^a H W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_D = \lvert D^2 H\rvert^2$
$\mathcal{O}_W = ig\left(H^\dagger t^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$	$\mathcal{O}_6 = \lvert H\rvert^6$
$\mathcal{O}_B = ig' Y_H \left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$	$\mathcal{O}_{2G} = -\frac{1}{2}\left(D^\mu G^a_{\mu\nu}\right)^2$
$\mathcal{O}_{3G} = \frac{1}{3!} g_s f^{abc} G^{a\mu}_\rho G^{b\nu}_\mu G^{c\rho}_\nu$	$\mathcal{O}_{2W} = -\frac{1}{2}\left(D^\mu W^a_{\mu\nu}\right)^2$
$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon^{abc} W^{a\mu}_\rho W^{b\nu}_\mu W^{c\rho}_\nu$	$\mathcal{O}_{2B} = -\frac{1}{2}\left(\partial^\mu B_{\mu\nu}\right)^2$

TABLE I. dimension-six bosonic operators for our analysis.

A MASSIVE SINGLET

We consider a heavy gauge singlet that couples to the SM via a Higgs portal

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - A\lvert H\rvert^2 S - \frac{1}{2}k\lvert H\rvert^2 S^2 - \frac{1}{3!}\mu S^3 - \frac{1}{4!}\lambda_S S^4. \quad (2)$$

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{A^2}{2m_S^2}\lvert H\rvert^4 + \frac{A^2}{m_S^4}\mathcal{O}_H - \left(\frac{A^2 k}{m_S^4} - \frac{A^3\mu}{m_S^6}\right)\mathcal{O}_6. \quad (3)$$

PHYSICAL REVIEW D VOLUME 50, NUMBER 11 1 DECEMBER 1994

Phenomenology of a nonstandard top quark Yukawa coupling

X. Zhang, S. K. Lee, K. Whisnant, and B.-L. Young
Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011
(Received 11 July 1994)

There are theoretical speculations that the top quark may have different properties from that predicted by the standard model. We use an effective Lagrangian technique to model such a nonstandard top quark scenario. We parametrize the CP-violating interactions of the top quark with the bubble wall in terms of an effective top quark Yukawa coupling, then study its effects on electroweak baryogenesis. We also discuss the phenomenology of such an effective Yukawa coupling in low and high energy regions.

PACS number(s): 14.65.Ha, 12.15.Ji, 14.80.Cp, 98.80.Cq

The bidoublet ϕ will be split into two $\mathrm{SU}_L(2) \times \mathrm{U}_Y(1)$ doublets below the scale V_R, which we denote by ϕ_1 and ϕ_2. The top quark Yukawa sector can be rewritten in terms of Higgs field ϕ_1 and ϕ_2 by

$$\mathcal{L}^t = h_1 \bar{\Psi}_L \phi_1 t_R + h_2 \bar{\Psi}_L \bar{\phi}_2 t_R, \tag{A1}$$

where h_1 and h_2 are Yukawa couplings in the LR symmetric Lagrangian. The vacuum expectation values of ϕ_1 and ϕ_2 are related to that of the bidoublet ϕ. For a general CP violating Higgs potential, one has

$$\langle\phi\rangle = e^{i\alpha} \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' \end{pmatrix}, \tag{A2}$$

where α is a CP phase. So $\langle\phi_1\rangle = e^{i\alpha}\kappa$, $\langle\phi_2\rangle = e^{i\alpha}\kappa'$. Thus the mass of the top quark is given by

$$m_t = h_1 \kappa e^{i\alpha} + h_2 \kappa' e^{-i\alpha}. \tag{A3}$$

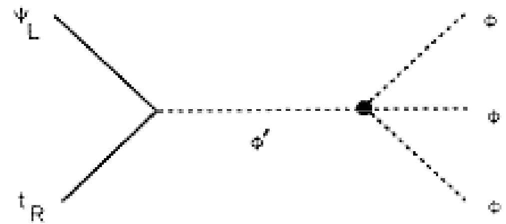


FIG. 6. A possible diagram for the generation of $\mathcal{O}^t$ in Eq. (2) in left-right symmetric models.

$$\begin{pmatrix} \Phi \\ \Phi' \end{pmatrix} = e^{i\alpha} \begin{pmatrix} \cos\zeta & \sin\zeta \\ -\sin\zeta & \cos\zeta \end{pmatrix}, \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}, \tag{A5}$$

where $\tan\zeta = \kappa'/\kappa$. In this basis, Φ serves as the SM doublet and the Φ' is just a massive scalar with mass $\sim V_R$. Integrating out the heavy field Φ' will generate many higher dimension operators [28]. The contribution of a Feynman diagram in Fig. 6 will give an operator similar to $\mathcal{O}^t$. In this model, $m^2_{\Phi'} \sim V_R^2 \sim \Lambda^2$,

