Discovering a Z' at the LHC with 7 TeV

Elena Accomando, Sasha Belyaev , Luca Fedeli, SFK and Claire Shepherd-Themistocleous

(All unpublished results are preliminary)

Steve King, RHUL, 12th May, 2010

What is a Z'?

To an LHC experimentalist: a resonance "bump" more massive that the Z which can be observed in pp → e^+e^- +X or pp→ $\mu^+ \mu^-$ +X

To a phenomenologist: a new massive electrically neutral, colourless boson (being its own antiparticle) which couples to quarks and leptons

To a theorist: it could be many things….

It is useful to classify the Z' according to its spin (even though measuring the spin will require high statistics):

Spin-0 (e.g. sneutrino in R-parity violating SUSY)

Spin-2 (e.g. KK excited graviton as in Randall-Sundrum)

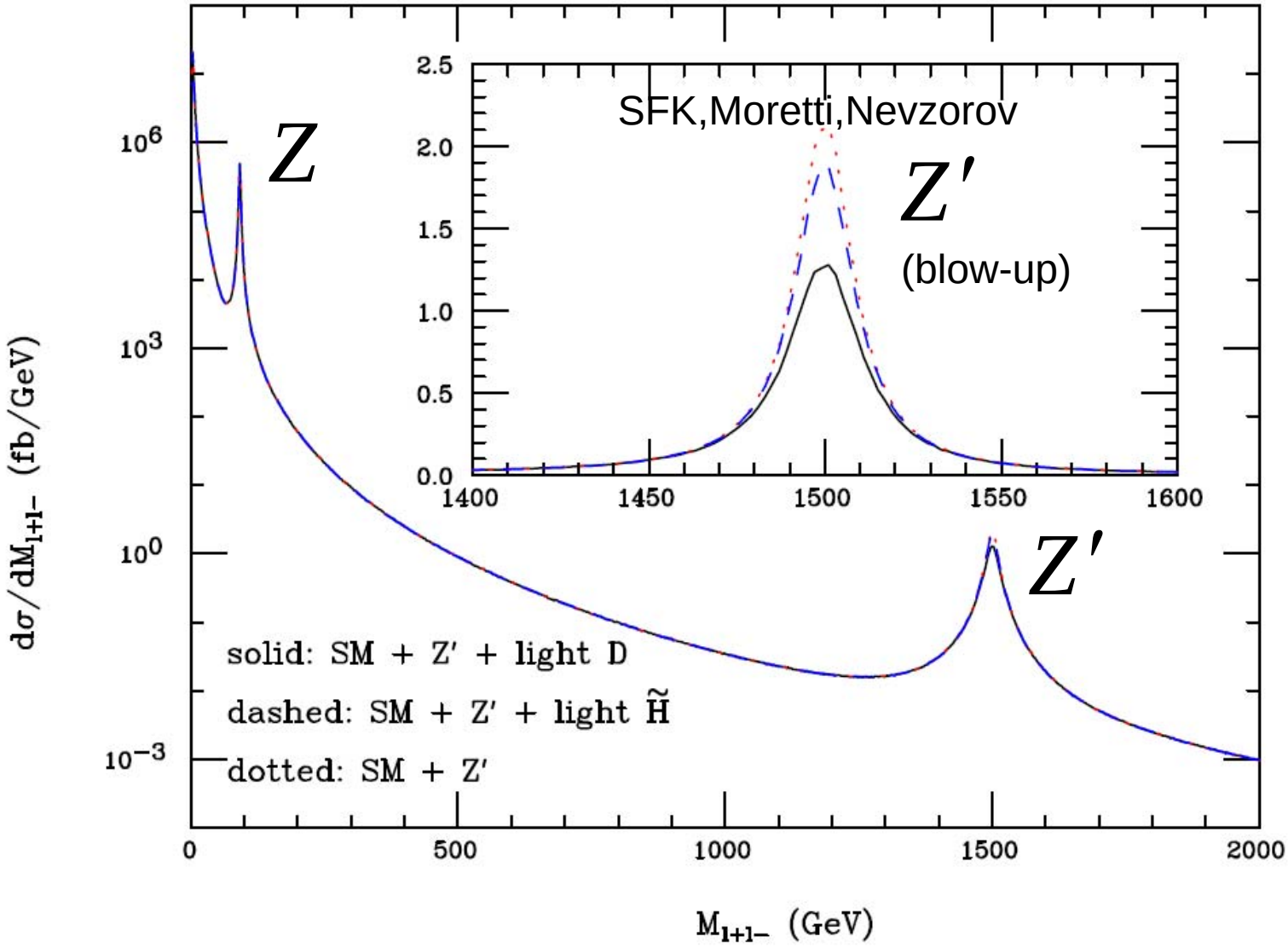
Spin-1 (The only cases considered here):-

a) A new U(1)' gauge boson (e.g. from E_6 or L-R models)

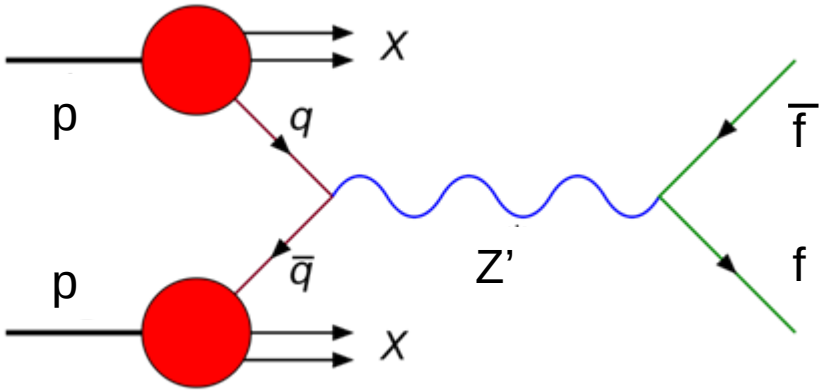
b) KK excited Z bosons (e.g. from Higgless models)

c) Techni-rho bound states (e.g. from Walking TC models)

Cross section for Drell-Yan production at the LHC 14 TeV



Drell-Yan production cross-section



$$\sigma_{f\bar{f}} \equiv \sigma(pp \to Z'X \to f\bar{f}X)$$

Narrow width approximation

$$\sigma_{f\bar{f}} \approx \int_{(M'_Z-\Delta)^2}^{(M'_Z+\Delta)^2} \frac{d\sigma}{dM^2}(pp \to f\bar{f})dM^2 \approx \left(\frac{1}{3}\sum_{q=u,d}\left(\frac{dL_{q\bar{q}}}{dM^2_{Z'}}\right)\hat{\sigma}(q\bar{q} \to Z')\right) \times Br(Z' \to f\bar{f})$$

Simple structure

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

Carena, Daleo, Dobrescu, Tait

Model dependent

$$\left\{ \begin{array}{l} c_u \propto \hat{\sigma}(u\bar{u} \to Z') \times Br(Z' \to l^+l^-) \\ c_d \propto \hat{\sigma}(d\bar{d} \to Z') \times Br(Z' \to l^+l^-) \end{array} \right\}$$

depend on g' and $g_{V,A}^f$

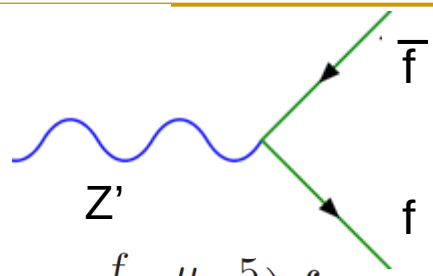
Model independent

$$\left\{ w_u \propto \frac{dL_{u\bar{u}}}{dM^2_{Z'}} \qquad w_d \propto \frac{dL_{d\bar{d}}}{dM^2_{Z'}} \right\}$$

depend on s and $M_{Z'}$

Spin-1 Z'

Feynman rule



Z' coupling to SM fermions f

$$\frac{g'}{2} Z'_\mu \overline{f} (g_V^f \gamma^\mu - g_A^f \gamma^\mu \gamma^5) f$$

In our analysis we assume:

