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

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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 ⇒ SUSY must be broken.

- ❖ Schematic structure of SUSY breaking:

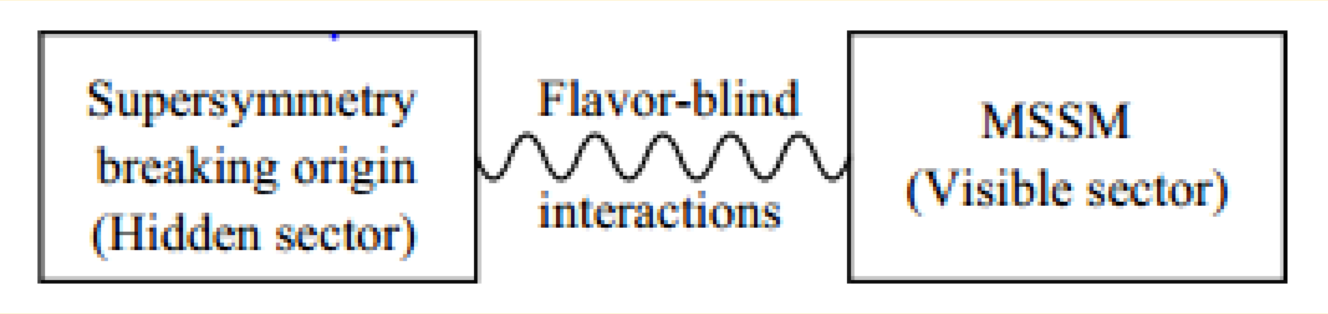


Image taken from S. Martin arXiv:hep-ph/9709356v6

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 $\mathrm{U(1)'}$gauge symmetry is introduced under which all fields are charged.

- This $\mathrm{U(1)'}$ gauge group couples to both the visible and hidden sectors.

- Gives a possible solution of “μ-problem”.

The Z' Mediation

- The schematic diagram of Z'-mediation:

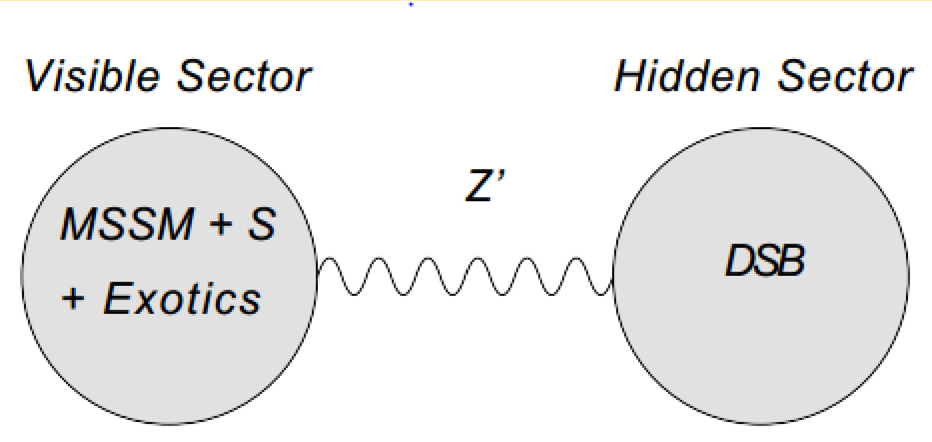
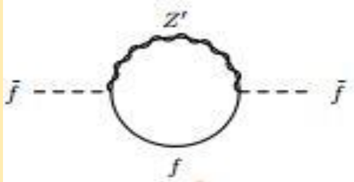


Image taken from Langacker et.al
PRL 100 041802 (2008)

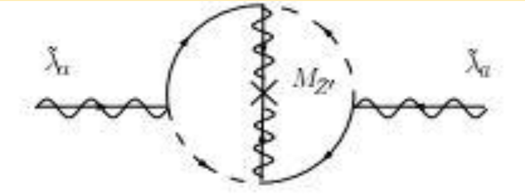
The Z' Mediation

- 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 ~ 100 TeV $\Rightarrow M_{\tilde{Z}'}$ ~ 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 μ 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 $\gamma = d \ln Z_Q / d \ln \mu$, $\beta_g = \mathrm{dg} / d\ln \mu$, $\beta_y = \mathrm{dy} / d\ln \mu$

