Constraints on nonstandard top-gluon couplings from the Tevatron, LHC7 and LHC8

K. Ohkuma（Fukui Tech.）
Z. Hioki（Tokushima Univ.）

Based on Z. Hioki, KO, PRD88 (2013) 017503

I. Introduction
II. Framework
III. Analyses and results
IV. Discussion and Summary

PASCOS 2013
Nov. 21,Taipei

Ⅰ. Introduction

Introduction

- **LHC Era (Probing TeV Scale Physics）**
  - **Confirmations of the Standard Model**
    - ✓ **Rediscover the standard particles**
    - ✓ **Discover Higgs particle**
  - **Search for the physics beyond the Standard Model**

➢ Probing the beyond the SM @ Collider

New Physics searches

Direct Search	Indirect Search
Direct detections of New particles → Clean signals from the BSM ← No signals	Measurement of deviations from the SM - u,d,s,c Very precise measurements →No anomaly - b, t (Teva＋LHC) Precise measurements → No anomaly?

Probing the beyond the SM @ Collider

New Physics searches

Direct Search	Indirect Search
Direct detections of New particles	Measurement of deviations from the SM
→ Clean signals from the BSM	- u,d,s,c Very precise measurements →No anomaly
← No signals	- b t (Teva＋LHC) Precise measurements → No anomaly?

Aim of this work

Top pair production process

– **Experimental results consistent with the SM predictions within the errors**

→ **Nonstandard effects are small at the current colliding energy**

→ **Constraints on the nonstandard top couplings are strengthened**

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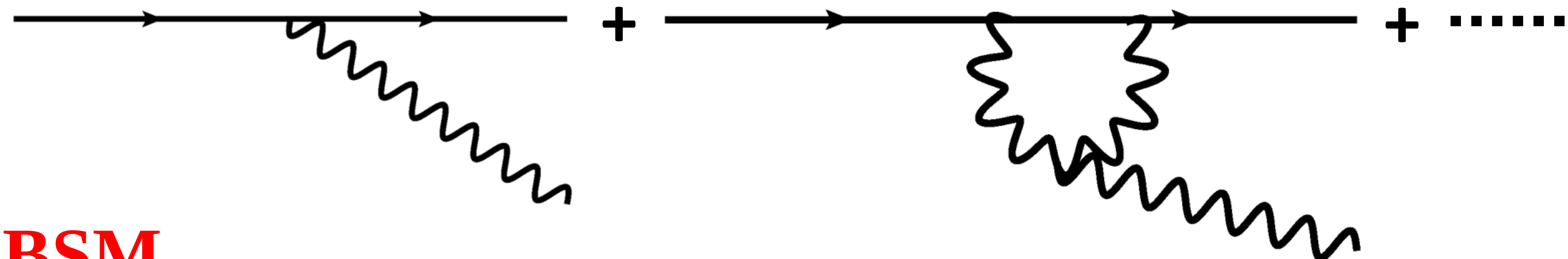
Ⅱ. Framework

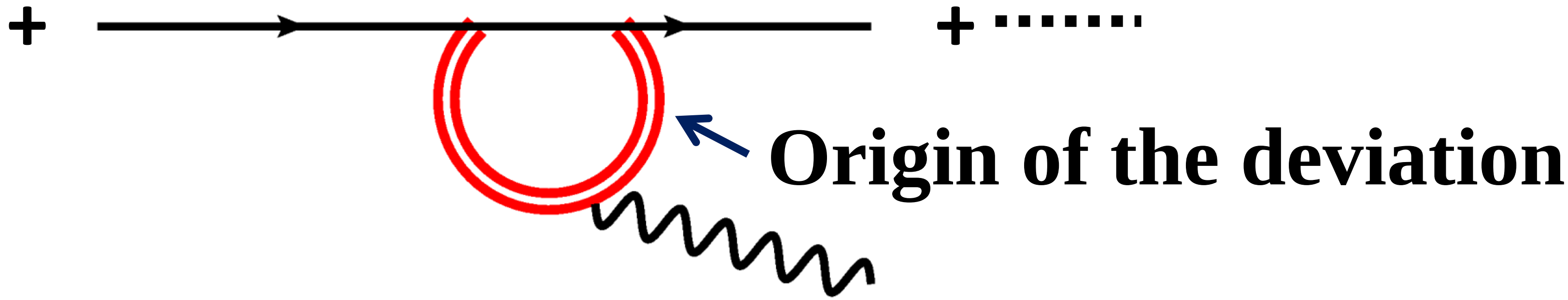
Framework

- **Indirect searches**
  - **Measurements the deviation from the SM prediction induced by new heavy particles**