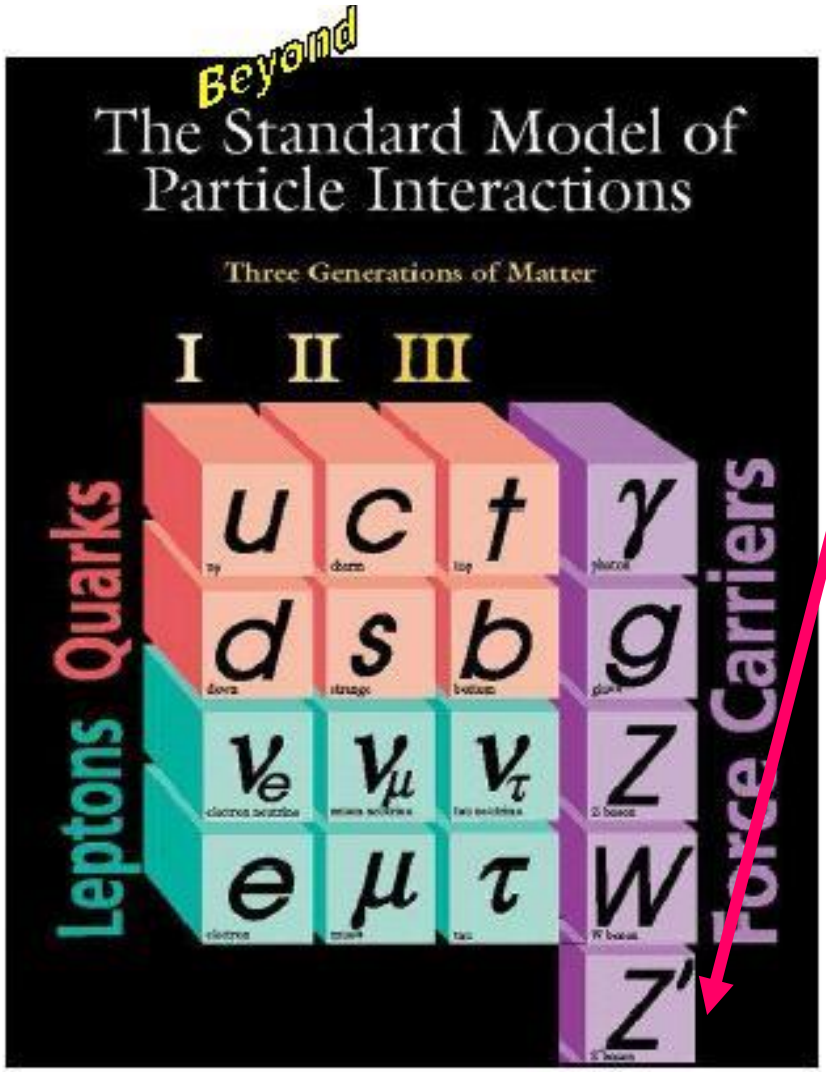
1. Family universal couplings u=c=t, d=s=b, e=μ=τ, $\nu_e=\nu_\mu=\nu_\tau$
2. Right-handed neutrinos, SUSY partners and exotics all have masses > $M_{Z'}$
3. No mass mixing between Z-Z'

Assuming $SU(2)_L$ is respected, the phenomenology of the Z' is described by five charges associated with Q,u_R,d_R,L,e_R (Q,L= quark, lepton left-handed doublets)

However we prefer to use the eight couplings appearing in the Feynman rule: $g_{V,A}^{\ f}$ (f=u,d,e,ν) with the three constraints $g_V^{u,\nu} + g_A^{u,\nu} = g_V^{d,e} + g_A^{d,e}$ and $g_V^{\nu}=g_A^{\nu}$

The gauge coupling constant g' and the Z' mass $M_{Z'}$ are additional parameters

Z' from a U(1)' gauge group



From whence comes the U(1)'?

We consider three possibilities:

(i) $E_6 \rightarrow SO(10) \times U(1)_\psi$
$\rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$
$\rightarrow SM \times U(1)'$
$U(1)' = \cos\theta\, U(1)_\chi + \sin\theta\, U(1)_\psi$

(ii) $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
$\rightarrow SU(2)_L \times U(1)_Y \times U(1)'$
$U(1)' = \cos\phi\, U(1)_R + \sin\phi\, U(1)_{B-L}$

N.B. left-right symmetry implies $\phi = -23^o$
other values are a pheno generalization

(iii) SM-like
$U(1)' = \cos\alpha\, U(1)_L + \sin\alpha\, U(1)_Q$
N.B. $\alpha = -13^o$ in SM

General U(1)' gauge models: couplings

$U(1)'$	Parameter	g_V^u	g_A^u	g_V^d	g_A^d	g_V^e	g_A^e	$g_V^{\nu_L}$	$g_A^{\nu_L}$
E_6	θ								
$U(1)_\chi$	0	0	-0.316	-0.632	0.316	0.632	0.316	0.474	0.474
$U(1)_\psi$	0.5π	0	0.408	0	0.408	0	0.408	0.204	0.204
$U(1)_\eta$	-0.29π	0	-0.516	-0.387	-0.129	0.387	-0.129	0.129	0.129
$U(1)_S$	0.129π	0	-0.129	-0.581	0.452	0.581	0.452	0.516	0.516
$U(1)_I$	0.21π	0	0	0.5	-0.5	-0.5	-0.5	-0.5	-0.5
$U(1)_N$	0.42π	0	0.316	-0.158	0.474	0.158	0.474	0.316	0.316
GLR	ϕ								
$U(1)_R$	0	0.5	-0.5	-0.5	0.5	-0.5	0.5	0	0
$U(1)_{B-L}$	0.5π	0.333	0	0.333	0	-1	0	-0.5	-0.5
$U(1)_{LR}$	-0.128π	0.329	-0.46	-0.591	0.46	0.068	0.46	0.196	0.196
$U(1)_Y$	0.25π	0.833	-0.5	-0.167	0.5	-1.5	0.5	-0.5	-0.5
SM									
$U(1)_{SM}$		0.193	0.5	-0.347	-0.5	-0.04	-0.5	0.5	0.5

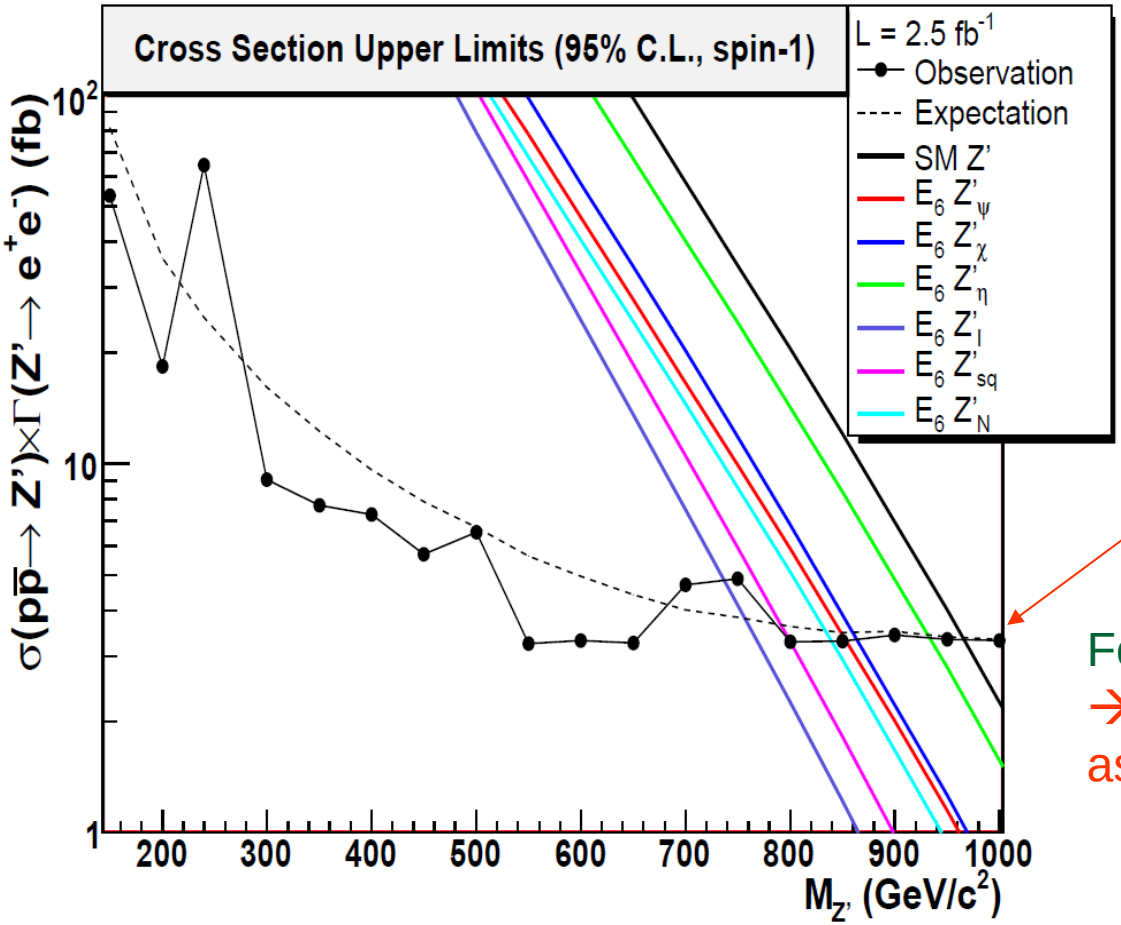
General U(1)' gauge models: predictions/constraints