Leptogenesis and Neutrino

Leptogenesis 是指正反轻子不对称的产生机制

为什么轻子不对称与重子不对称有关？

Sphaleron 过程将部分轻子数转化为重子数

$$100\text{GeV} < T < 10^{12}\text{GeV}$$

$$B = \frac{28}{79}(B-L)$$

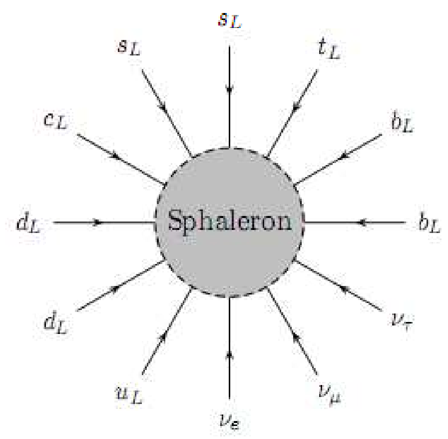
B ＝½ （B+L）＋ ½ （B-L）？？

要考虑**gauge interaction, Yukawa interaction and also QCD sphaleron**

V.A. Kuzmin, V.A. Rubakov and

M.E. Shaposhnikov, Phys. Lett. B **155**, 36 (1985)**;**

R. Mohapatra and X. Zhang, Phys.Rev.D45, 2699- 2705, (1992)



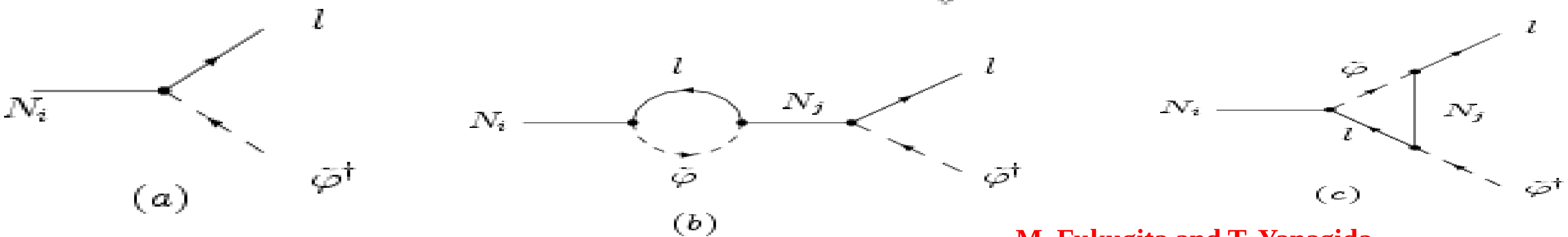
Type-I Seesaw 模型下的 Leptogenesis 机制

1. 右手中微子的 Majorana 质量项破坏轻子数
2. 右手中微子的 Yukawa 耦合项破坏 C 和 CP
3. 右手中微子脱离热平衡

$$
\begin{aligned}
\delta\mathcal{L} &= i\bar{\nu}_{Ri}\gamma^\mu\partial_\mu\nu_{Ri} - \frac{1}{2}M_{ij}\bar{\nu}^C_{Ri}\nu_{Rj} - y^\nu_{\alpha i}\bar{l}_{L\alpha}\tilde{\varphi}\nu_{Ri} + h.c. \\
&= \frac{i}{2}\bar{N}_i\gamma^\mu\partial_\mu N_i - \frac{1}{2}M_i\bar{N}_iN_i - y^\nu_{\alpha i}\bar{l}_{L\alpha}\tilde{\varphi}N_i + h.c.
\end{aligned}
$$

$$N_i = \nu_{Ri} + (\nu_{Ri})^C$$

$$m_\nu \simeq -(m_D)^* M^{-1}(m_D)^\dagger \qquad m_D = y^\nu v \qquad v \equiv \langle\tilde{\varphi}\rangle \simeq 174\text{GeV}$$



$$\varepsilon_i = \frac{\sum_\alpha\left[\Gamma\left(N_i \to l_\alpha + \tilde{\varphi}^\dagger\right) - \Gamma\left(N_i \to \bar{l}_\alpha + \tilde{\varphi}\right)\right]}{\sum_\alpha\left[\Gamma\left(N_i \to l_\alpha + \tilde{\varphi}^\dagger\right) + \Gamma\left(N_i \to \bar{l}_\alpha + \tilde{\varphi}\right)\right]}$$

M. Fukugita and T. Yanagida, Phys. Lett. B 174, 45 (1986); P. Langacker, R.D. Peccei, and T. Yanagida, Mod. Phys. Lett. A 1, 541 (1986); M.A. Luty, Phys. Rev. D 45, 455 (1992); R.N. Mohapatra and X. Zhang, Phys. Rev. D 45, 2688 (1992).

90年代初，大家并不感兴趣！！？？

Quintessential Baryo/Leptogenesis

M.Li, X.Wang, B.Feng, X. Zhang PRD65,103511 (2002)
De Felice, Nasri, Trodden, PRD67:043509(2003)
M.Li & X. Zhang, PLB573,20 (2003)

I) $$L_{\rm int} = c\frac{\partial_\mu Q}{M} J_B^\mu \Rightarrow \qquad \mu_b = c\frac{\dot{Q}}{M} = -\mu_{\bar{b}}$$

In thermo equilibrium⇒

Cohen & Kaplan

$$n_B = n_b - n_{\bar{b}} = \frac{g_b}{2\pi^2}\int_m^\infty E(E^2-m^2)^{1/2}dE \times \left[\frac{1}{1+\exp[(E-\mu_b)/T]} - \frac{1}{1+\exp[(E+\mu_b)/T]}\right]$$

$$= \frac{g_b T^3}{6}\left[\frac{\mu_b}{T} + O\left(\frac{\mu_b}{T}\right)^3\right] \approx c\frac{g_b \dot{Q} T^2}{6M}$$

$$\eta = n_B / s \approx \frac{15c}{4\pi^2}\frac{g_b \dot{Q}}{g_* MT}$$

$\dot{Q}$ **depends on the model of Quintessence**

II) $$\partial_\mu J^\mu_{(B-L)_{\rm L}} \sim -\frac{e^2}{12\pi^2}F_{\mu\nu}\tilde{F}^{\mu\nu} = -\frac{\alpha_{\rm em}}{3\pi}F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$J^\mu_{(B-L)_{\rm L}} = (1/2)J^\mu_{(B-L)} - (1/2)J^{5\mu}_{(B-L)}$$

↓ **Leptogenesis** ↓ **Anomaly for CMB**

Cosmological CPT violation, baryo/leptogenesis and CMB polarization
M. Li, J. Xia, H. Li and X. Zhang
Phys. Lett. B651, 357 (2007)

I Cosmological CPT violation

**M.Li, X.Wang，
B.Feng, X.Zhang,
PRD65,103511(2002)，**

$$\mathcal{L}_{\rm int} = \frac{c}{M}\partial_\mu \phi J^\mu$$ ⇒ **Baryo/Leptogenesis**