SM

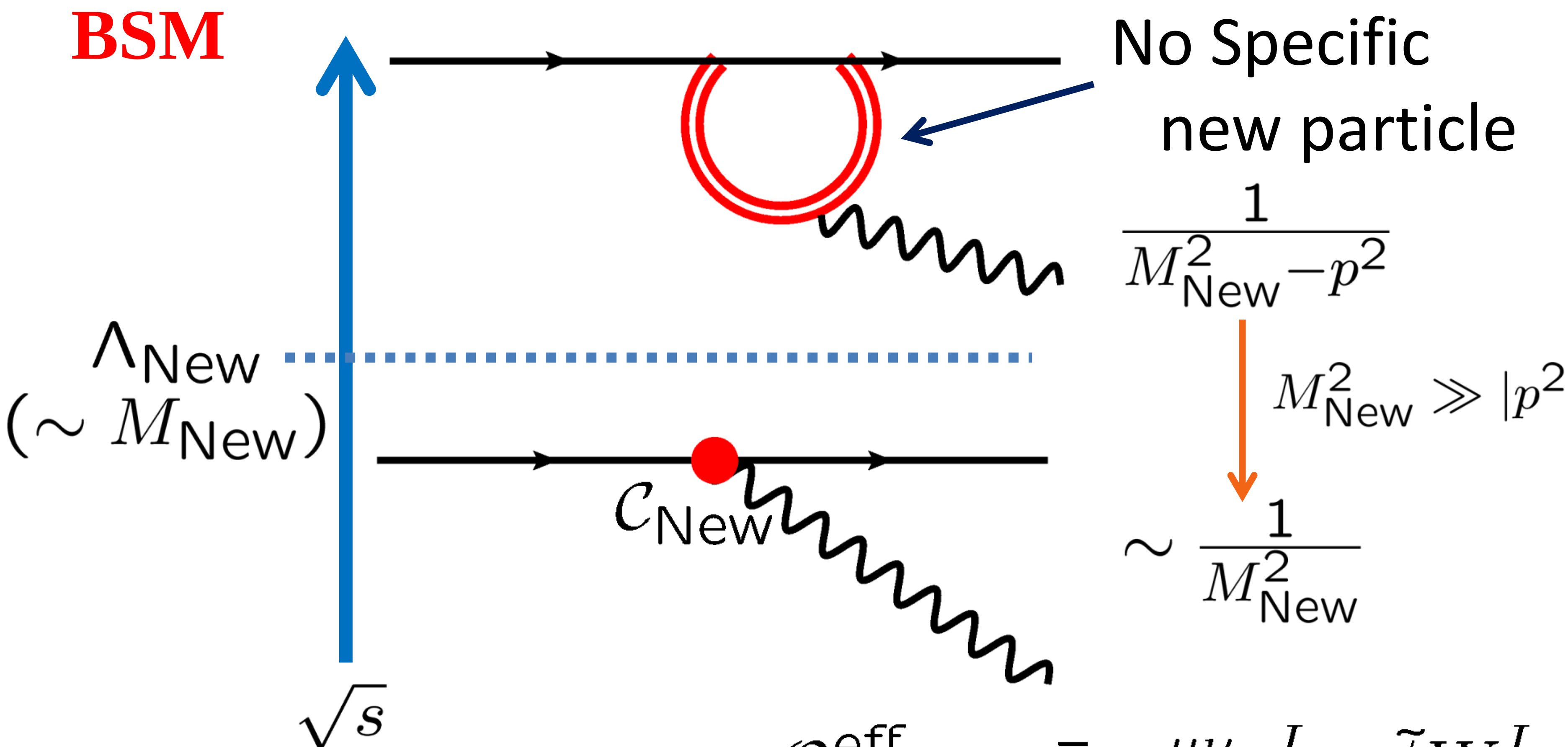


BSM



Framework

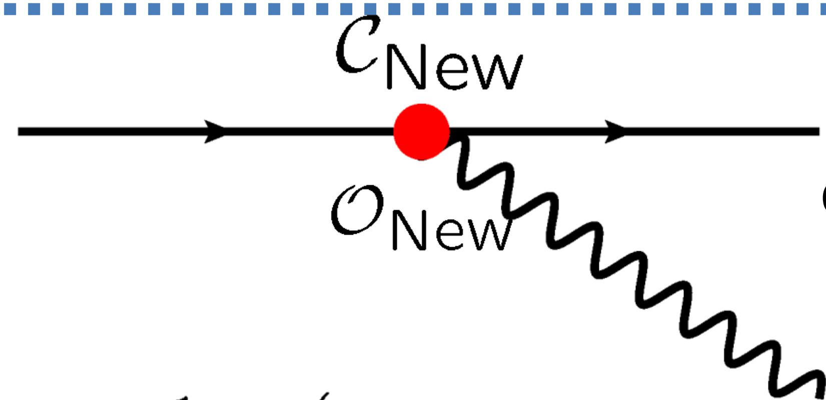
➢ Effective Lagrangian



$$\mathcal{O}_{\rm New}^{\rm eff} \sim \bar{q}_L \sigma^{\mu\nu} \tau^I q_R \tilde{\phi} W_{\mu\nu}^I$$

Framework

Λ_{New}
$(\sim M_{\mathrm{New}})$



cf. Fermi interaction

$$G_F \sim \frac{g^2}{M_W^2}$$

$$\mathcal{L}_{\mathrm{New}} = \frac{1}{\Lambda^2_{\mathrm{New}}}\left(\mathcal{C}_{\mathrm{New}}\mathcal{O}_{\mathrm{New}} + \mathcal{C}^*_{\mathrm{New}}\mathcal{O}^\dagger_{\mathrm{New}}\right)$$

$$\mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda^2}\sum_i [\, C_i\mathcal{O}_i + C_i^*\mathcal{O}_i^\dagger \,]$$

$\mathcal{O}_i$ **Consist of only the SM particles**
SU(3) × SU(2) × U(1) invariant

JHEP

JHEP10(2010)085

Published for SISSA by Springer

Received: September 24, 2010
Accepted: September 28, 2010
Published: October 25, 2010

Dimension-six terms in the Standard Model Lagrangian[1]

B. Grzadkowski,[a] M. Iskrzyński,[a] M. Misiak[a,b] and J. Ros

[a] Institute of Theoretical Physics, University of Warsaw, Hoża 69, PL-00-681 Warsaw, Poland

[b] Institut für Theoretische Teilchenphysik, Karlsruhe Institute of
D-76128 Karlsruhe, Germany

E-mail: Bohdan.Grzadkowski@fuw.edu.pl, mkisk@okwf.f
Mikolaj.Misiak@fuw.edu.pl, Janusz.Rosiek@fuw.edu.p

cf. Fermi interaction

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM}$$

$\mathcal{O}_i$ Co

SU

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p \gamma^\mu d_r)$

Table 2. Dimension-six operators other than the four-fermion ones.