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

$U(1)'$	$Br(l^+l^-)$	c_u	c_d	c_u/c_d	$\Gamma_{Z'}/M_{Z'}$	Direct limit $M_{Z'}^{\rm D}$	Indirect limit $M_{Z'}^{\rm I}$	Z-Z' mixing limit $\lvert\theta_{ZZ'}\rvert$
E_6 $(g' = 0.462)$								
$U(1)_\chi$	0.0606	$6.46.10^{-4}$	$3.23.10^{-3}$	0.2	0.0117	892	1141[e]	$1.6.10^{-3}$
$U(1)_\psi$	0.0444	$7.90.10^{-4}$	$7.90.10^{-4}$	1	0.0053	878	481[c]	$1.8.10^{-3}$
$U(1)_\eta$	0.0371	$1.05.10^{-3}$	$6.59.10^{-4}$	1.6	0.00636	982	434[c]	$4.7.10^{-3}$
$U(1)_S$	0.0656	$1.18.10^{-4}$	$3.79.10^{-3}$	0.31	0.0117	821	1257[e]	$1.3.10^{-3}$
$U(1)_I$	0.0667	0	$3.55.10^{-3}$	0	0.0106	789	1204[e]	$1.2.10^{-3}$
$U(1)_N$	0.0555	$5.94.10^{-4}$	$1.48.10^{-3}$	0.40	0.00635	861	623[e]	$1.5.10^{-3}$
GLR $(g' = 0.595)$								
$U(1)_R$	0.0476	$4.21.10^{-3}$	$4.21.10^{-3}$	1	0.0247	-	442[e]	-
$U(1)_{B-L}$	0.154	$3.02.10^{-3}$	$3.02.10^{-3}$	1	0.015			
$U(1)_{LR}$	0.0246	$1.39.10^{-3}$	$2.44.10^{-3}$	0.57	0.0207	630	998[e]	$1.3.10^{-3}$
$U(1)_Y$	0.125	$1.04.10^{-2}$	$3.07.10^{-3}$	3.4	0.0235	-	-	-
SM $(g' = 0.74)$								
$U(1)_{SM}$	0.0308	$2.42.10^{-3}$	$3.12.10^{-3}$	0.775	0.0297	1030	1787[c]	9.10^{-4}

CDF Run II Preliminary

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



$$c_u = a - b c_d$$

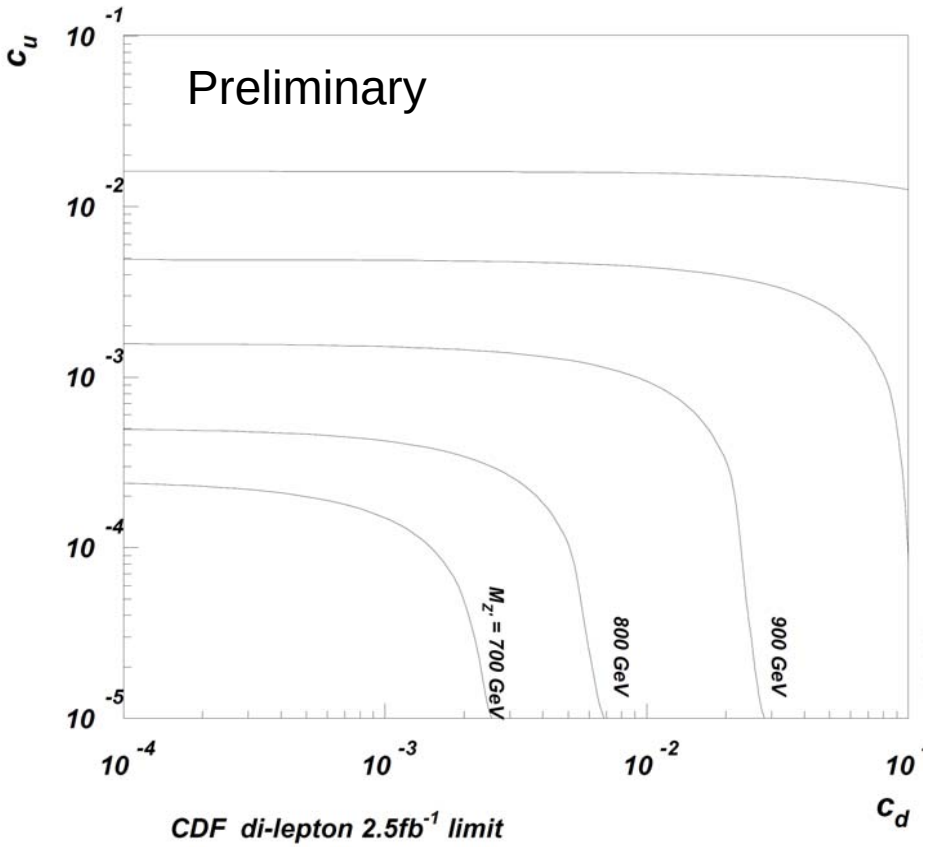
$$a = \frac{48s}{\pi}\frac{\sigma_{l^+l^-}}{w_u}$$