- 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; $\quad Q_{H_u} = -\frac{2}{5}, \quad Q_Q = -\frac{1}{3}$

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

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

- The $U(1)'$ gauge coupling at Λ_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

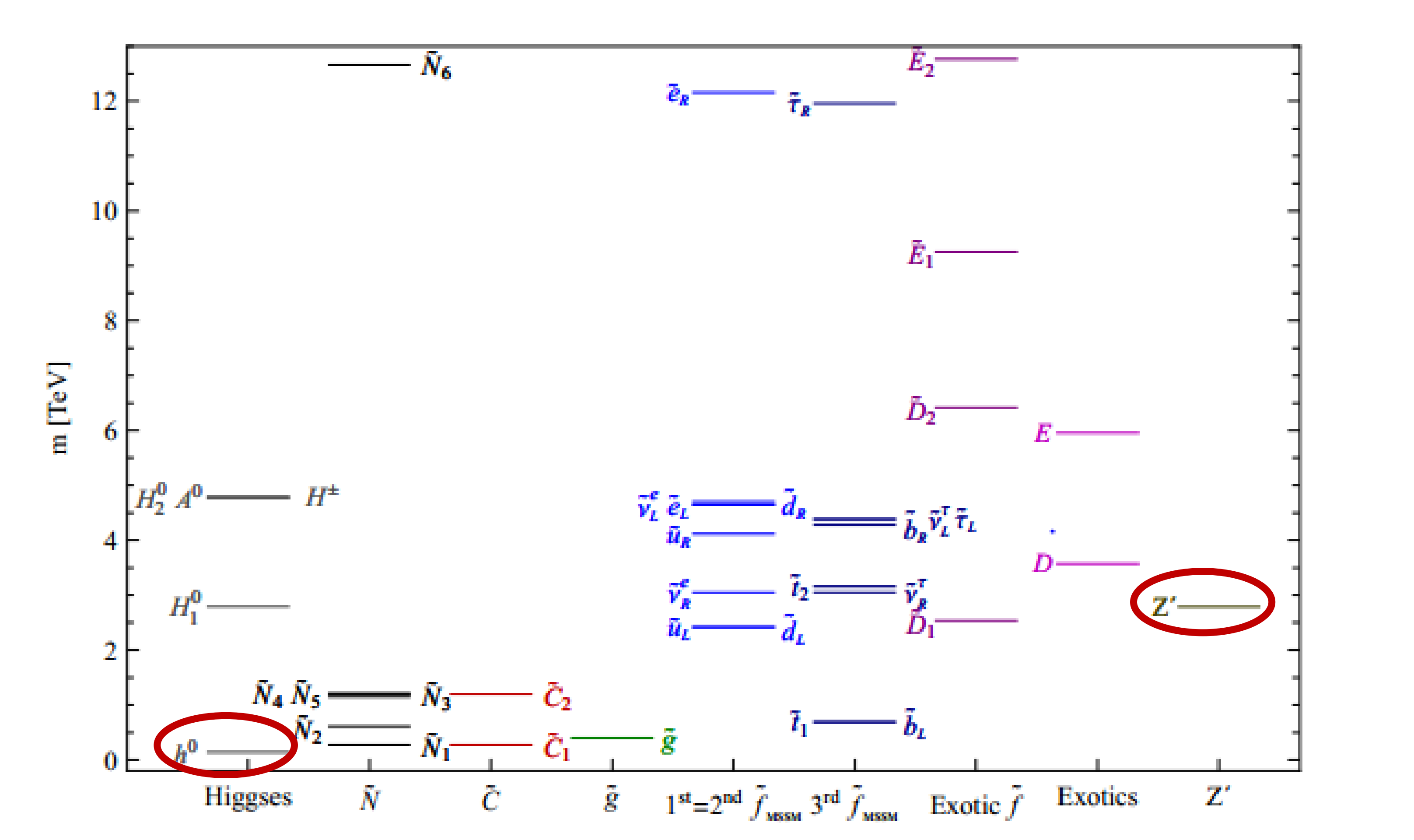
- Stops

$\tilde{t}_1$	$\tilde{t}_2$
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)