Effective Lagrangian（1）

Top pair production (top – gluon interaction)

$$\mathcal{O}_{uG} = \sum_a \bar{q}_{L3}\lambda^a\sigma^{\mu\nu}u_{R3}\tilde{\phi}G^a_{\mu\nu}$$

↓

$$\mathcal{L}_{t\bar{t}g,gg} = \frac{1}{2}g_s\sum_a[\bar{\psi}_t\lambda^a\frac{\sigma^{\mu\nu}}{m_t}(d_V + id_A\gamma_5)\psi_t G^a_{\mu\nu}]$$

$$d_V \equiv \frac{\sqrt{2}vm_t}{\Lambda^2}Re(\alpha_{uG\phi})$$

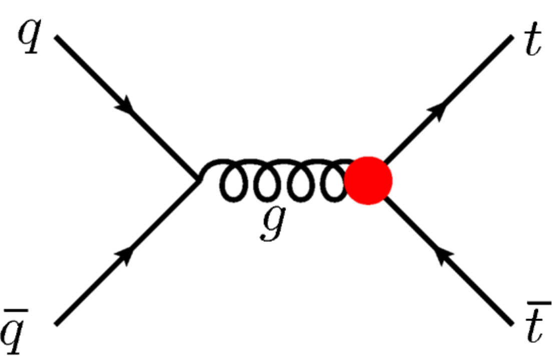
(CMDM)

$$d_A \equiv \frac{\sqrt{2}vm_t}{\Lambda^2}Im(\alpha_{uG\phi})$$

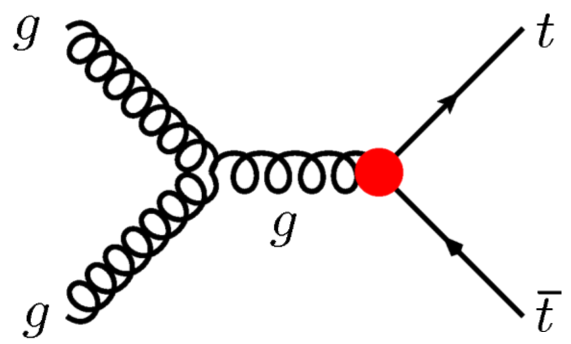
(CEDM)

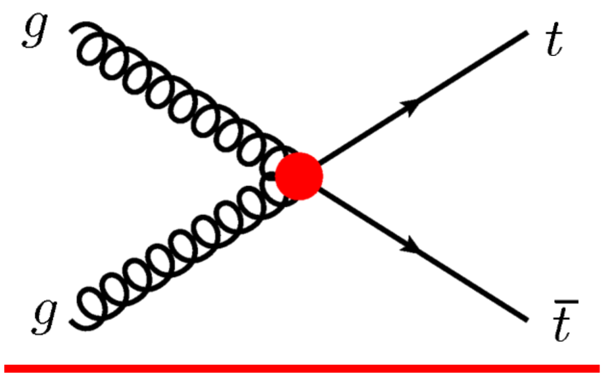
➢ Production processes at Hadron Colliders

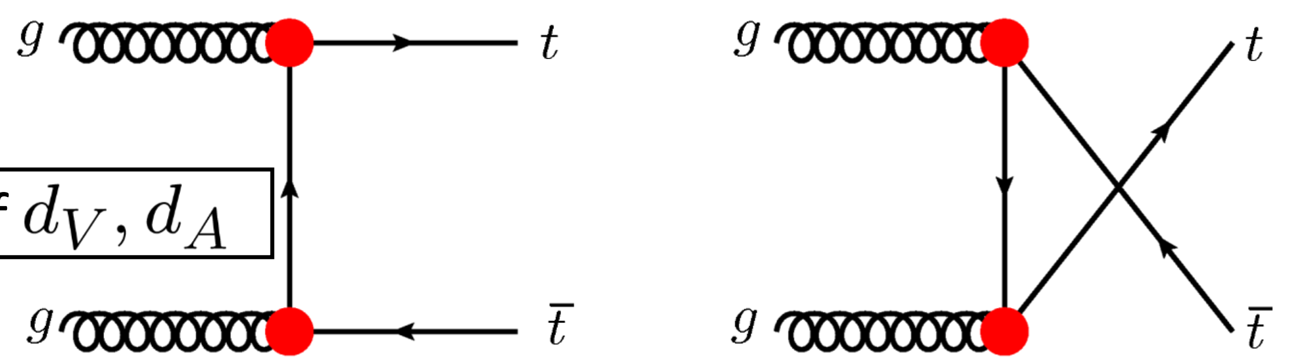
Tev. > LHC



Tev. < LHC







Memo

●: including effects of d_V, d_A

Ⅲ. Analyses and Results

Analyses and results

- **Data (based on HCP2012)**
  - **Experimental results**

Teva _comb. : $\sigma_{\text{exp}} = 7.65 \pm 0.41$ pb

LHC 7_comb : $\sigma_{\text{exp}} = 173.3 \pm 10.1$ pb

ATLAS 8 : $\sigma_{\text{exp}} = 241 \pm 32$ pb

CMS 8 : $\sigma_{\text{exp}} = 227 \pm 15$ pb

  - **Theoretical values**

Teva : $\sigma_{\text{QCD}} = 7.24 \pm 0.24$pb

LHC 7 : $\sigma_{\text{QCD}} = 167.0 \, {}^{+17}_{-18}$ pb

LHC 8 : $\sigma_{\text{QCD}} = 220 \, {}^{+14}_{-13}$ pb

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LHC 8 : $\sigma_{\rm QCD} = 220 {}^{+14}_{-13}$ pb

