

*Imposing LHC Constraints on the Combined  
Anomaly and  $Z'$ -Mediation Mechanism of  
Supersymmetry Breaking*

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PHENO 2017, 8-10 May, U of Pittsburgh, USA

# SUSY Breaking

- ❖ Supersymmetry is a symmetry between a fermion and a boson:  
 $Q | \text{Boson} \rangle = | \text{Fermion} \rangle$  ;  $Q | \text{Fermion} \rangle = | \text{Boson} \rangle$ .
- ❖ No electronic superpartner ‘selectron’ observed  $\Rightarrow$  SUSY must be broken.
- ❖ Schematic structure of SUSY breaking:

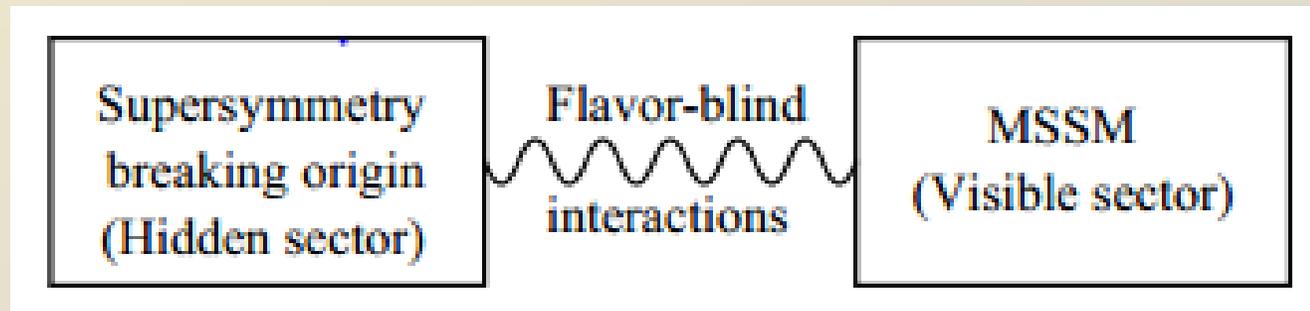


Image taken from S. Martin  
arXiv:hep-ph/9709356v6

# SUSY Breaking

- ❖ To observe new particles at LHC we must know how the supersymmetry breakdown is “communicated”.
  
- ❖ Several possible SUSY breaking mediation mechanisms:
  - a) Planck-scale-mediated supersymmetry breaking (PMSB)
  - b) Gauge-mediated supersymmetry breaking (GMSB)
  - c) Extra-dimensional supersymmetry breaking (“XMSB”)
  - d) Anomaly-mediated supersymmetry breaking (AMSB)

# Previous work (2008)

“Z'-mediated Supersymmetry Breaking”

PRL **100** 041802 (2008) [arXiv:0710.1632]

“Aspects of Z'-mediated Supersymmetry Breaking”

PRD **77** 085033 (2008) [arXiv:0801.3693]

Paul Langacker, Gil Paz, Lian-Tao Wang, Itay Yavin

# Motivation for $Z'$ - Mediation

- ❖ A new  $U(1)'$  gauge symmetry is introduced under which all fields are charged.
- ❖ This  $U(1)'$  gauge group couples to both the visible and hidden sectors.
- ❖ Gives a possible solution of “ $\mu$ -problem”.

# The $Z'$ Mediation

❖ The schematic diagram of  $Z'$ -mediation:

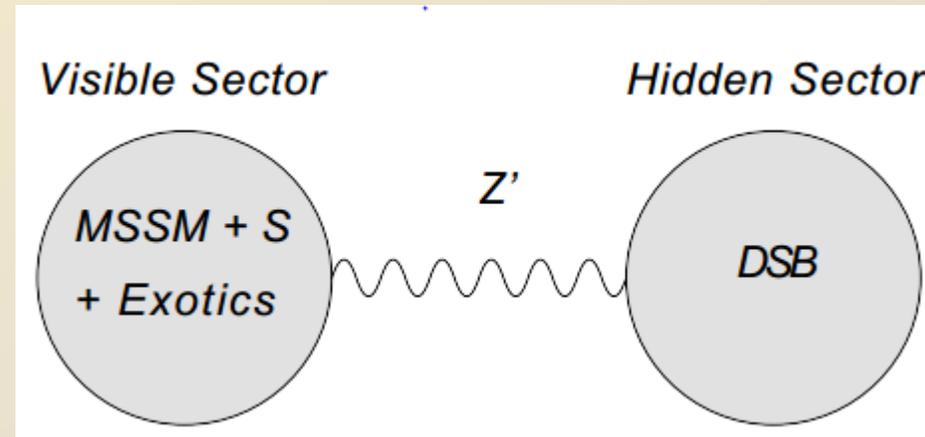
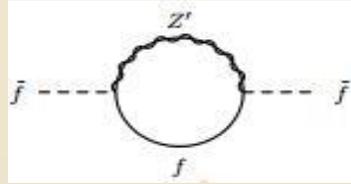


Image taken from Langacker et.al  
PRL 100 041802 (2008)

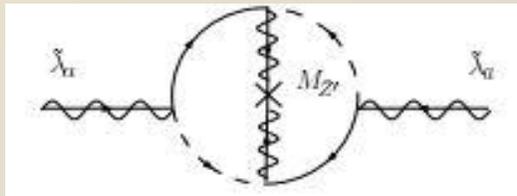
# The $Z'$ Mediation

- ❖ Scalars get a mass at one loop



$$m_{\tilde{f}_i}^2 \sim g_{Z'}^2 Q_{f_i}^2 \frac{M_{\tilde{Z}'}^2}{16\pi^2} \log\left(\frac{\Lambda_S}{M_{\tilde{Z}'}}\right)$$

- ❖  $SU(3)_C \times SU(2)_L \times U(1)_Y$  gauginos get mass at two loops



$$M_a \sim g_{Z'}^2 g_a^2 \frac{M_{\tilde{Z}'}}{(16\pi^2)^2} \log\left(\frac{\Lambda_S}{M_{\tilde{Z}'}}\right)$$

# The $Z'$ Mediation(2008)

## ❖ Ratio of masses

$$\frac{m_{\tilde{f}_i}}{M_a} \sim \frac{M_{\tilde{Z}'}}{4\pi} / \frac{M_{\tilde{Z}'}}{(4\pi)^4} = (4\pi)^3 \sim 1000$$

## ❖ LEP direct searches suggest EW-ino $> 100$ GeV

## ❖ Two options:

1) Gauginos at EW scale ( $\sim 100 - 1000$  GeV)

$\Rightarrow$  heavy scalars  $\sim 100$  TeV  $\Rightarrow M_{\tilde{Z}'} \sim 1000$  TeV

$\Rightarrow$  Fine tuning needed

# The $Z'$ Mediation

2) Scalars at EW scale ( $\sim 100 - 1000$  GeV)

$\Rightarrow$  gauginos too light, must acquire mass from other mechanism

e.g

Combine “Anomaly &  $Z'$  mediation”

- We will follow the work done by de Blas et. al. in JHEP 1001 037 (2010) [arXiv:0911.1996]

# Previous work (2009)

“Combining Anomaly and  $Z'$  Mediation of Supersymmetry Breaking”

JHEP **1001** 037 (2010) [arXiv:0911.1996]

Jorge de Blas, Paul Langacker, Gil Paz, Lian-Tao Wang

# Some specifics of The $Z'$ Model

- ❖ The  $U(1)'$  charges are family universal.
- ❖ The  $\mu$  term is replaced by a SM singlet superfield  $S$  which is charged under  $U(1)'$ , such that the superpotential term  $SH_uH_d$  is allowed.
- ❖ To cancel the anomalies the following “exotic” matters are introduced:
  - a) 3 pairs of colored,  $SU(2)_L$  singlet exotics  $D, D^c$  with hypercharge  $Y_D = -1/3$  and  $Y_{D^c} = 1/3$ .
  - b) 2 pairs of uncolored,  $SU(2)_L$  singlet exotics  $E, E^c$  with hypercharge  $Y_E = -1$  and  $Y_{E^c} = 1$ .