$$b = \frac{w_d}{w_u}$$

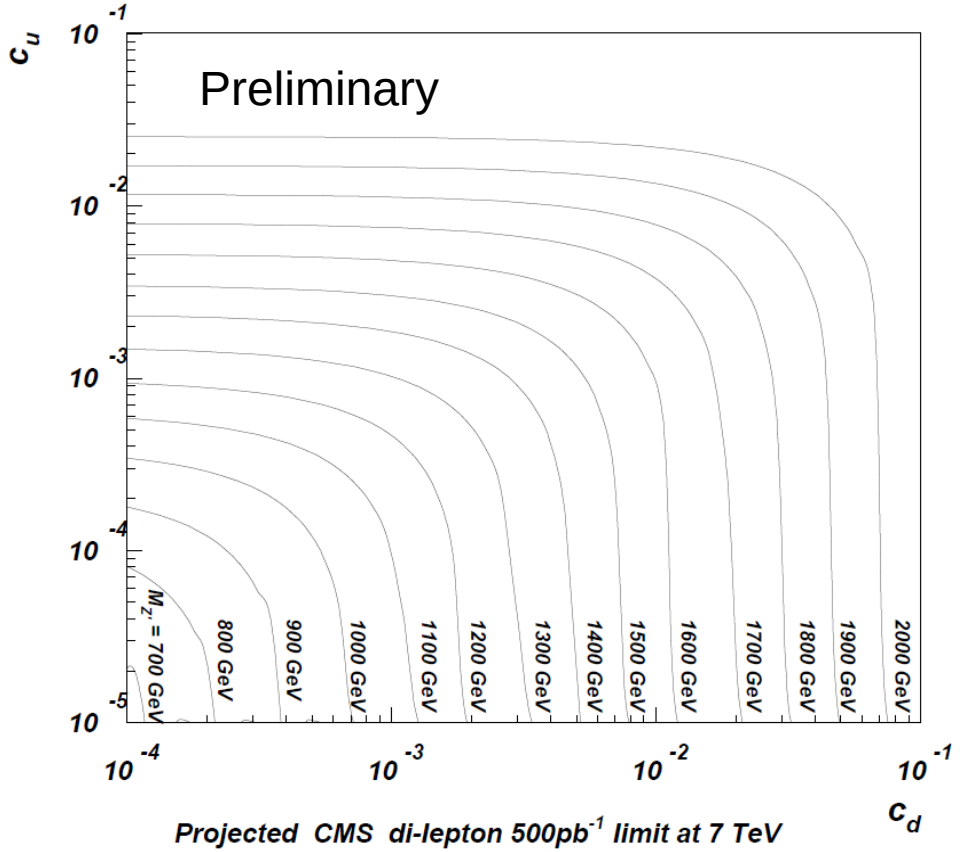
For fixed s, $M_{Z'}$ a,b are known
→ can plot cross-section limit as contours in c_u-c_d plane