➢ Experimental values VS Theoretical values

– **Effective experimental vales (including theoretical errors)**

$$\sigma_{\text{exp}} = 7.65\,^{+\,0.48}_{-\,0.49}\ \text{pb (Teva\_comb)}$$

$$= 173\,^{+\,22.3}_{-\,23.0}\ \text{pb (LHC7\_comb)}$$

$$= 241 \pm 35\text{pb (ATLAS8)}$$

$$= 227\,^{+\,21}_{-\,20}\ \text{pb (CMS8)}$$

– **Theoretical value**

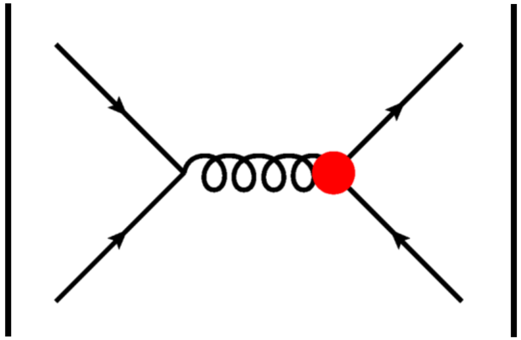
$$\sigma_{\text{th}} = \sigma_{SM} + \sigma_{NP}(d_V, d_A)$$

➡ **The constraint on d_V, d_A are derived from comparing σ_{exp} with σ_{th} .**

Analyses and results

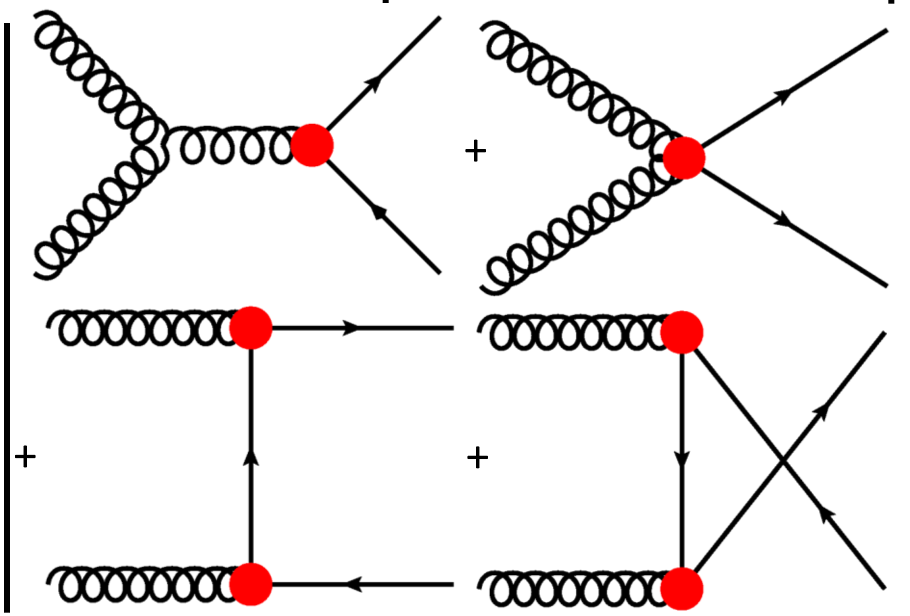
Total Cross section (top-pair production)