⇓ 反常方程

$$\mathcal{L} \sim -\frac{1}{2} C \partial_\mu \phi K^\mu$$ ⇒ **CMB极化检验CPT对称性**

$$K^\mu = A_\nu \tilde{F}^{\mu\nu} = \frac{1}{2} A_\nu \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$$

II. 与实验室检验CPT对称性的方法比较

CMB光子经历了近**137**亿年， 相比与实验室的实验，它具有累积效应， 将大大提高对于**CPT**检验的灵敏度

CMB检验CPT对称性的基本思想

$$\mathcal{L} \sim -\frac{1}{2} C \partial_\mu \phi K^\mu \qquad K^\mu = A_\nu \tilde{F}^{\mu\nu} = \frac{1}{2} A_\nu \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$$

CPT破坏 ⟶ 旋转角 $\Delta\alpha \neq 0$

$$\tan\alpha \equiv \frac{B_z}{B_y} = \tan(\frac{1}{2}C\phi + I) \quad \alpha = \frac{1}{2}C\phi + I \quad \Delta\alpha = \frac{1}{2}C\Delta\phi$$

$$\begin{cases} Q' = Q\cos 2\Delta\alpha + U \sin 2\Delta\alpha \\ U' = -Q \sin 2\Delta\alpha + U\cos 2\Delta\alpha \end{cases}$$

$$C'^{TT}_l = C^{TT}_l$$

$$C'^{EE}_l = C^{EE}_l \cdot \cos^2 2\Delta\alpha + C^{BB}_l \sin^2 2\Delta\alpha$$

$$C'^{BB}_l = C^{EE}_l \cdot \sin^2 2\Delta\alpha + C^{BB}_l \cos^2 2\Delta\alpha$$

$$C'^{TE}_l = C^{TE}_l \cdot \cos 2\Delta\alpha$$

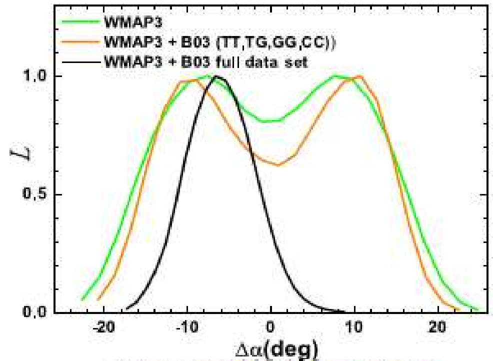
$$C'^{TB}_l = C^{TE}_l \cdot \sin 2\Delta\alpha$$

$$C'^{EB}_l = \frac{1}{2}(C^{EE}_l - C^{BB}_l) \sin 4\Delta\alpha$$

(Note here the notation: G ~ E, C~ B)

1）**Gravitational leptogenesis and its signatures in CMB.**
Bo Feng, Hong Li, Ming-zhe Li, Xin-min Zhang,
Phys.Lett.B620:27-32,2005.
当时没有数据，用模拟的数据做了研究

2）**Bo Feng, Mingzhe Li , Jun-Qing Xia, Xuelei Chen and Xinmin Zhang**
Phys. Rev. Lett. 96, 221302 (2006)
使用的数据是WMAP和BOOMERanG的极化数据；
MCMC方法，修改的CosmoMC



$\Delta\alpha = -6.0^{+4.0}_{-4.0}{}^{+3.9}_{-3.7}$ deg(1, 2σ)

FIG. 1 (color online). One-dimensional constraints on the rotation angle $\Delta\alpha$ from WMAP data alone (green or light gray line), WMAP and the 2003 flight of BOOMERANG B03 TT, TG, GG and CC (orange or gray line), and from WMAP and the full B03 observations (TT, TG, GG, CC, TC, GC) (black line).

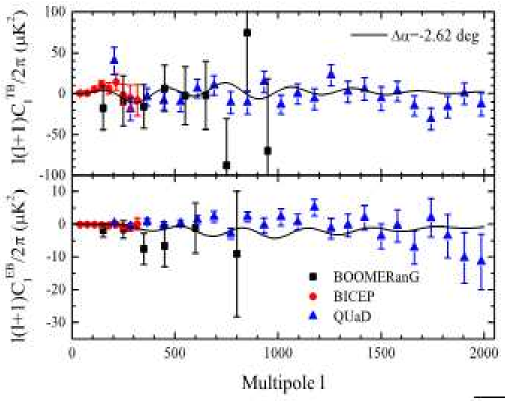
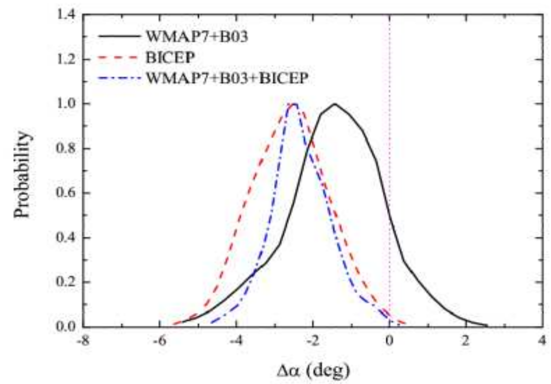


Fig. 1. The binned TB and EB spectra measured by the small-scale of BOOMERanG (black squares), BICEP (red circles) and QUaD (b black solid curves show the theoretical prediction of a model with (For interpretation of colors in this figure, the reader is referred t of this Letter.)