Z' mass limit contours in the c_u-c_d plane

Tevatron $p\bar{p}$ $\sqrt{s} = 1.8\ TeV$

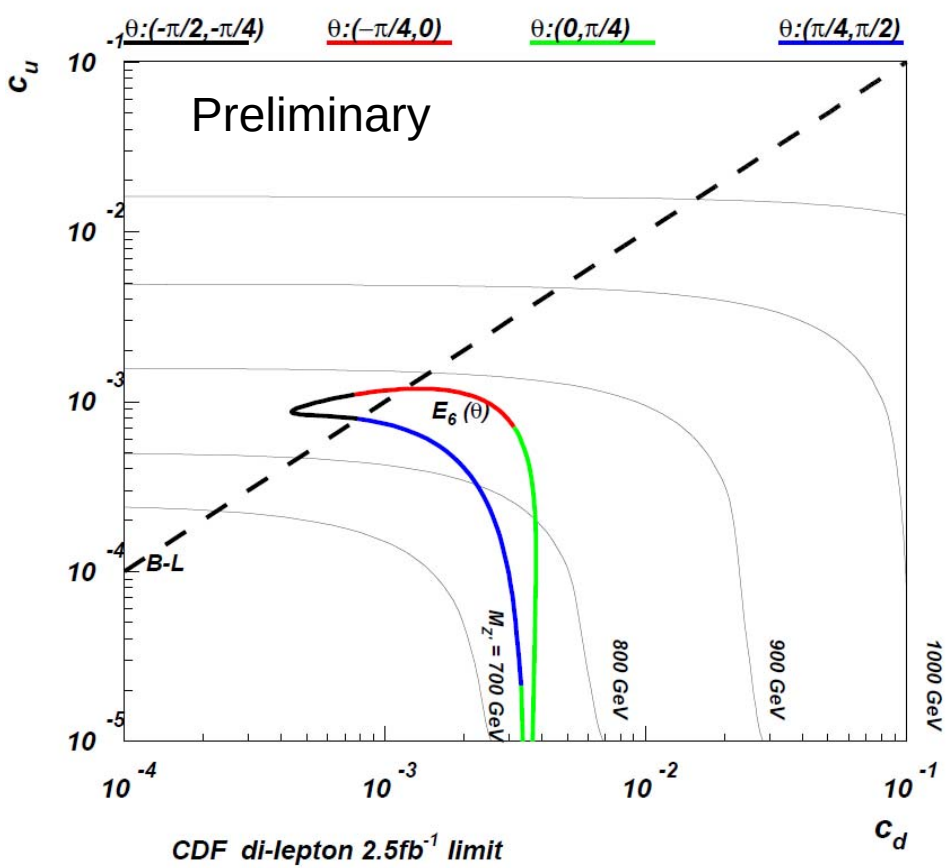


LHC pp $\sqrt{s} = 7\ TeV$

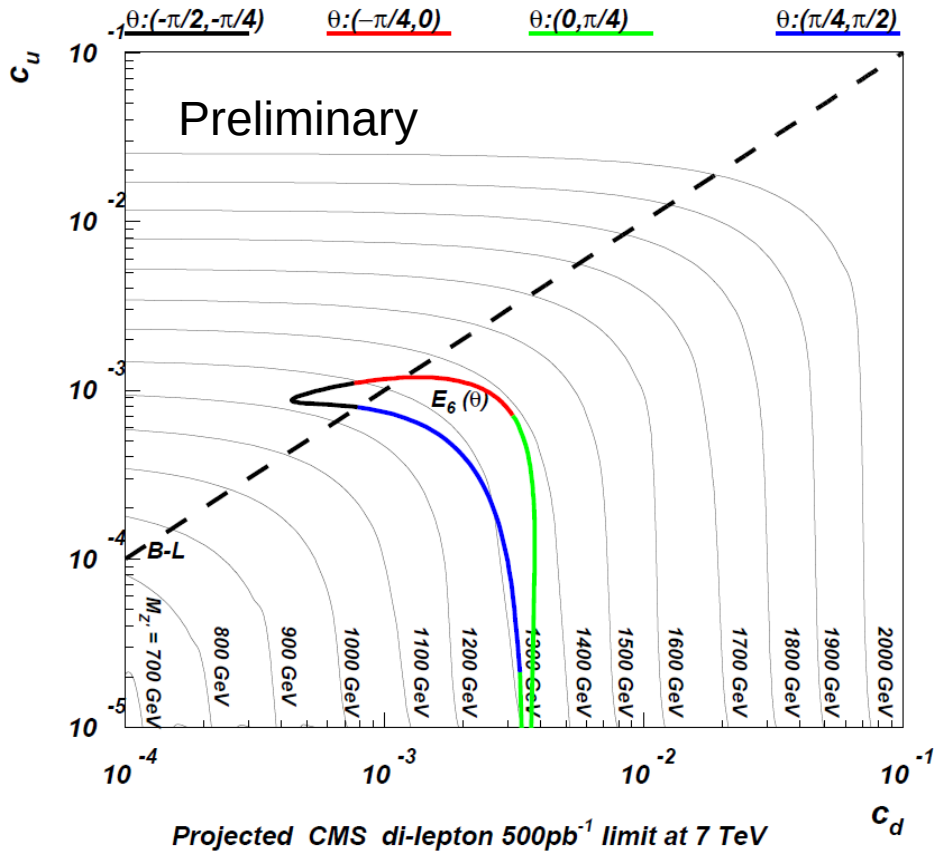


E_6 Models

Tevatron $p\bar{p}$ $\sqrt{s} = 1.8\ TeV$

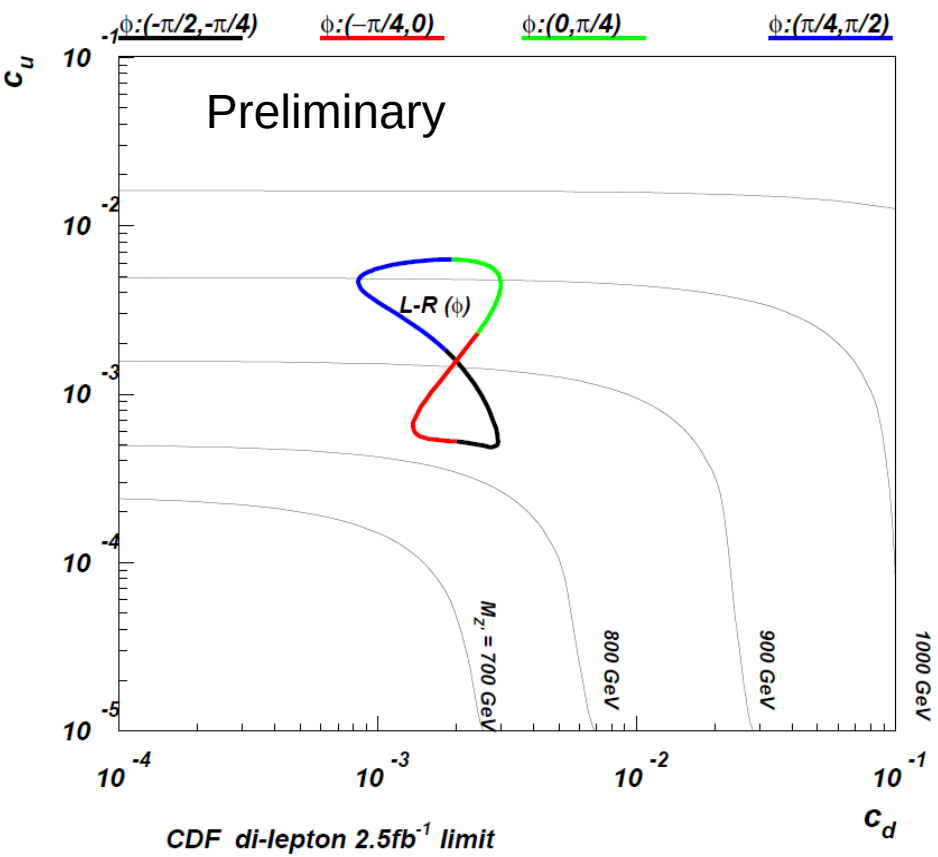


LHC pp $\sqrt{s} = 7\ TeV$



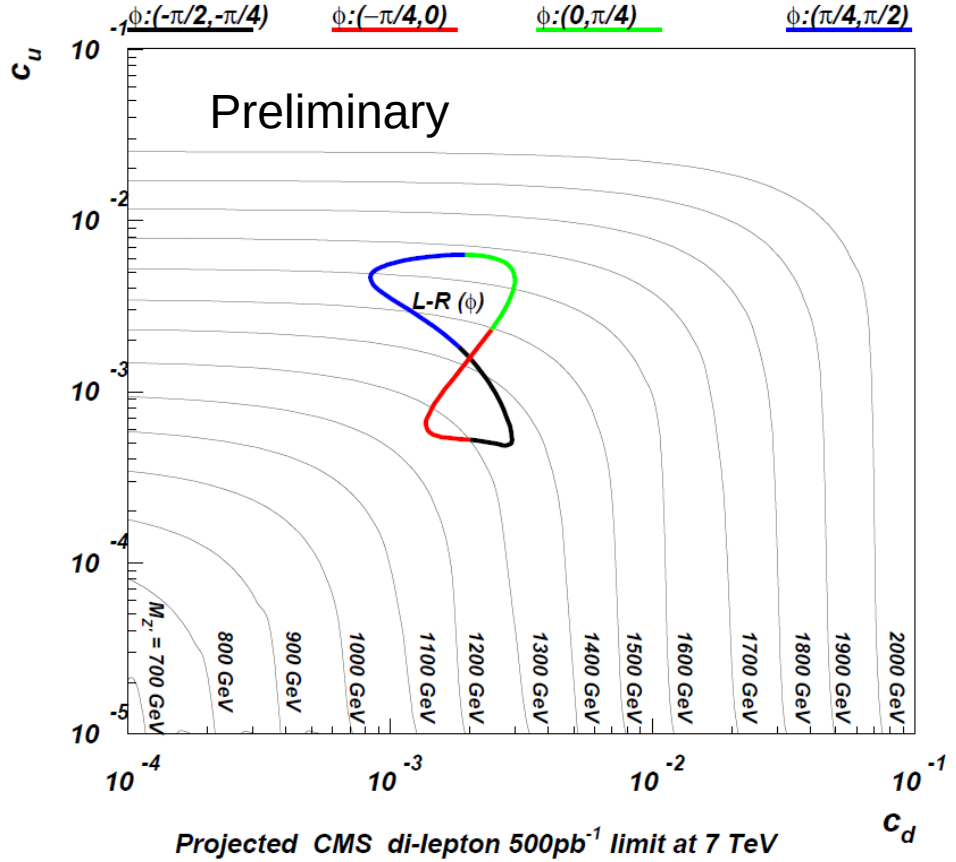
Generalized Left-Right Models

Tevatron $p\bar{p}$ $\sqrt{s} = 1.8\ TeV$



CDF di-lepton 2.5fb^{-1} limit

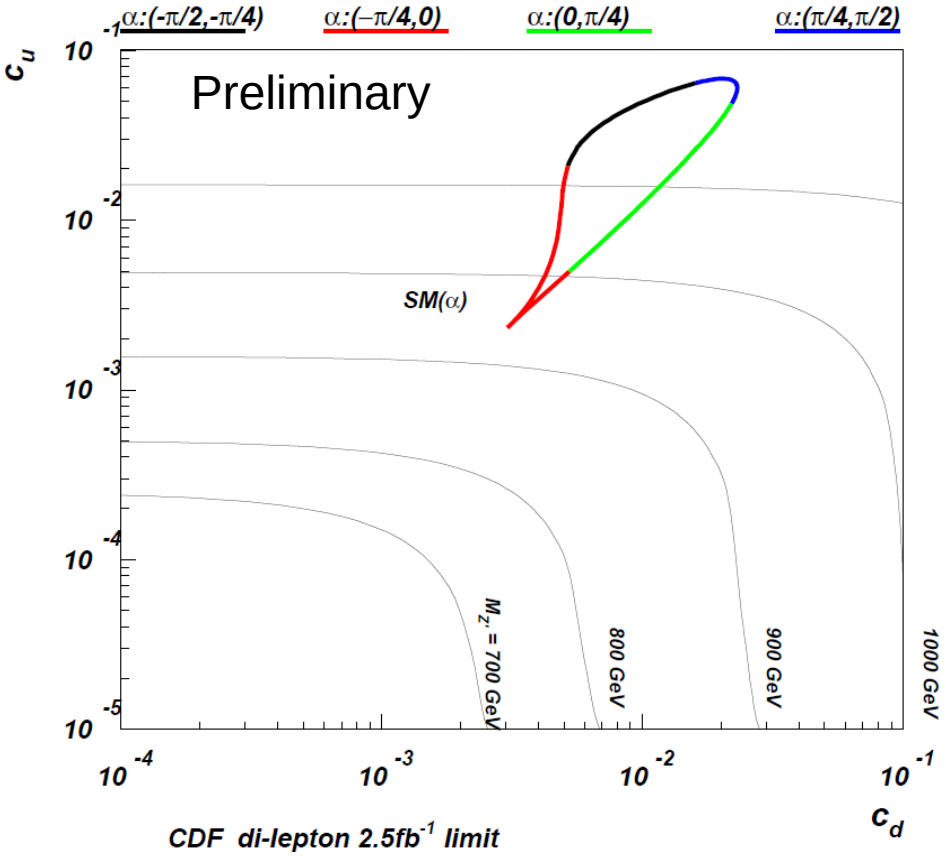
LHC pp $\sqrt{s} = 7\ TeV$



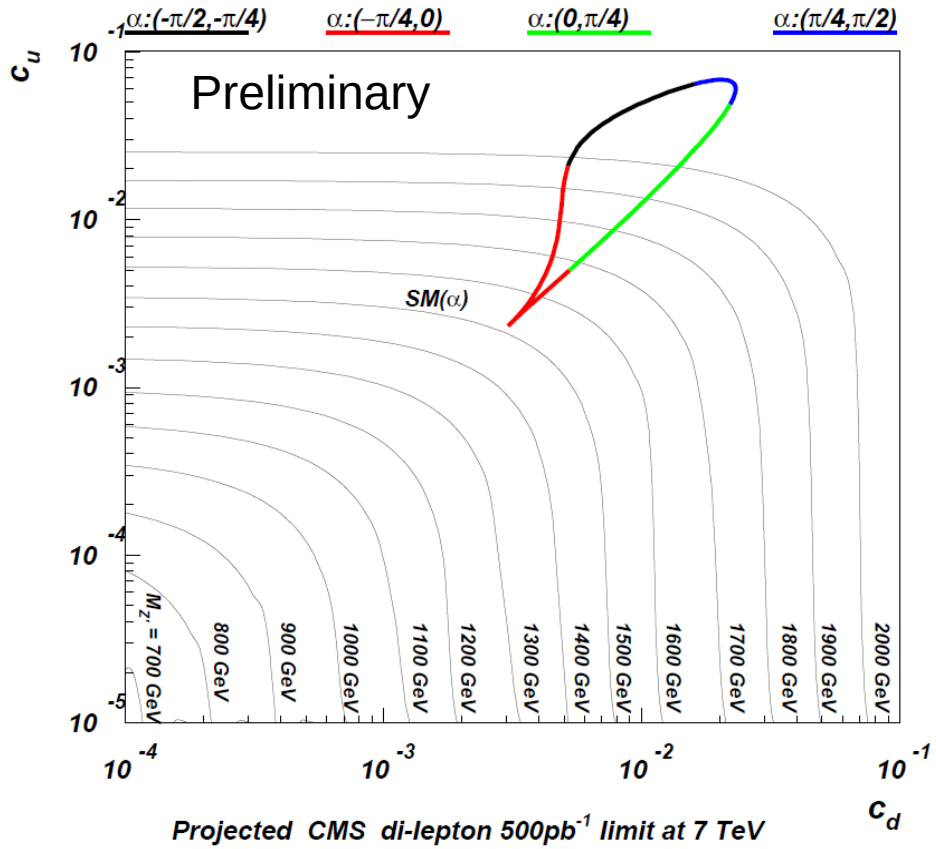
Projected CMS di-lepton 500pb^{-1} limit at 7 TeV

Generalized Standard-like Models