$d\sigma_{\text{th}} \propto$



$^2 \; N_{q/p}(x_1) N_{\bar{q}/\overset{(-)}{p}}(x_2) dx_1 dx_2$

$+$

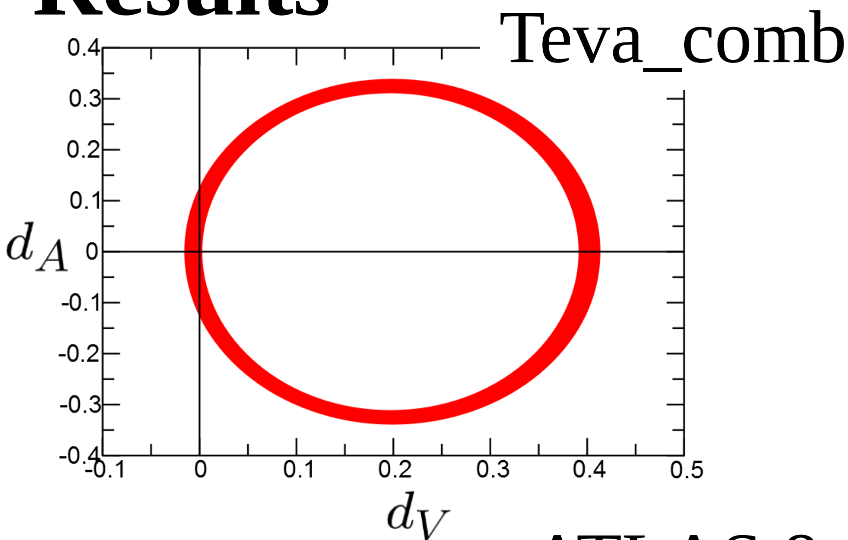


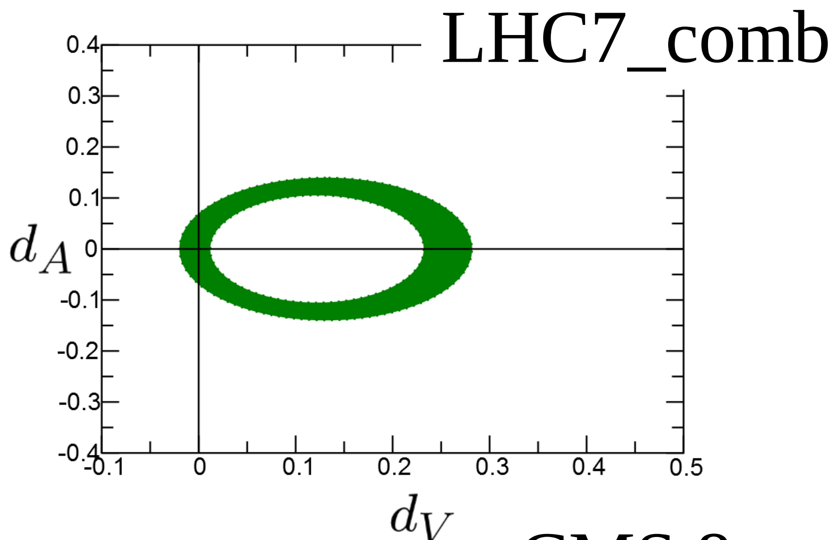
$^2 \; N_{g/p}(x_1) N_{g/\overset{(-)}{p}}(x_2) dx_1 dx_2$

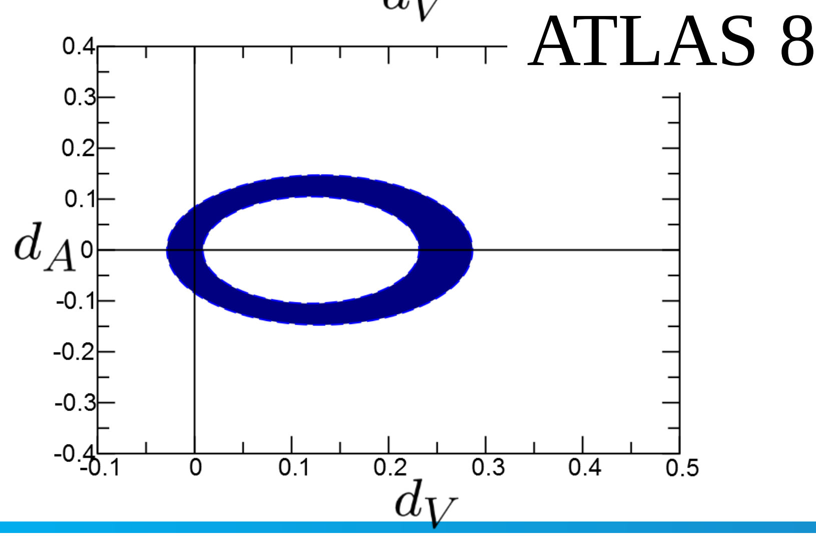
Memo

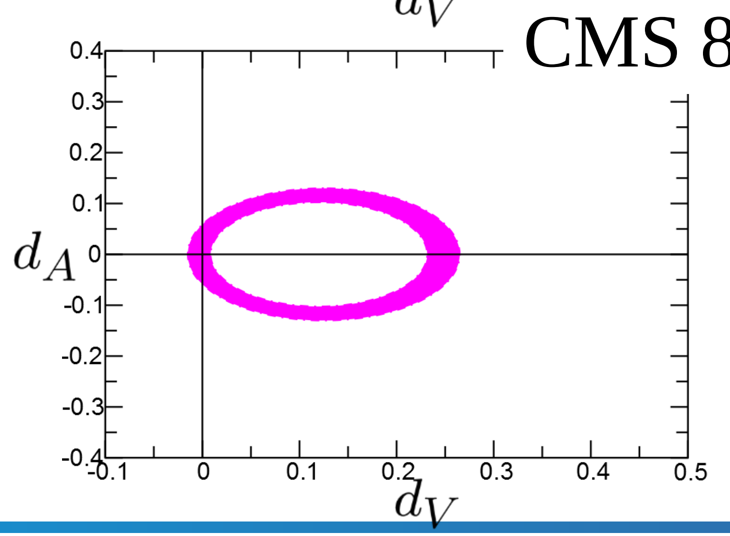
$N(x)$: PDF [CTEQ 66M]