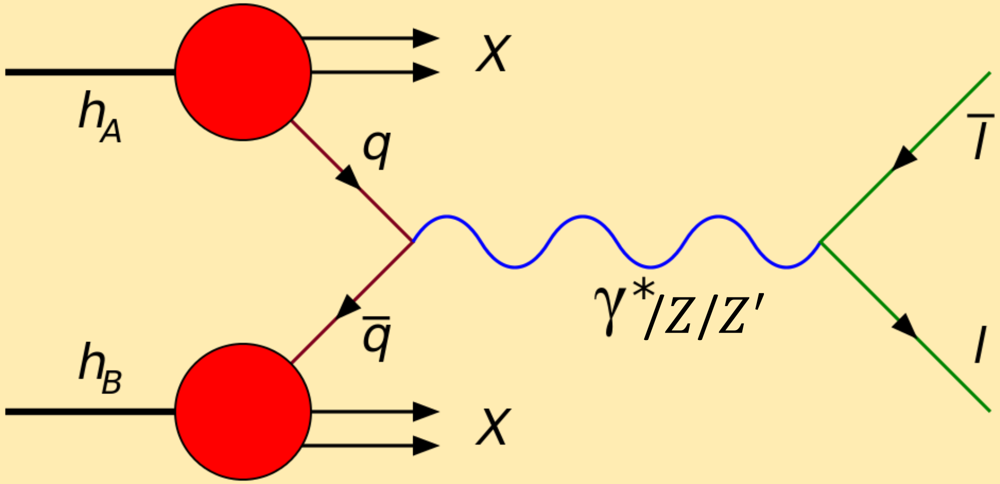
Spectrum calculation
for the illustration point

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

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

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

Z' Production & Decay

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

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

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

and $$w_{u,d} = \iint_0^1 \left[dx_1 dx_2 f_{u,d}(x_1) f_{\bar{u},\bar{d}}(x_2) + (x_1 \leftrightarrow x_2)\right] \delta\left(\frac{M_{Z'}^2}{s} - x_1 x_2\right)$$