Current status on the measurements of the rotation angle



Group	$\Delta\alpha$ (degree)	Datasets
Feng et al	-6.0 ± 4.0	WMAP3+B03
Cabella et al	-2.5 ± 3.0	WMAP3
WMAP Collaboration	-1.7 ± 2.1	WMAP5
Xia et al	-2.6 ± 1.9	WMAP5+B03
WMAP Collaboration	-1.1 ± 1.4	WMAP7
QUaD Collaboration	0.64 ± 0.50	QUaD
Xia et al	-2.60 ± 1.02	BICEP
Xia et al	-2.33 ± 0.72	WMAP7+B03+BICEP
Xia et al	-0.04 ± 0.35	WMAP7+B03+BICEP+QUaD
Gruppuso et al	-1.6 ± 1.7	WMAP7

3σ detection ===➔ (Xia et al, -2.33 ± 0.72, WMAP7+B03+BICEP)

$$PLANCK: \ \sigma = 0.057 \text{ deg}$$

（夏俊卿， **Planck 组**）

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Probing CPT violation with CMB polarization measurements

Jun-Qing Xia [a,*], Hong Li [b,c], Xinmin Zhang [b,c]

$$\Delta\alpha = -2.62 \pm 0.87 \text{ deg } (68\%\ C.L.)$$

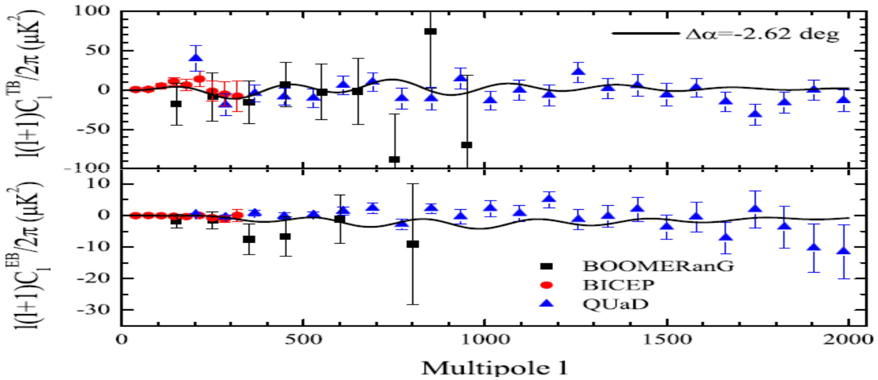
$$C_l^{\prime TB} = C_l^{TE} \sin(2\Delta\alpha),$$

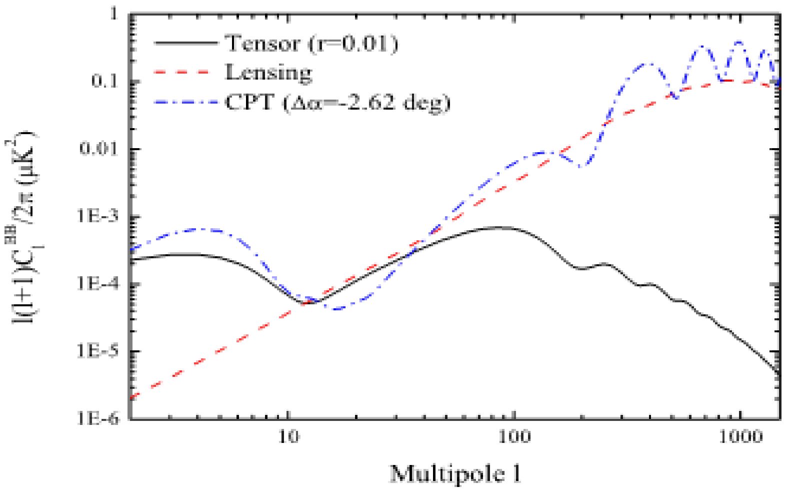
$$C_l^{\prime EB} = \frac{1}{2}(C_l^{EE} - C_l^{BB}) \sin(4\Delta\alpha),$$

$$C_l^{\prime TE} = C_l^{TE} \cos(2\Delta\alpha),$$

$$C_l^{\prime EE} = C_l^{EE} \cos^2(2\Delta\alpha) + C_l^{BB} \sin^2(2\Delta\alpha),$$

$$C_l^{\prime BB} = C_l^{BB} \cos^2(2\Delta\alpha) + C_l^{EE} \sin^2(2\Delta\alpha),$$





Self-Calibration of BICEP1 Three-Year Data and Constraints on Astrophysical Polarization Rotation

J.P. Kaufman,[1] N.J. Miller,[2] M. Shimon,[3,1] D. Barkats,[4] C. Bischoff,[5] I. Buder,[5] B.G. Keating,[1] J.M. Kovac,[5] P.A.R. Ade,[6] R. Aikin,[7] J.O. Battle,[8] E.M. Bierman,[1] J. J. Bock,[7,8] H.C. Chiang,[9] C.D. Dowell,[8] L. Duband,[10] J. Filippini,[7] E.F. Hivon,[11] W.L. Holzapfel,[12] V.V. Hristov,[7] W.C. Jones,[13] S.S. Kernasovskiy,[14,15] C.L. Kuo,[14,15] E.M. Leitch,[16] P.V. Mason,[7] T. Matsumura,[17] H.T. Nguyen,[8] N. Ponthieu,[18] C. Pryke,[19] S. Richter,[7] G. Rocha,[7,8] C. Sheehy,[16] M. Su,[20,21] Y.D. Takahashi,[12] J.E. Tolan,[14,15] and K.W. Yoon[14,15]

[1] Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0424, USA
[2] Observational Cosmology Laboratory, Code 665, Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, USA
[3] School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel
[4] Joint ALMA Observatory, ESO, Santiago, Chile
[5] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street MS 42, Cambridge, MA 02138, USA
[6] Department of Physics and Astronomy, University of Wales, Cardiff, CF24 3YB, Wales, UK
[7] Department of Physics, California Institute of Technology, Pasadena, CA 91125, USA
[8] Jet Propulsion Laboratory, Pasadena, CA 91109, USA
[9] Astrophysics and Cosmology Research Unit, University of KwaZuluNatal, Durban, South Africa
[10] SBT, Commissariat à lEnergie Atomique, Grenoble, France
77 Massachusetts Avenue, Cambridge, MA, USA

(Dated: December 31, 2013)