Results

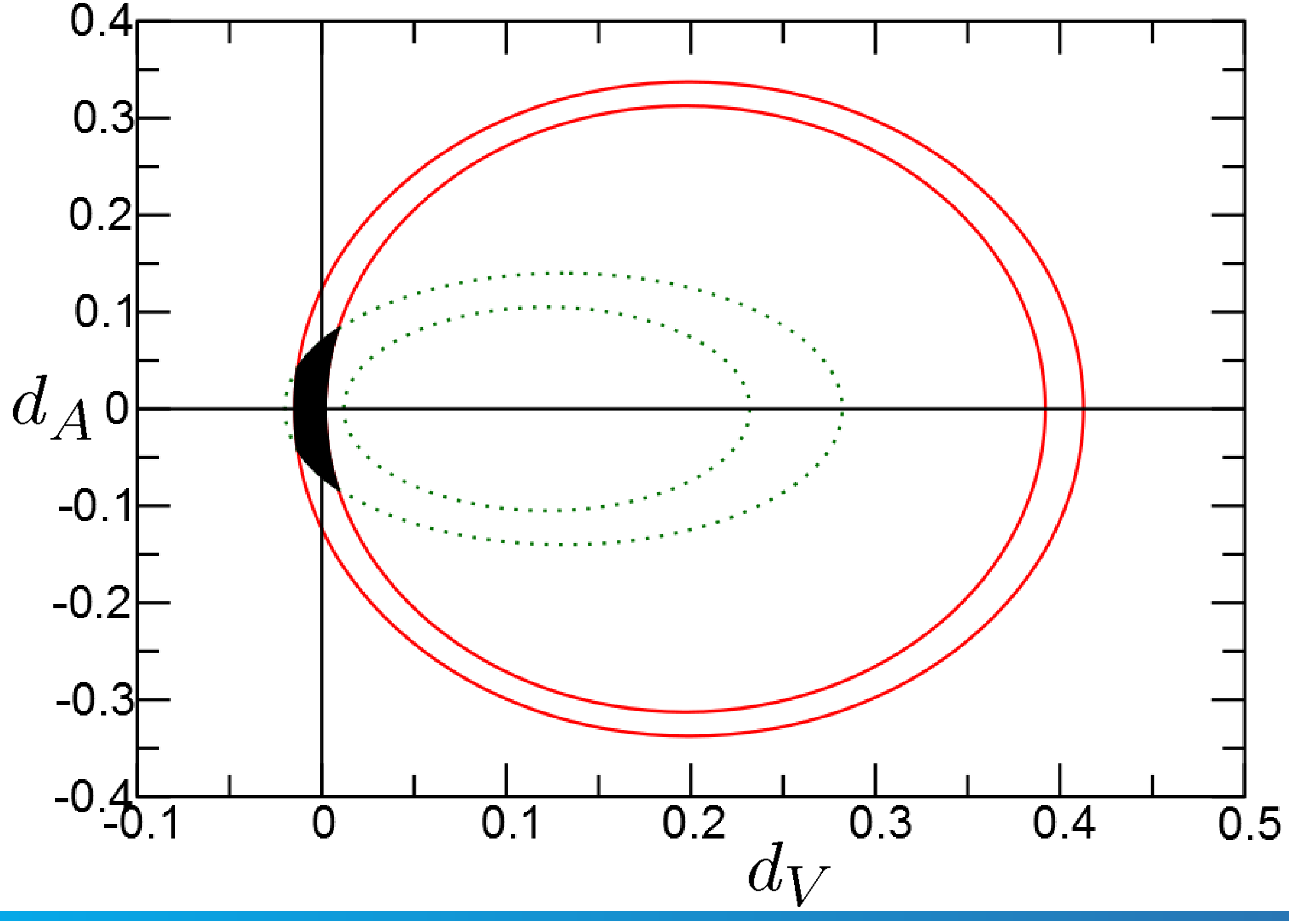




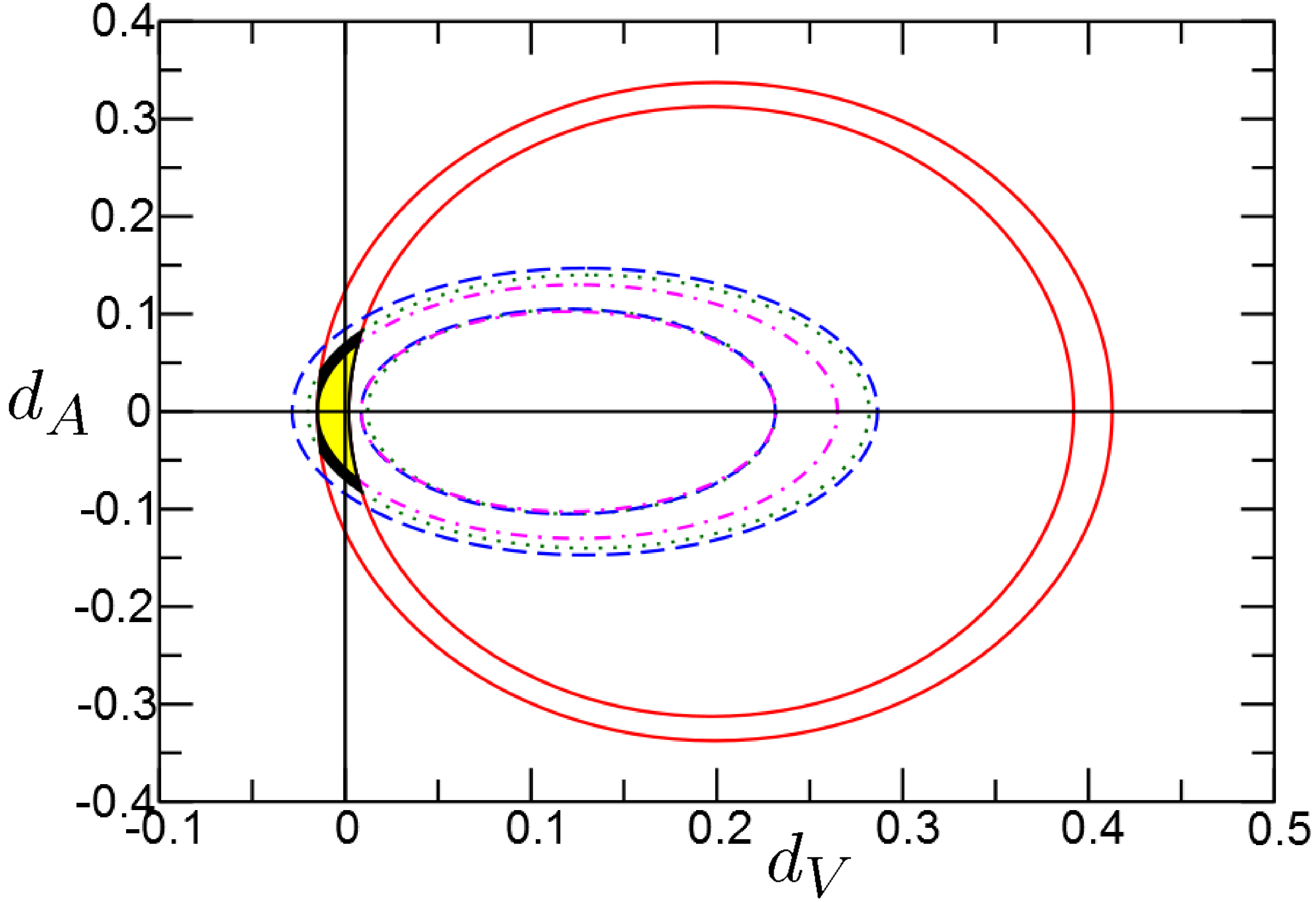




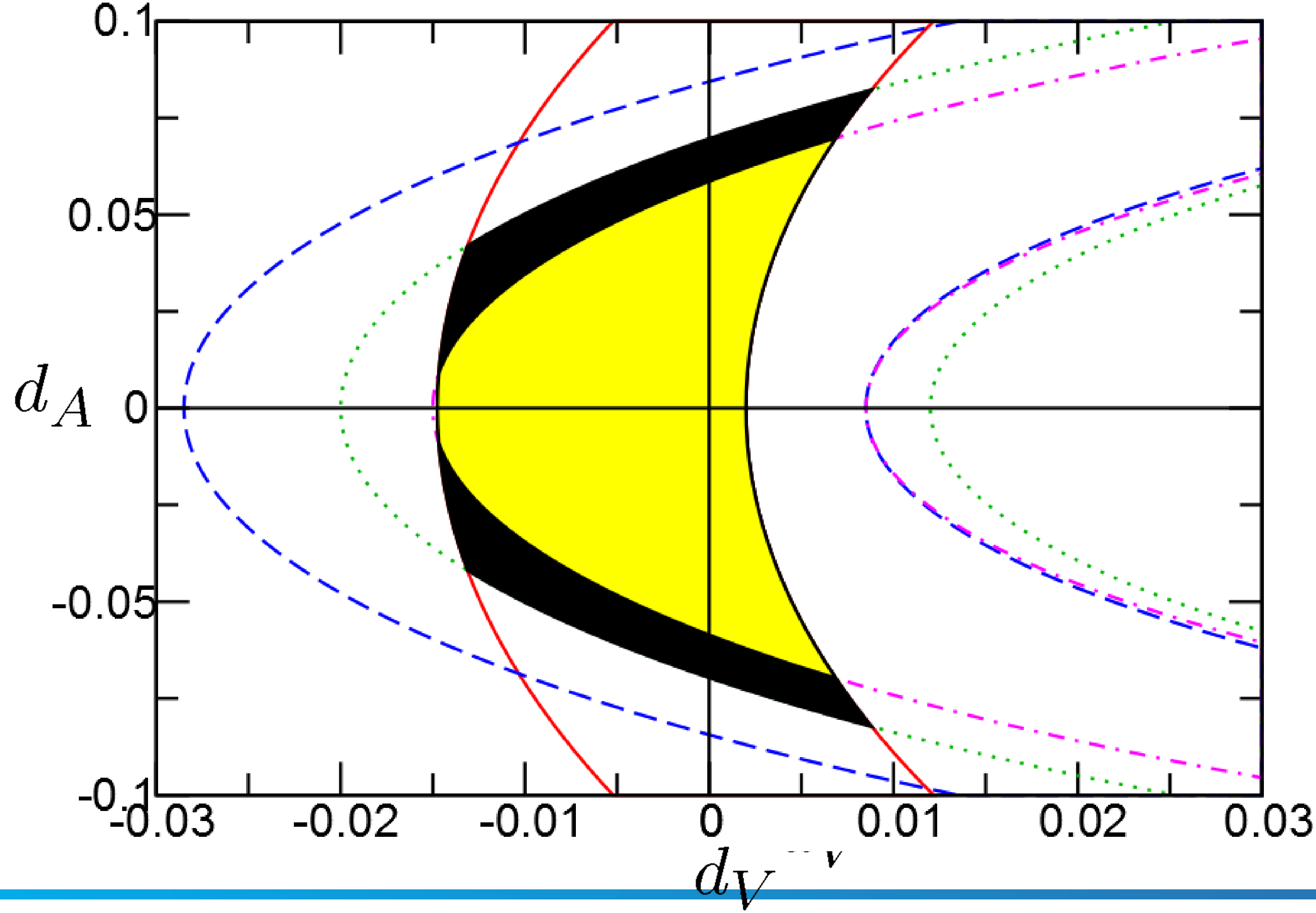
➤Teva + LHC7



➢ Teva + LHC7 + ATLAS 8 + CMS 8



➢ Teva + LHC7 + ATLAS 8 + CMS 8



Ⅳ Discussion and Summary

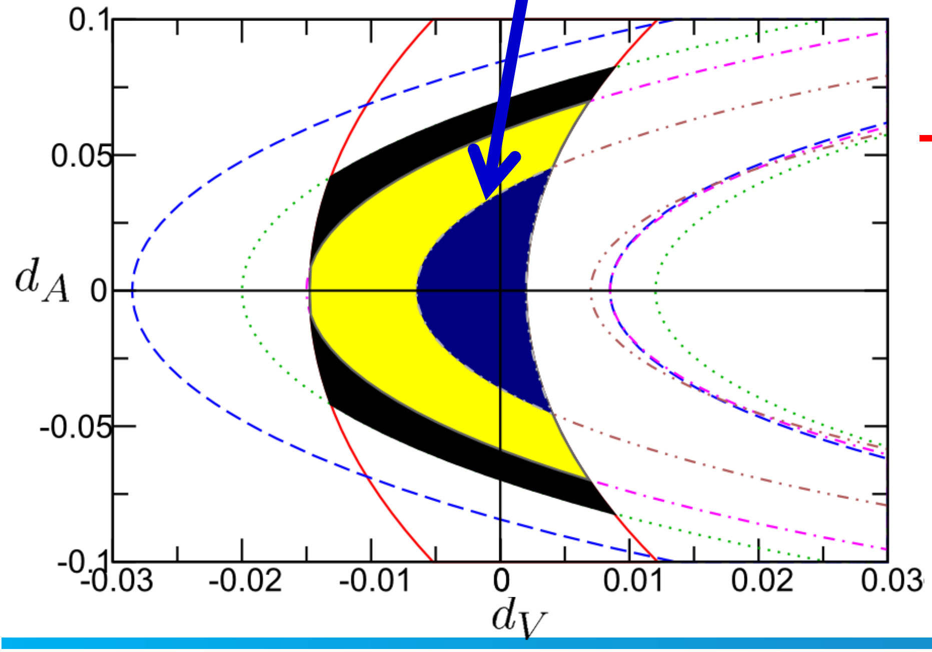
Discussion(1)

– LHC14 data (Virtual data Analysis)

$$\sigma(\sqrt{s} = 14\text{TeV}) = 920 \pm 46 \text{ pb}$$

5% error

Theoretical value(NNLO)



– The allowed area could get almost quarter size, if the 5% level error were possible.

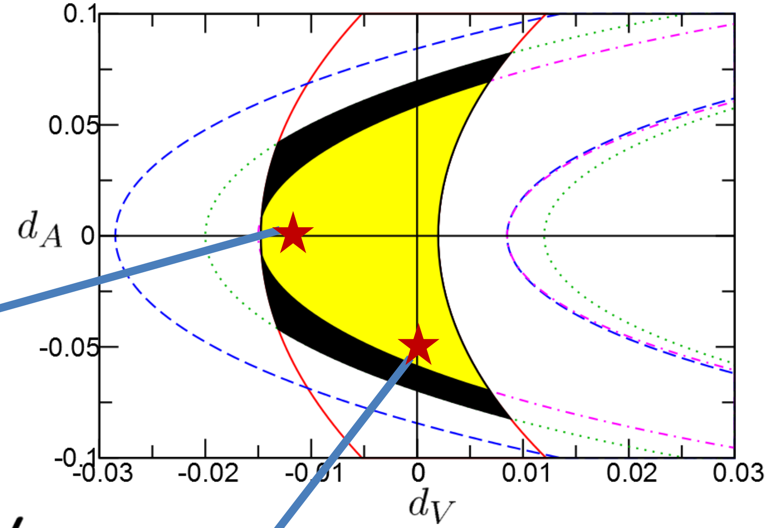
➢ Discussion(2)

– **CMDM**

$$d_V \equiv \frac{\sqrt{2} v m_t}{\Lambda^2} Re(\alpha_{uG\phi}) \sim -0.01$$