↑ Hadronic structure functions

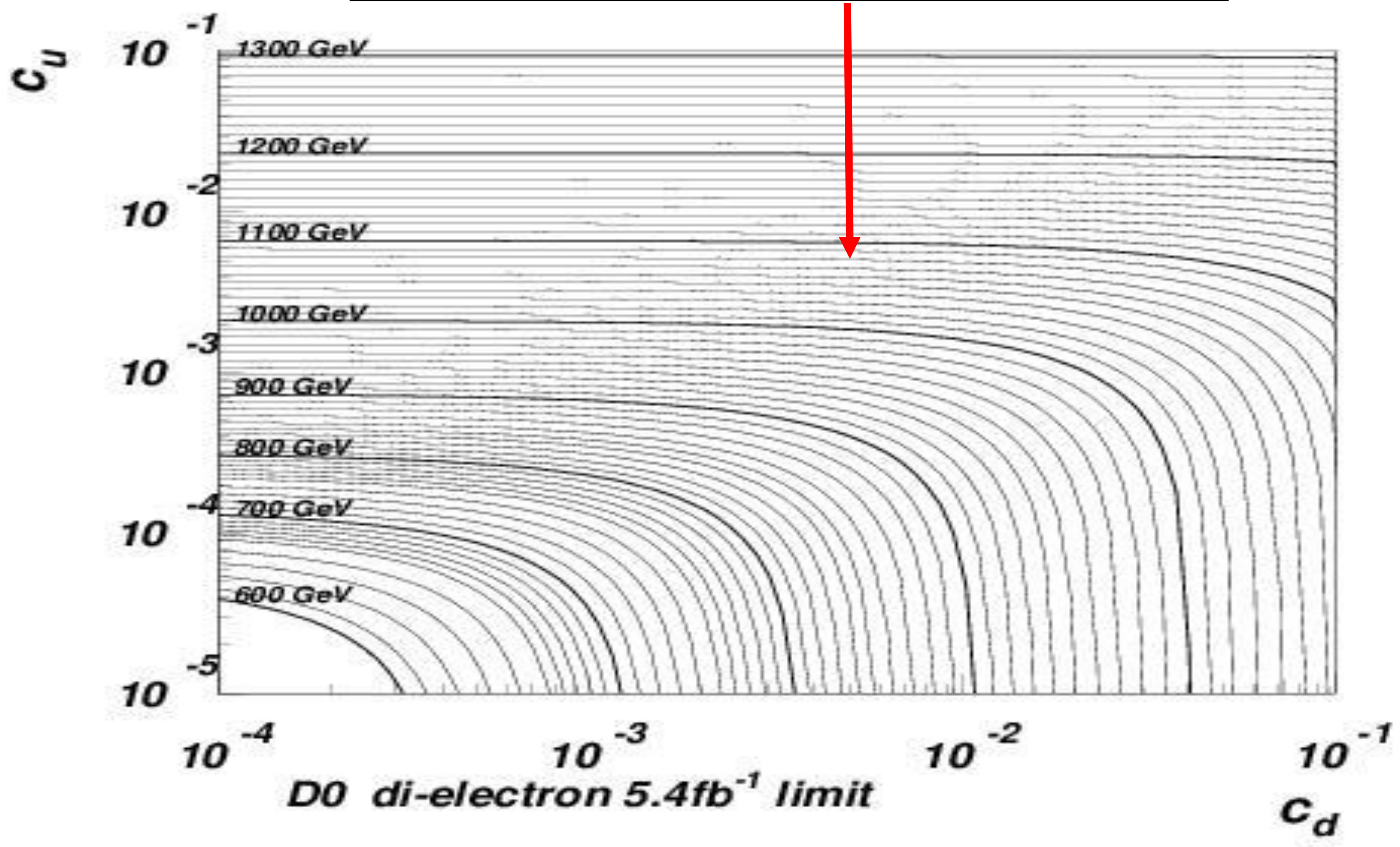
Constraints

- 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)