Cosmic Microwave Background (CMB) polarimeters aspire to measure the faint B-mode signature predicted to arise from inflationary gravitational waves. They also have the potential to constrain cosmic birefringence, rotation of the polarization of the CMB arising from parity-violating physics, which would produce non-zero expectation values for the CMB's TB and EB spectra. However, instrumental systematic effects can also cause these TB and EB correlations to be non-zero. In particular, an overall miscalibration of the polarization orientation of the detectors produces TB and EB spectra which are degenerate with isotropic cosmological birefringence, while also introducing a small but predictable bias on the BB spectrum. We find that BICEP1 three-year spectra, which use our standard calibration of detector polarization angles from a dielectric sheet, are consistent with a polarization rotation of $\alpha = -2.77^\circ \pm 0.86^\circ$(statistical) $\pm 1.3^\circ$(systematic). We have revised the estimate of systematic error on the polarization rotation angle from the two-year analysis by comparing multiple calibration methods. We also account for the (negligible) impact of measured beam systematic effects. We investigate the polarization rotation for the BICEP1 100 GHz and 150 GHz bands separately to investigate theoretical models that produce frequency-dependent cosmic birefringence. We find no evidence in the data supporting either these models or Faraday rotation of the CMB polarization by the Milky Way galaxy's magnetic field. If we assume that there is no cosmic birefringence, we can use the TB and EB spectra to calibrate detector polarization orientations, thus reducing bias of the cosmological B-mode spectrum from leaked E-modes due to possible polarization orientation miscalibration. After applying this "self-calibration" process, we find that the upper limit on the tensor-to-scalar ratio decreases slightly, from $r < 0.70$ to $r < 0.65$ at 95% confidence.

PACS numbers: 98.70.Vc

[9] V. Gluscevic and M. Kamionkowski, Phys. Rev. D **81**, 123529 (2010), arXiv:1002.1308 [astro-ph.CO].
[10] J.-Q. Xia, H. Li, and X. Zhang, Physics Letters B **687**, 129 (2010), arXiv:0908.1876 [astro-ph.CO].
[11] J.-Q. Xia, J. Cosmology Astropart. Phys. 1, 46 (2012), arXiv:1201.4457 [astro-ph.CO].
[12] G. Gubitosi and F. Paci, (2012), arXiv:1211.3321.

3点：

1〉 用通常 "standard Calibration "，BICEP组得到：

$\alpha = -2.77^\circ \pm 0.86^\circ$(statistical) $\pm 1.3^\circ$(systematic)

与我们的结果一致；

2）在 ~ 2 sigma 内，旋转角可取 ~ -5 度-------〉虽说不能宣称发现CPT破坏，但给BB 谱带来的误差很大, 见下页图。

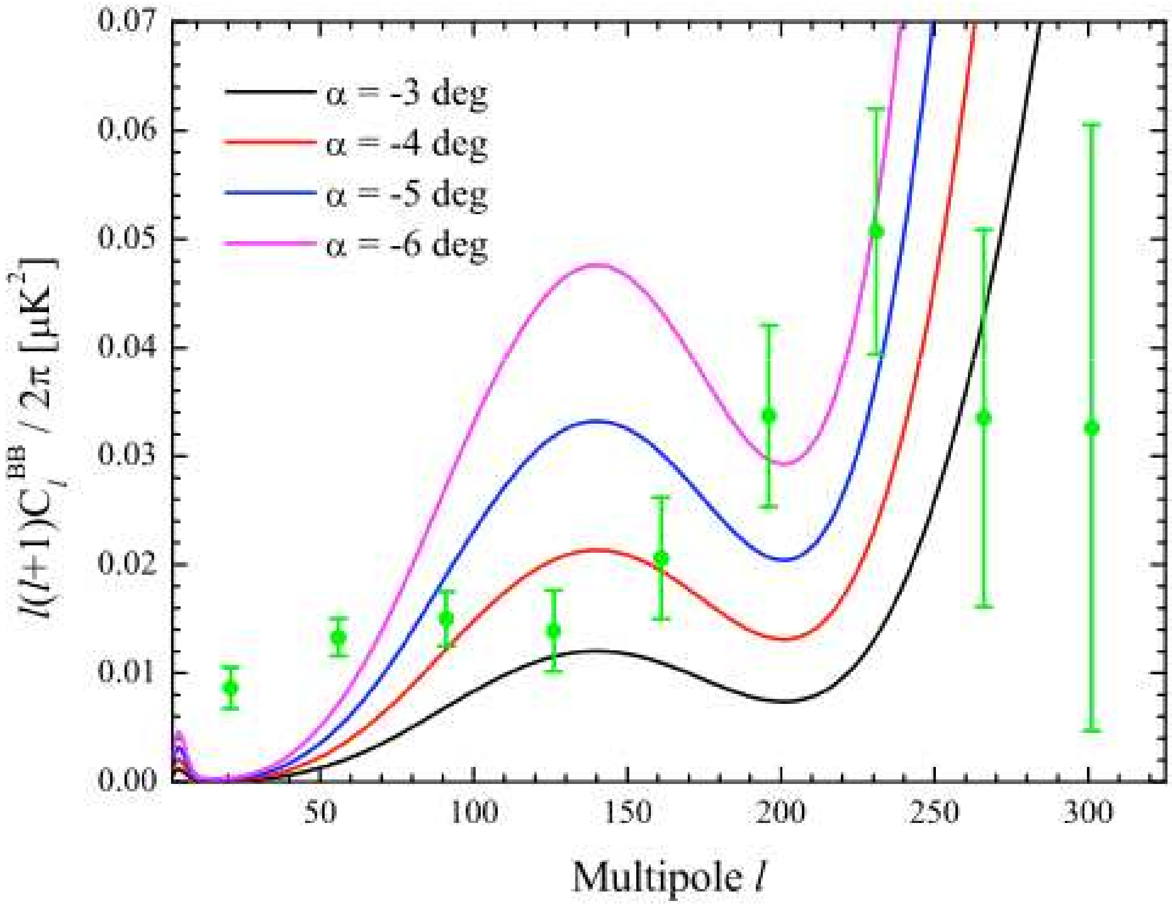
3）他们提出 "self callibration" 新方法。用这个方法后，

文章说 r 值由

r < 0.70 到 r < 0.65

BICEP2: r or rotation angle from CPT violation?