$\longrightarrow$ **More than** $\Lambda \sim 2.5\mathrm{TeV}$

$\mathrm{Re}(\alpha_{uG\phi}) \sim \mathcal{O}(1)$



– **CEDM**

$$d_A \equiv \frac{\sqrt{2} v m_t}{\Lambda^2} Im(\alpha_{uG\phi}) \sim |0.05|$$

$\longrightarrow$ **More than** $\Lambda \sim 1\mathrm{TeV}$

$\mathrm{Im}(\alpha_{uG\phi}) \sim \mathcal{O}(1)$

Summary

- Focusing on the top-pair production

  General extension of top-gluon interaction was probed based on the Effective Lagrangian.

- Constraints on d_V and d_A

  ✓ Chromo-Magnetic-Dipole-Moment d_V

  - relatively-stronger constraint is given.
  - d_V is negative?

Discussion and Summary

- ✓ **Chromo-Electric-Dipole-Moment** d_A
  - › **much stronger constraint is not given.**
  - › d_A **induce CP-violation** $\leftarrow$ **Asymmetry？**

– **Future**

- ✓ **14 TeV LHC might give much stronger constraints on d_V and d_A .**

Thanks!

Backup

CMDM and CEDM in the SM

- **CMDM**
  - **generated at one-loop level as both QCD corrections and EW corrections in the SM.**
    - ✓ **QCD corrections were taken into account in our analysis.**
    - ✓ **EW corrections : $O(10^{-4})$**

      ← Careful handling might be needed for LHC14.

CMDM and CEDM in the SM

- **CEDM**
  - **only arise at three-loop level through CP-violating electroweak interactions in the SM.**

    ← **Safely neglectable.**