# Some specifics of The $Z'$ Model

- ❖ The exotic fields can couple to  $S$ , namely the superpotential terms  $SDD^c$  and  $SEE^c$  are allowed.
- ❖ The superpotential is given by

$$W = y_u H_u Q u^c + y_d H_d Q d^c + y_e H_d L e^c + y_\nu H_u L \nu^c + \lambda S H_u H_d + y_D S \left( \sum_{i=1}^3 D_i D_i^c \right) + y_E S \left( \sum_{j=1}^2 E_j E_j^c \right)$$

# Anomaly Mediated SUSY Breaking (AMSB)

- ❖ Scalars get mass at 2-loops

$$m^2 = -\frac{1}{4} \left( \frac{\partial \gamma}{\partial g} \beta_g + \frac{\partial \gamma}{\partial y} \beta_y \right) m_{3/2}^2$$

- ❖ Gauginos get mass at 1-loop

$$M_a = \frac{\beta_g}{g} m_{3/2}$$

Where  $\gamma = d \ln Z_Q / d \ln \mu$ ,  $\beta_g = dg / d \ln \mu$ ,  $\beta_y = dy / d \ln \mu$

- ❖ Pure anomaly mediation has ‘negative’ slepton mass problem

## Combining $Z'$ and anomaly mediation

- ❖ Avoid fine tuning for  $Z'$  mediation
- ❖ Addresses the negative ‘slepton’ mass problem of anomaly mediation due to small Yukawa coupling.
- ❖ Comparing the scalar masses for two cases we

find

$$M_{\tilde{Z}'} \sim \frac{m_{3/2}}{4\pi}$$

# Specific Illustration point I: Inputs(2009)

❖ Dimensionful input parameters:

$$m_{3/2} = 80 \text{ TeV}, \quad M_{\tilde{Z}'} = 14 \text{ TeV}, \quad \Lambda_{\text{SUSY breaking}} = 10^6 \text{ TeV}$$

❖ Dimensionless input parameters:

a)  $U(1)'$  charges of  $H_u$  and  $Q$ ;  $Q_{H_u} = -\frac{2}{5}, \quad Q_Q = -\frac{1}{3}$

b) The Yukawa (superpotential) couplings at EW scale:

$$y_t = 1, \quad y_b = 0.5, \quad y_\tau = 0.294, \quad \lambda = 0.1, \quad y_D = 0.3, \quad y_E = 0.5$$

❖ The  $U(1)'$  gauge coupling at  $\Lambda_S$ :

$$g_{Z'} = 0.45$$

# Specific Illustration point I: Results(2009)

- ❖ Higgs particles including one loop radiative corrections:

$m_{h^0}$	$m_{H_1^0}$	$m_{H_2^0}$
0.138 TeV	2.79 TeV	4.78 TeV

- ❖ Gauginos

Wino	Gluino	Bino
0.279 TeV	0.399 TeV	1.17 TeV

- ❖ Stops

$\tilde{t}_1$	$\tilde{t}_2$
0.695 TeV	3.16 TeV

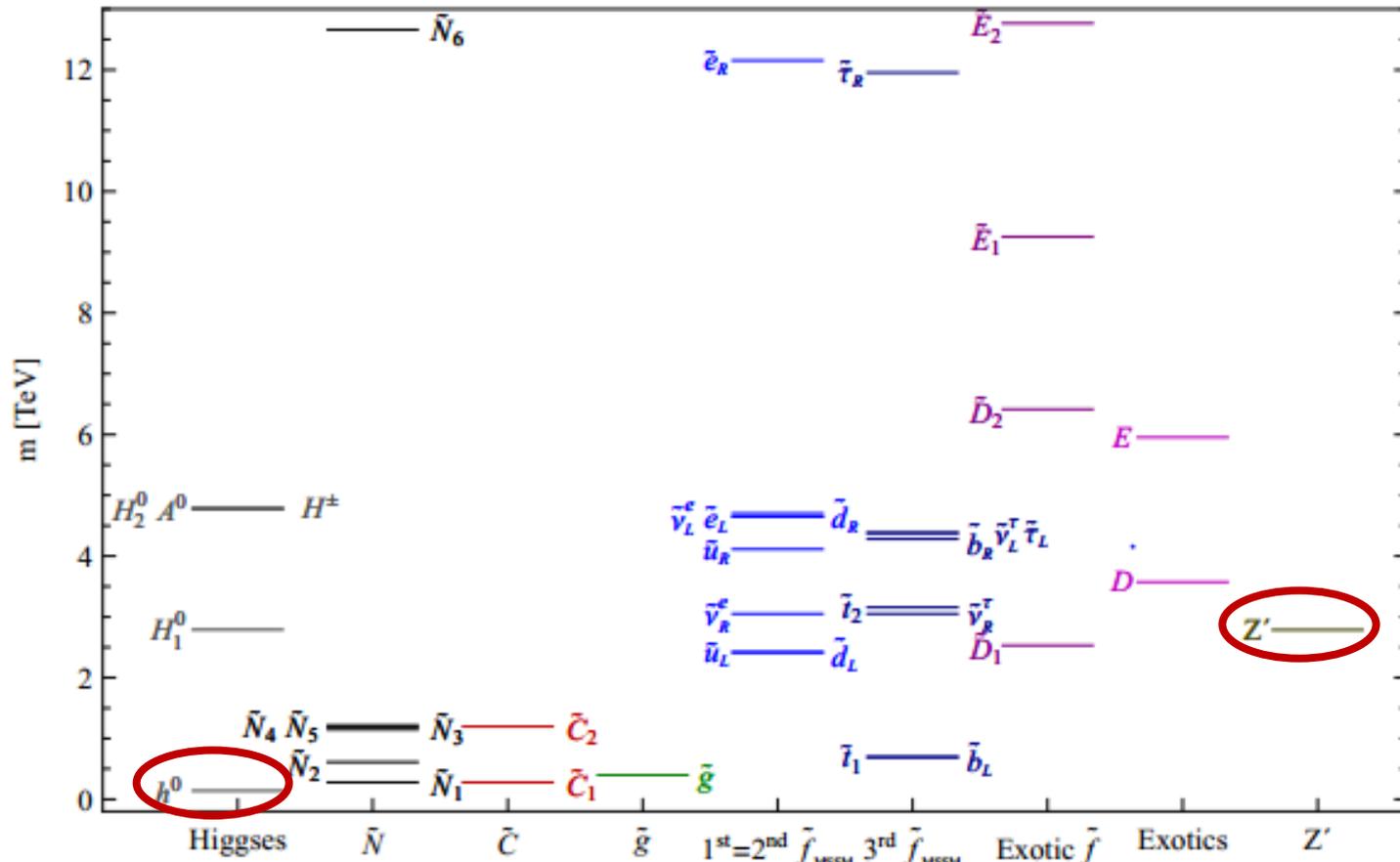
- ❖  $Z'$  gauge boson  $M_{Z'}=2.78$  TeV