Hong Li, Jun-Qing Xia, Xinmin Zhang (2014)



PHYSICAL REVIEW D **78**, 103516 (2008)

Cosmological *CPT* violating effect on CMB polarization

Mingzhe Li[1,2,3] and Xinmin Zhang[4]
[1]*Fakultät für Physik, Universität Bielefeld, D-33615 Bielefeld, Germany*
[2]*Department of Physics, Nanjing University, Nanjing 210093, People's Republic of China*
[3]*Joint Center for Particle, Nuclear Physics and Cosmology, Nanjing University–Purple Mountain Observatory, Nanjing 210093, People's Republic of China*
[4]*Institute of High Energy Physics, Chinese Academy of Sciences, P.O. Box 918-4, Beijing 100049, People's Republic of China*
(Received 15 October 2008; published 14 November 2008)

A dark energy scalar (or a function of the Ricci scalar) coupled with the derivative to the matter fields will violate the *CPT* symmetry during the expansion of the Universe. This type of cosmological *CPT* violation helps to generate the baryon number asymmetry and gives rise to the rotation of the photon polarization which can be measured in the astrophysical and cosmological observations, especially the experiments of the cosmic microwave background radiation. In this paper, we derive the rotation angle in a fully general relativistic way and present the rotation formulas used for the cosmic microwave background data analysis. Our formulas include the corrections from the spatial fluctuations of the scalar field. We also estimate the magnitude of these corrections in a class of dynamical dark energy models for quintessential baryo/leptogenesis.

USTC-ICTS-14-07

Fluctuations of cosmological birefringence and the effect on CMB B-mode polarization

Wen Zhao[1] and Mingzhe Li[2]
[1]*Key Laboratory for Researches in Galaxies and Cosmology, Department of Astronomy, University of Science and Technology of China, Hefei, Anhui, 230026, China*
[2]*Interdisciplinary Center for Theoretical Study, University of Science and Technology of China, Hefei, Anhui 230026, China*

The cosmological birefringence caused by the coupling between the cosmic scalar field and the cosmic microwave background (CMB) photons through the Chern-Simons term can rotate the polarization planes of the photons, and mix the CMB E-mode and B-mode polarizations. The rotation angle induced by the dynamical scalar field can be separated into the isotropic background part and the anisotropic fluctuations. The effect of the background part has been be studied in the previous work (Zhao & Li, arXiv:1402.4324). In this paper, we focus on the influence of the anisotropies of the rotation angle. We find that, if the cosmic scalar field is identified as the quintessence field, the anisotropies of the rotation angle are always too small to be detectable. However, if the scalar field is massless, the rotation spectrum can be quite large, which may be detected by the potential CMB observations. In addition, we find that, the rotated B-mode polarization could be fairly large, and comparable with those generated by relic gravitational waves or cosmic weak lensing, which forms a new contamination for the detection of relic gravitational waves in the CMB. In this paper, we also propose the method to reconstruct and subtract the rotated B-mode polarization, by which the residuals become negligible for the gravitational-wave detection.

Cosmic Birefringence Fluctuations and Cosmic Microwave Background B-mode Polarization

Seokcheon Lee[1,2], Guo-Chin Liu[3], and Kin-Wang Ng[1,4]
[1]*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*
[2]*Korea Institute for Advanced Study, Seoul 130-722, Korea*
[3]*Department of Physics, Tamkang University, Tamsui, New Taipei City 25137, Taiwan*
[4]*Institute of Astronomy and Astrophysics, Academia Sinica, Taipei 11529, Taiwan*
(Dated: March 25, 2014)

Recently, BICEP2 measurements of the cosmic microwave background (CMB) B-mode polarization has indicated the presence of primordial gravitational waves at degree angular scales, inferring the tensor-to-scalar ratio of $r = 0.2$ and a running scalar spectral index. In this *Letter*, we show that the existence of the fluctuations of cosmological birefringence can give rise to CMB B-mode polarization that fits BICEP2 data with $r < 0.11$ and no running of the scalar spectral index. Thus, ... flation models with small r are ruled out based on

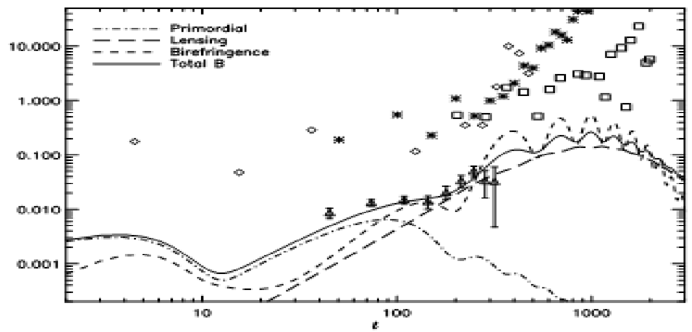
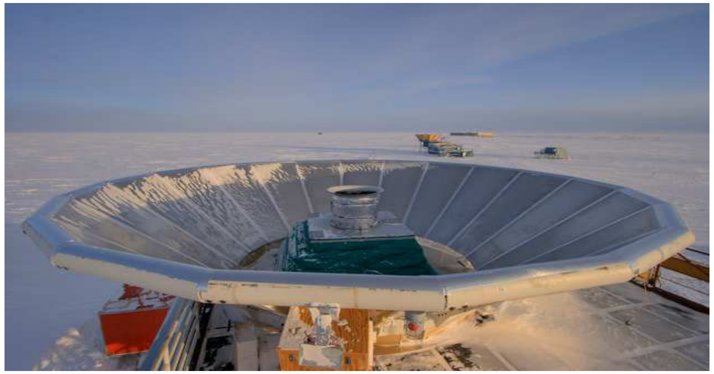


FIG. 1: Cosmological birefringence induced B-mode power spectrum through the perturbed nearly massless scalar field (short-dashed). Also shown are the theoretical power spectra of lensing induced B modes (long-dashed) and gravity-wave induced B modes (dot-dashed) with $r = 0.11$. The thick solid curve is the best-fitting averaged B-mode band powers that are the sum of these three B-mode power spectra convolved with the BICEP2 window function. Upper limits (95% c.l.) of QUaD (square), Quiet (asterisk), and WMAP9 (diamond), plus BICEP2 data (triangle) are shown.