Tevatron $p\bar{p}$ $\sqrt{s} = 1.8\ TeV$



LHC pp $\sqrt{s} = 7\ TeV$



A Realistic model: E_6SSM

SFK, Moretti, Nevzorov

$$E_6 \to SO(10) \times U(1)_\psi \qquad SO(10) \to SU(5) \times U(1)_\chi$$

E_6 broken via SU(5) chain

Right handed neutrinos are neutral under: $U(1)_N = \frac{\sqrt{15}}{4} U(1)_\psi + \frac{1}{4} U(1)_\chi \longrightarrow Z'(N)$

M_{GUT} — $E_6 \to SM \times U(1)_N$

$$27_i \to (10,1)_i + (5^*,2)_i + (5^*,-3)_i + (5,-2)_i + (1,5)_i + (1,0)_i \qquad 27',\ \overline{27}'$$

RH ν masses: M_3, M_2, M_1

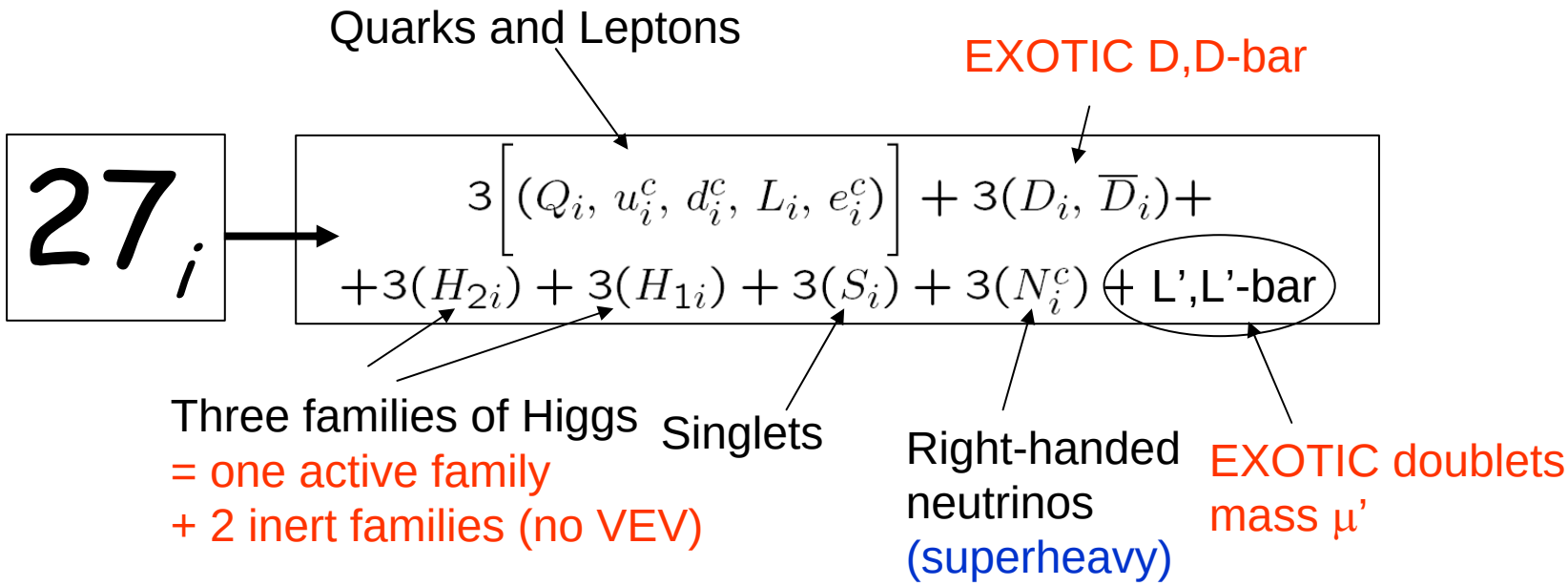
Quarks, leptons | Exotics and Higgs | Singlets and RHν s | L',L'-bar