- ❖  $M_{Z'}=5.68$  TeV and  $m_{h^0} = 0.142$  TeV



Illustration point II

# Results(2009)



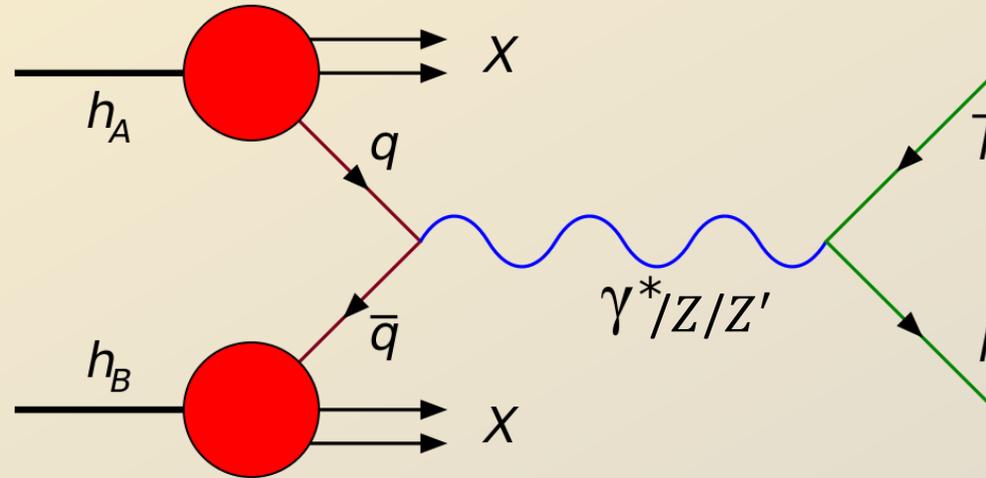
Spectrum calculation  
for the illustration point

# Present work

“Imposing LHC constraints on combined Anomaly and  $Z'$  Mediation mechanism”

Joydeep Roy, Gil Paz

# Z' Production & Decay



❖ Leading Order (LO) Cross-section at LHC relevant for Drell-Yan process

$$\sigma_{l^+l^-}^{LO} = \frac{\pi}{48s} [c_u w_u(s, M_{Z'}^2) + c_d w_d(s, M_{Z'}^2)]$$

Carena et. al PRD **70** 093009 (2004)  
Accomando et. al PRD **83** 075012 (2011)

# Z' Production & Decay

$$\sigma_{l^+l^-}^{LO} = \frac{\pi}{48s} [c_u w_u(s, M_{Z'}^2) + c_d w_d(s, M_{Z'}^2)]$$

with

$$c_{u,d} = \frac{g_{Z'}^2}{2} [(g_V^{u,d})^2 + (g_A^{u,d})^2],$$

Vector/Axial couplings  $\longrightarrow$   $g_{V,A}^f = \epsilon_L^f \pm \epsilon_R^f$   $\longleftarrow$  Chiral couplings

and  $w_{u,d} = \int_0^1 dx_1 f_{u,d}(x_1) \int_0^1 dx_2 f_{\bar{u},\bar{d}}(x_2) \delta\left(\frac{M_{Z'}^2}{s} - x_1 x_2\right)$