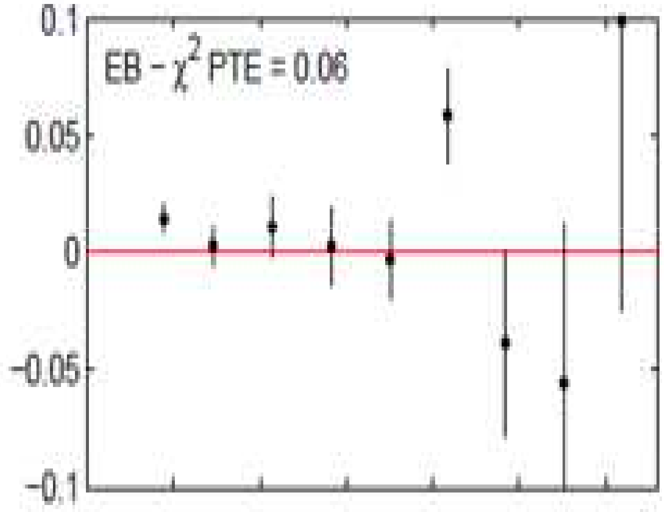


(Ade et al., 1403.3985)

Self-calibration

8.2. *Overall Polarization Rotation*

Once differential ellipticity has been corrected we notice that an excess of TB and EB power remains at $\ell > 200$ versus the ΛCDM expectation. The spectral form of this power is consistent with an overall rotation of the polarization angle of the experiment. While the detector-to-detector relative angles have been measured to differ from the design values by $< 0.2°$ we currently do not have an accurate external measurement of the overall polarization angle. We therefore apply a rotation of $\sim 1°$ to the final Q/U maps to minimize the TB and EB power (Keating et al. 2013; Kaufman et al. 2013). We emphasize that this has a negligible effect on the BB bandpowers at $\ell < 200$.



$\alpha = 0.12 \pm 0.16$ deg at the 68% C.L.

Rotation angle before self calibration estimated (?):

0.88 +- 0.16

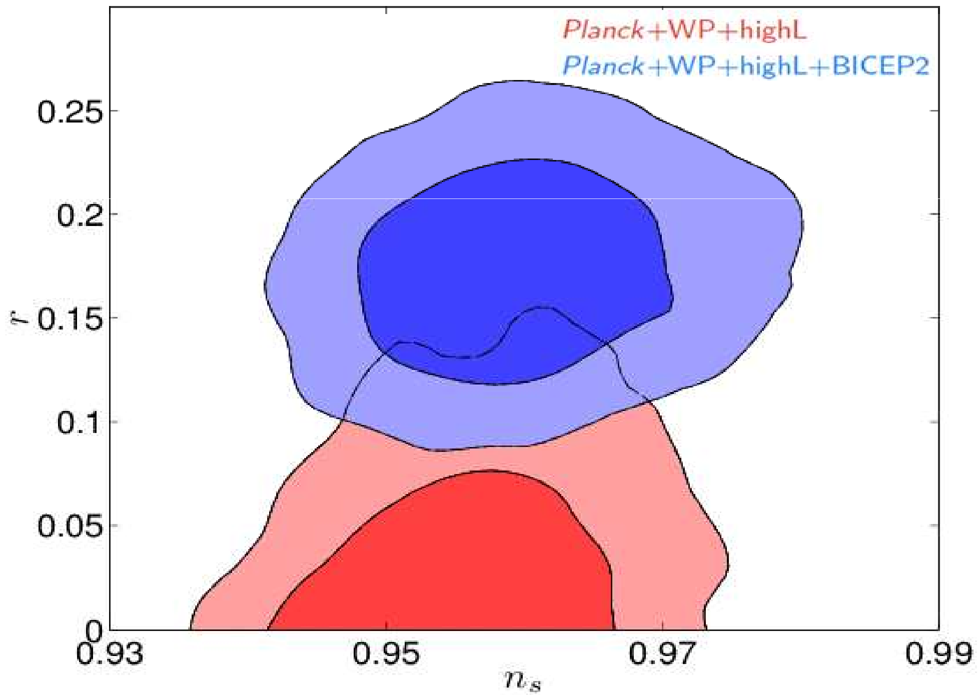
non-zero with 5 sigma

Tension between BICEP2 and Planck

$r = 0.20^{+0.07}_{-0.05}$ (68%) **VS** $r < 0.11$ (95% C.L.)

BICEP2 collaboration

Planck collaboration



(Li, Xia & Zhang, 1404.0238)