$(c_u, c_d) = (5.6 \times 10^{-3}, 6.8 \times 10^{-3})$

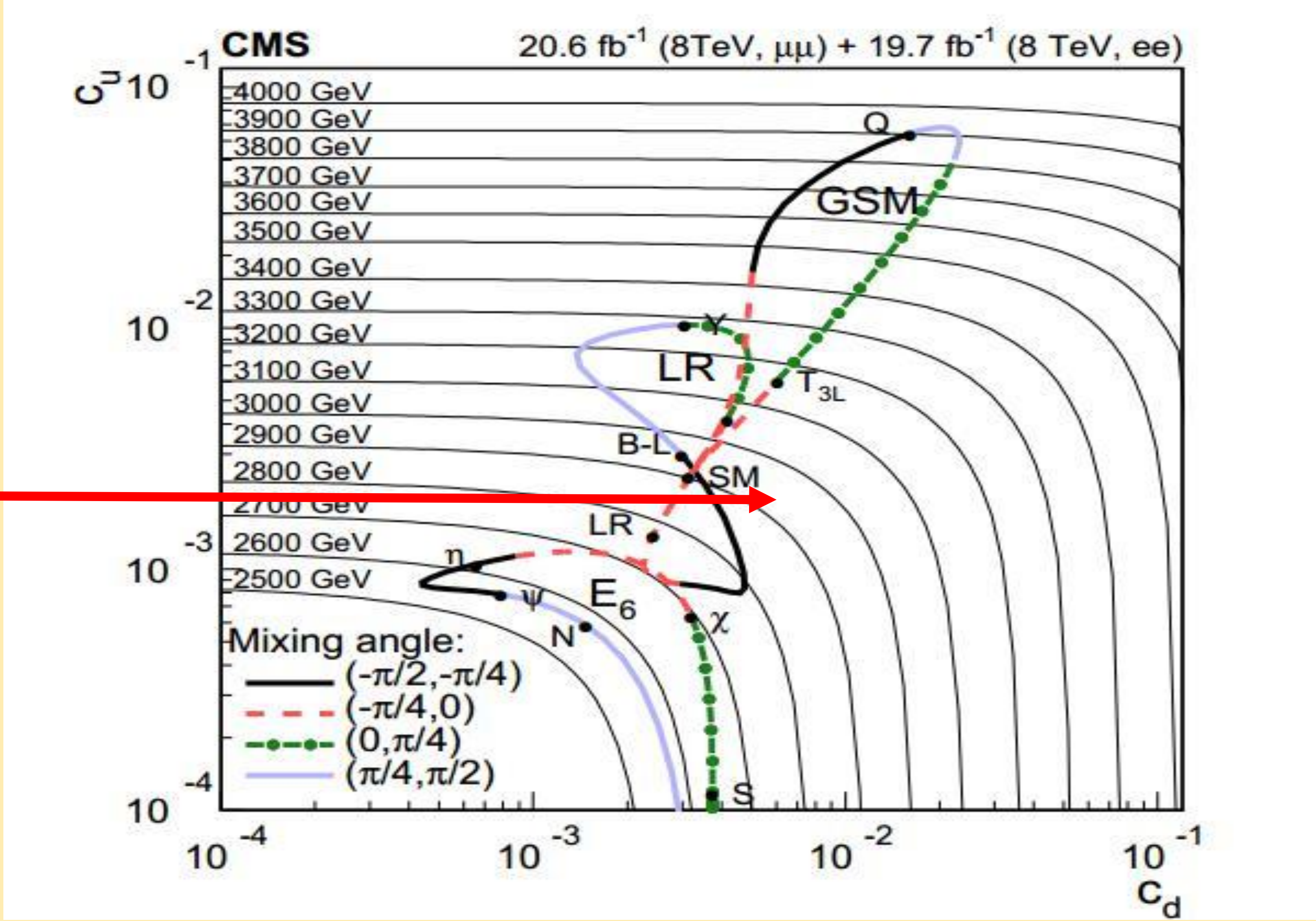


$M_{Z'} = 2.78$ TeV

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

Current Constraints

$M_{Z'} = 5.68$ TeV



$M_{Z'} = 2.78$ TeV

CMS limits (2014)

Image taken from:
JHEP 04 (2015) 025

Preliminary Results

Using stop mass constraints

- Parameters that determine the mass spectrum are

$$\lambda,\ \tan\beta,\ g_{Z'},\ \langle S\rangle,\ A_t,\ m^2_{\tilde{Q}_3},\ m^2_{\tilde{t}^c}$$

- Current constraint of stop mass is > 950 GeV.
  (Ref: ATLAS 'inspirehep.net/record/1589903')

- Perform parameter scan to satisfy this constraint

Preliminary Results

Using stop mass constraints

Parameters	λ	$\tan\beta$	$g_{Z'}$	$\langle S \rangle$ (TeV)	A_t(TeV)	$m^2_{\tilde{Q}_3}$(TeV)	$m^2_{\tilde{t}^c}$(TeV)
Lower limit	0.01	9	0.25	1.61	0.01	1.61	2.01
Upper limit	0.27	49	0.8	9.61	20.51	9.61	24.01

Parameter limits obtained from the parameter scan

Outlook and future work

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

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

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

- 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.

❖ Imposed LHC constraints on stops masses.

To be Done

❖ Impose LHC constraints on gluinos

❖ Use observed Higgs mass (125 GeV) as an input, rather than predicted mass (138 GeV) in 2009 for this model.

Outlook and future work