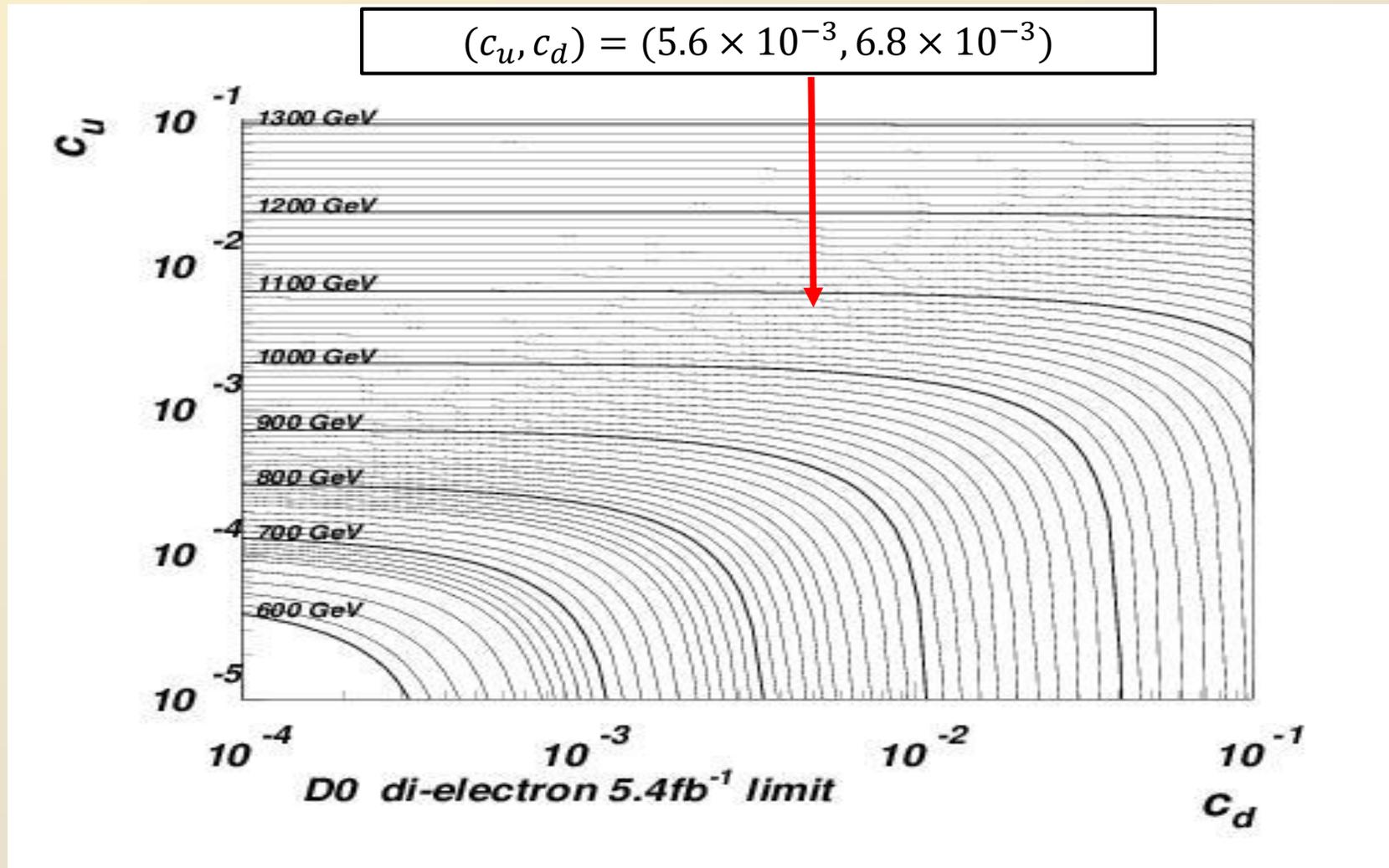
Hadronic structure functions

# Constraints

- ❖ All the model dependence of cross-section is contained in  $C_u$  and  $C_d$ .
- ❖ Collider limits on  $Z'$  mass can be obtained by contours in  $C_u$ -  $C_d$  plane for benchmark models.
- ❖ For  $g_{Z'} = 0.45$ ,  $(C_u, C_d) = (5.6 \times 10^{-3}, 6.8 \times 10^{-3})$

# 2010 Constraints

Tevatron limits (2010)