To achieve GUT scale unification

TeV — $U(1)_N$ broken, Z' & exotics get mass, μ term generated

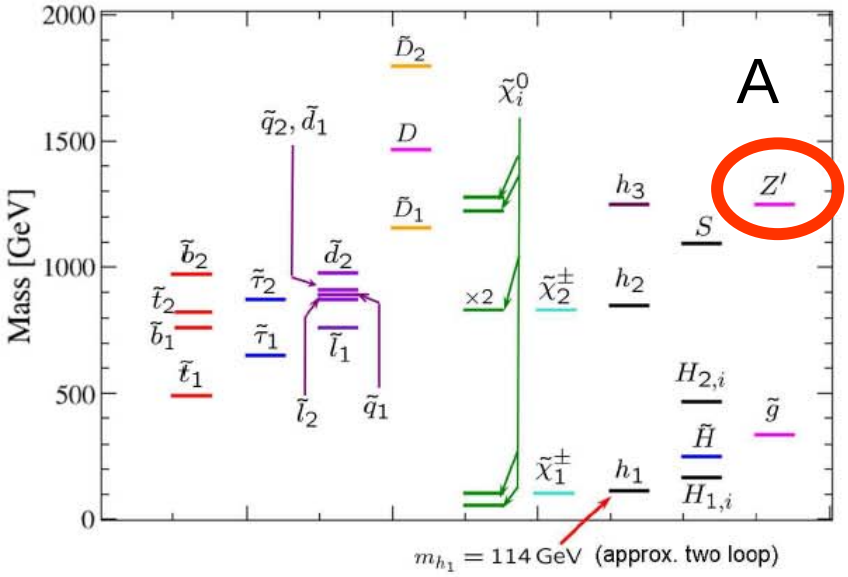
M_W — $SU(2)_L \times U(1)_Y$ broken

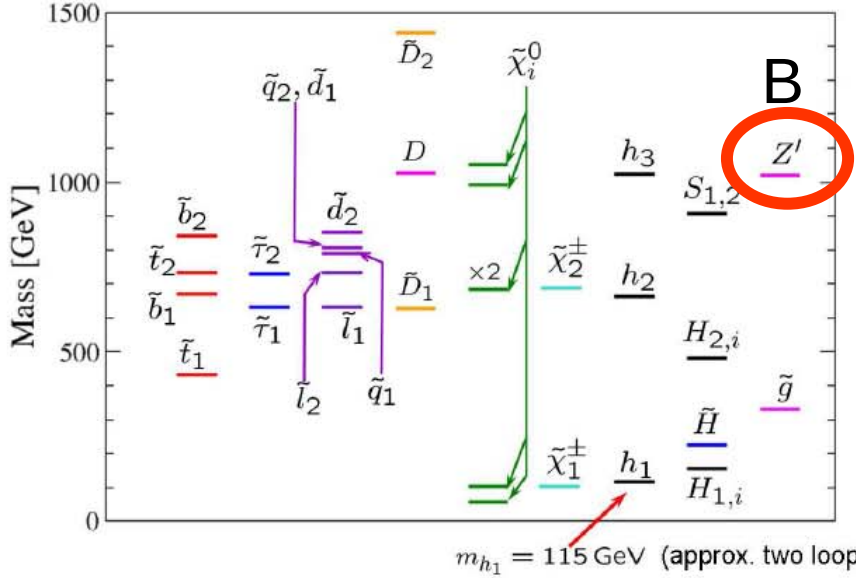
Matter content of E_6SSM at TeV



Plus a TeV scale Z'_N

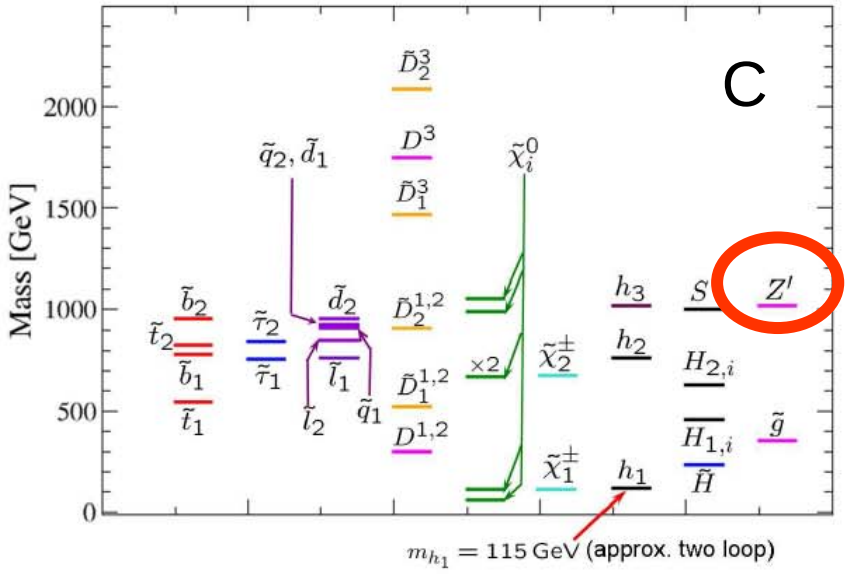
(Plus all their SUSY superpartners)

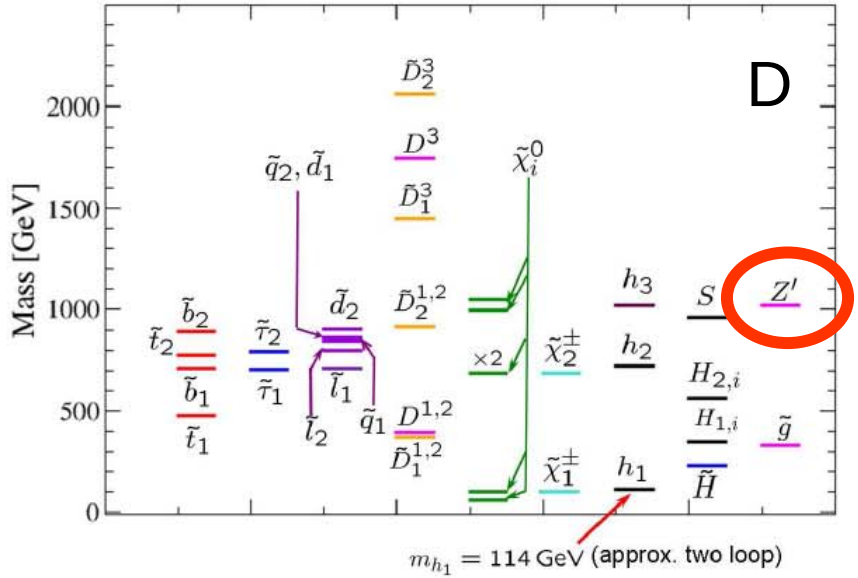




cE$_6$SSM Low Mass Benchmarks

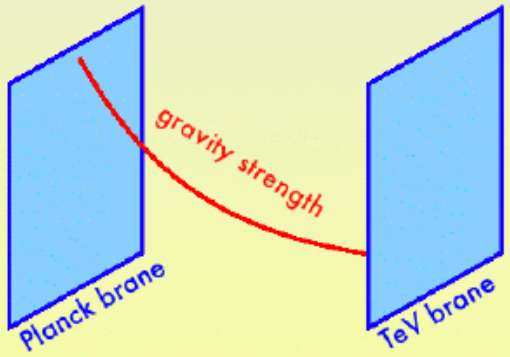
Athron, SFK, Miller, Moretti, Nevzorov





Warped Extra Dimensions

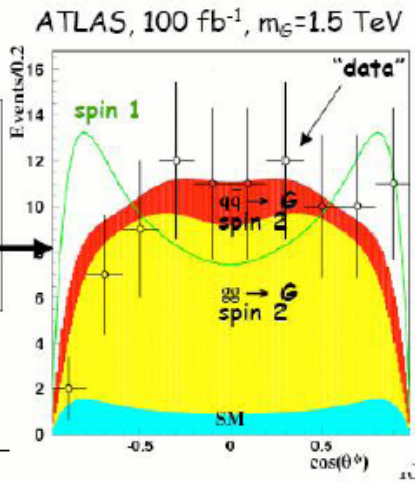
- RS1: "warped" XD, with second (EW or TeV) brane, where gravity exp. suppressed
  - TeV resonances on EW brane ⇔ KK modes .



- Warped XD provide calculable substitutes for strongly coupled 4D theories (eg technicolor)

J. Orloff

Graviton (s=2) or Z' (s=1) ? → look at $e^{\pm}$ angular distributions



With $SU(2)_L$ x $SU(2)_R$ x U(1) in the bulk we can break electroweak gauge symmetry by boundary conditions → "Higgsless models"
(or Higgs may be located close to TeV brane → "Walking TC models")

Higgsless models predict spin-1 KK excited versions of W,Z gauge bosons

The warped extra dimension may be deconstructed as n-lattice sites, the simplest examples being the 3-site and 4-site models

Equivalent description of the languages of Deconstructon and Technicolor

Barbieri et al

Accomando, De Curtis, Dominici,Fedeli

4-site Higgsless model

equivalent to

Belyaev, Foadi, Frandsen, Järvinen, Pukhov, Sannino

Next to Minimal Walking Technicolor (NMWT)

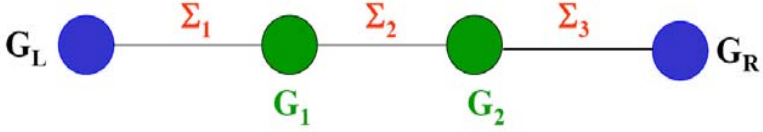
$N_c = 3$, $N_f = 2$
in the two-index symmetric
$SU(2)_L$ *X* $SU(2)$ *X* $SU(2)_V$
two triplets of "technirhos"