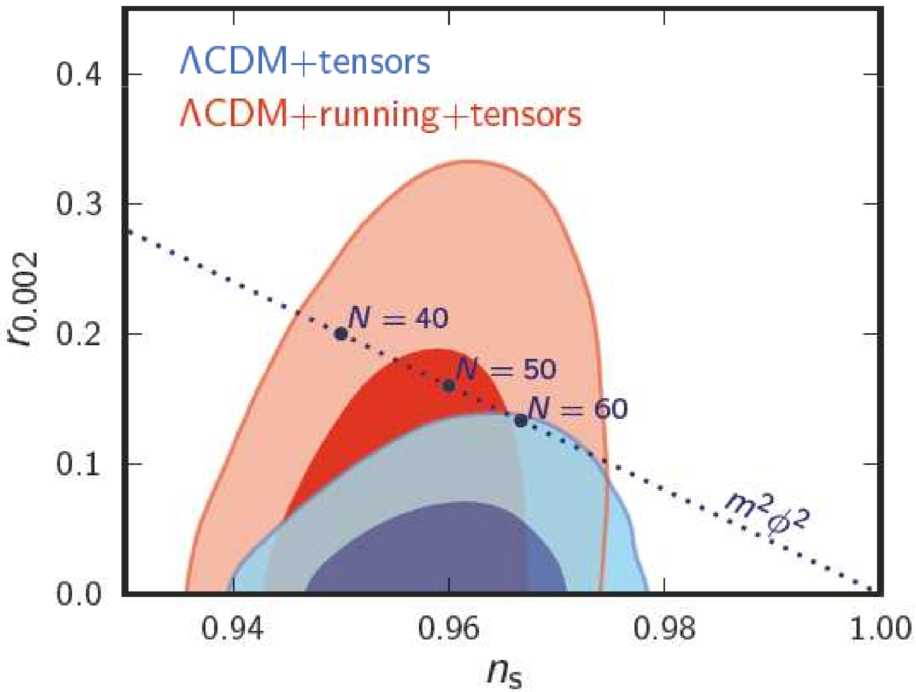
This tension appears because
Both data fitting are performed
Within the power-law LCDM,

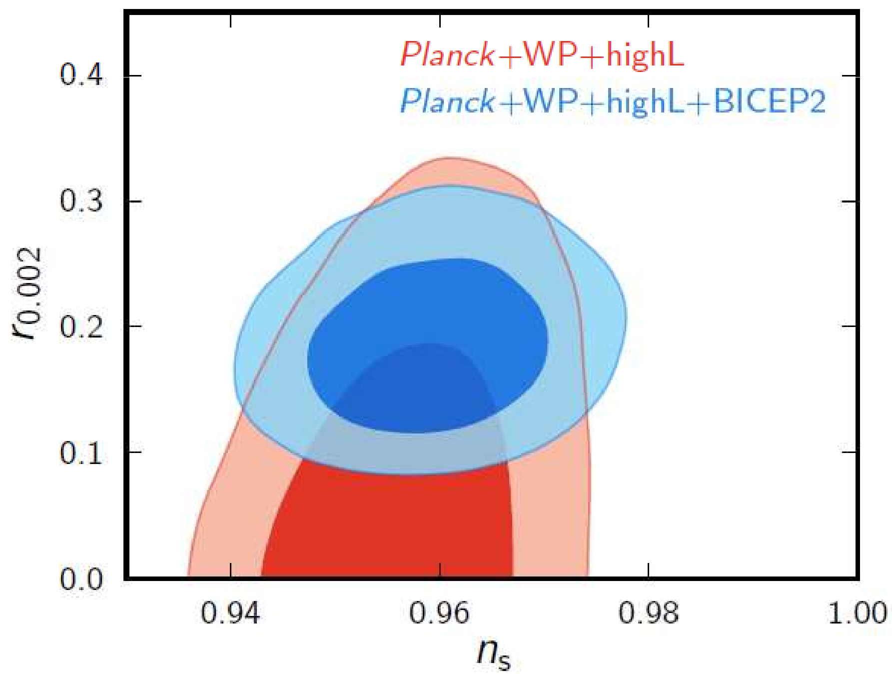
What happens if beyond LCDM ??

(*Ade et al., 1403.3985*)

Including extra parameters

In order to lessen the tension between BICEP2 and Planck results, one could include extra cosmological parameters, like the running of scalar spectrum index, to relax the constraint on r from Planck .





Degeneracies among ns, r, α_s

Hong Li, and J.-Q. Xia, JCAP 11(2012) 039

	n_s	α_s	r	$\Delta\chi^2$
ΛCDM	0.969 ± 0.011	–	–	–
$\Lambda\text{CDM} \oplus \alpha_s$	0.951 ± 0.020	-0.018 ± 0.016	–	-2.0
$\Lambda\text{CDM} \oplus r$	0.974 ± 0.012	–	< 0.15	-0.5
$\Lambda\text{CDM} \oplus \alpha_s \oplus r$	$0.946^{+0.020}_{-0.021}$	-0.038 ± 0.022	< 0.37	-2.2
$\Lambda\text{CDM} \oplus m_\nu \oplus \alpha_s$	$0.960^{+0.021}_{-0.022}$	-0.012 ± 0.017	–	-1.6
$\Lambda\text{CDM} \oplus m_\nu \oplus r$	$0.960^{+0.024}_{-0.023}$	–	< 0.39	-1.6
CPL	0.966 ± 0.013	–	–	-0.3
$CPL \oplus \alpha_s$	$0.930^{+0.025}_{-0.026}$	$-0.029^{+0.019}_{-0.020}$	–	-2.7
$CPL \oplus r$	$0.979^{+0.016}_{-0.018}$	–	< 0.20	-0.2

Table 2. 1σ constraints on the Inflationary parameters n_s, α_s, and r from Union2.1+WMAP7+BAO+HST. For the weakly constrained parameters, we quote the 95% upper limits instead.

- This is our results in 2012, which show the importance Of degeneracies between cosmological parameters.
- Which is very useful today for the resolution of BICEP2 and Planck.

Inflation models with large running、power suppressed at small l

- 2003年国际上研究是个高潮、起点
- 中国学者工作突出

高能所组：

张新民、朴云松、李明哲、冯波

理论所组：李淼、黄庆国

。。。。。。

围绕BICEP2国内学者在过去的几周已作了大量的工作

夏俊卿、李虹、蔡一夫、张新民

李明哲、赵文

邱涛涛

龚云贵等

黄庆国、王一、蔡荣根、郭宗宽。。。

张鑫等

陈学雷等

朴云松等。。。。。

准备之中：王斌等，赵公博等。。。

将出版《中国科学》专刊

guest editor: 张新民

Discussions

LHC/Higgs: origin of mass

CEPC/SPPC:

understanding the

origin of matter

Why no anti-matter

in our universe

(Electroweak phase transition , effective potential;
Bubble Wall dynamics, CP violation ……..)

Thank you !