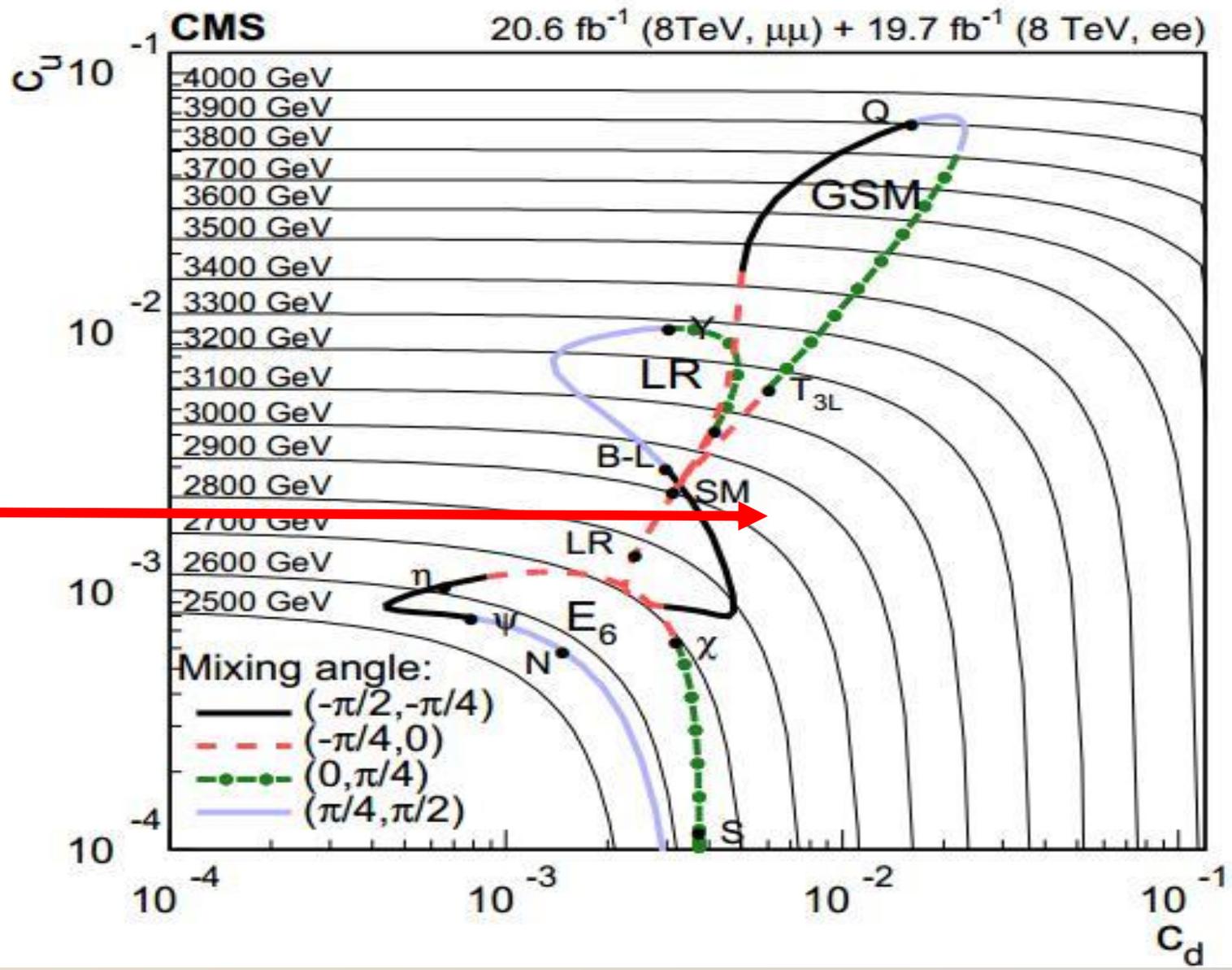
$M_{Z'} = 2.78 \text{ TeV}$

Data taken from D0 Collaboration (Phys.Lett. B 695 (2011)) and Image taken from Accomando et. al PRD **83** 075012 (2011)

# Current Constraints

$M_{Z'} = 5.68 \text{ TeV}$

$M_{Z'} = 2.78 \text{ TeV}$



CMS limits (2014)

Image taken from:  
JHEP 04 (2015) 025

# Outlook and future work

- ❖ Adjust the parameters  $g_{Z'}$  and  $\langle S \rangle$

$$c_{u,d} = \frac{g_{Z'}^2}{2} [(g_V^{u,d})^2 + (g_A^{u,d})^2]$$

$$M_{Z'} \approx \sqrt{2} g_{Z'} Q_S \langle S \rangle$$

- ❖ Tension in choosing suitable  $g_{Z'}$  and  $\langle S \rangle$ , to be in the experimentally allowed region.

# Outlook and future work

## Done

- ❖ Imposed LHC constraints on the  $Z'$ -boson mass.

## To be Done

- ❖ Impose LHC constraints on gluinos and stops masses.
- ❖ Use observed Higgs mass (125 GeV) as an input, rather than predicted mass (138 GeV) in 2009 for this model.

# Outlook and future work