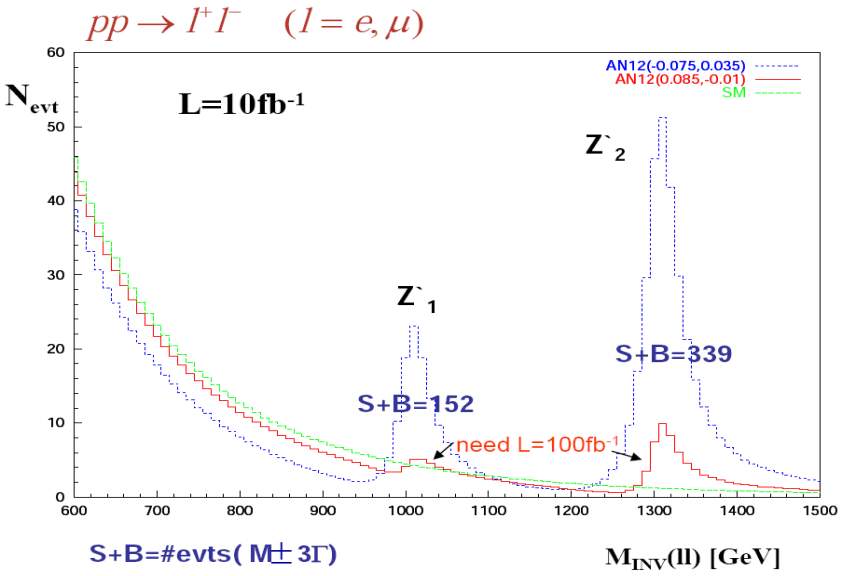
N.B. Z' can decay to Z+Higgs

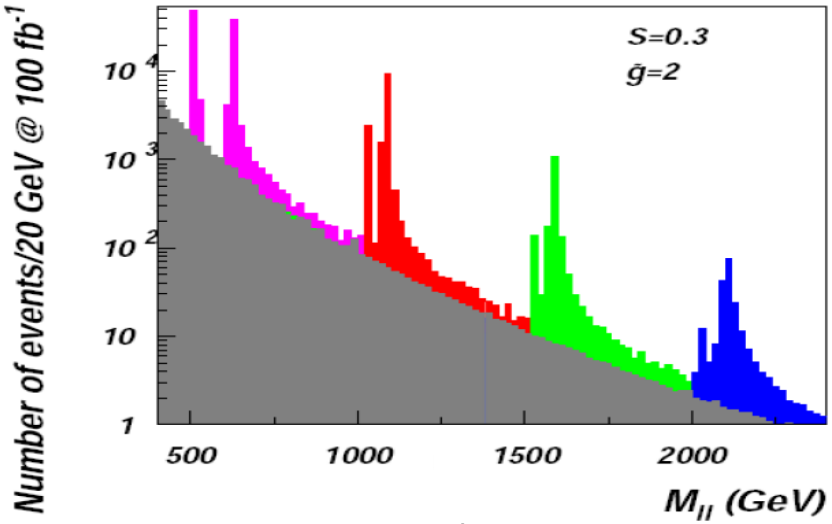
$R_1^{\pm}(R_2^{\pm})$

and

$R_1^0(R_2^0)$



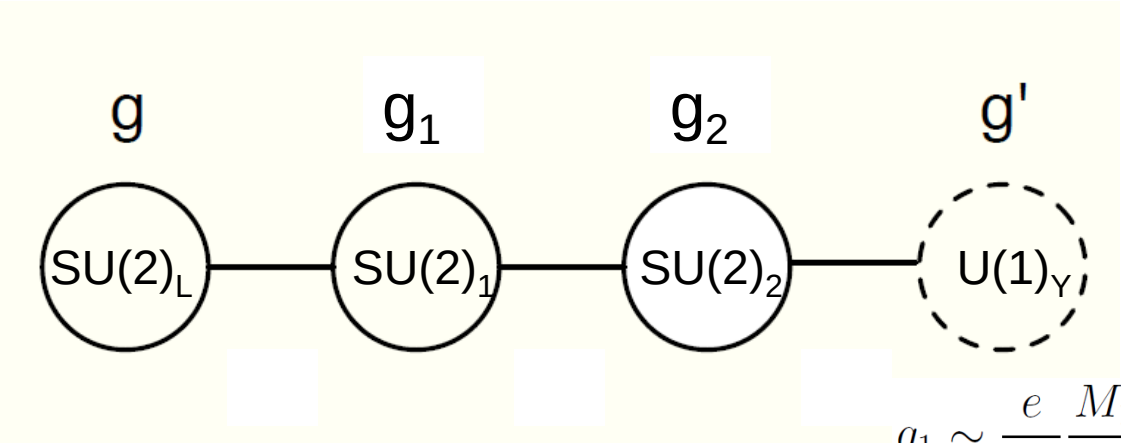




Slide due to Sasha Belyaev

4-site Higgsless Model

Accomando, De Curtis, Dominici,Fedeli

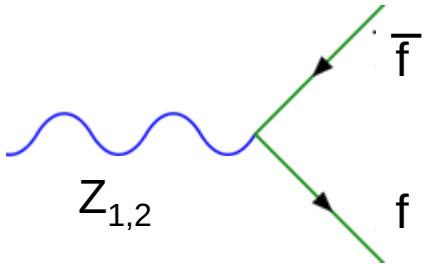


$$g_1 \sim \frac{e}{s_{2\theta}} \frac{M_1}{M_Z} \sqrt{2(1-z^2)}$$

$$M_1 = z M_2 < M_2$$

Parameters $g_1=g_2$, b_1, b_2, M_1, M_2

New gauge bosons $Z_1, Z_2, W_1^{\pm}, W_2^{\pm}$ $\sim$ KK excitations of Z,W



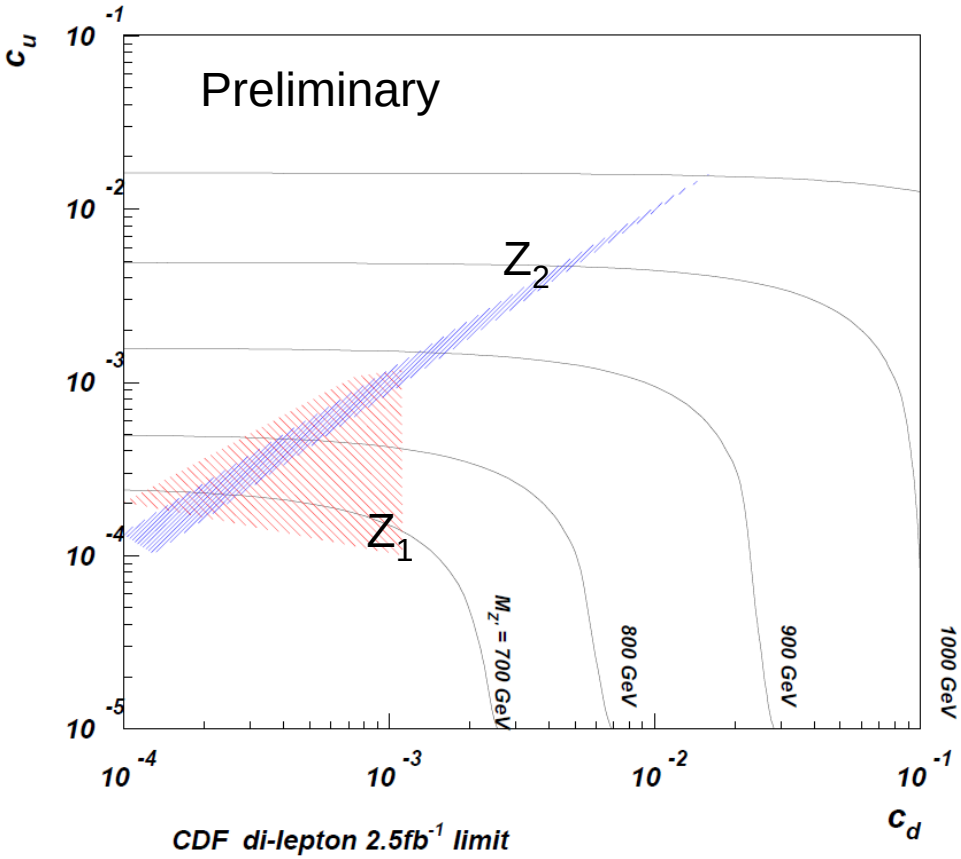
$g_{1V,1A}^{f}(b_1, b_2, M_1, M_2)$

$g_{2V,2A}^{f}(b_1, b_2, M_1, M_2)$

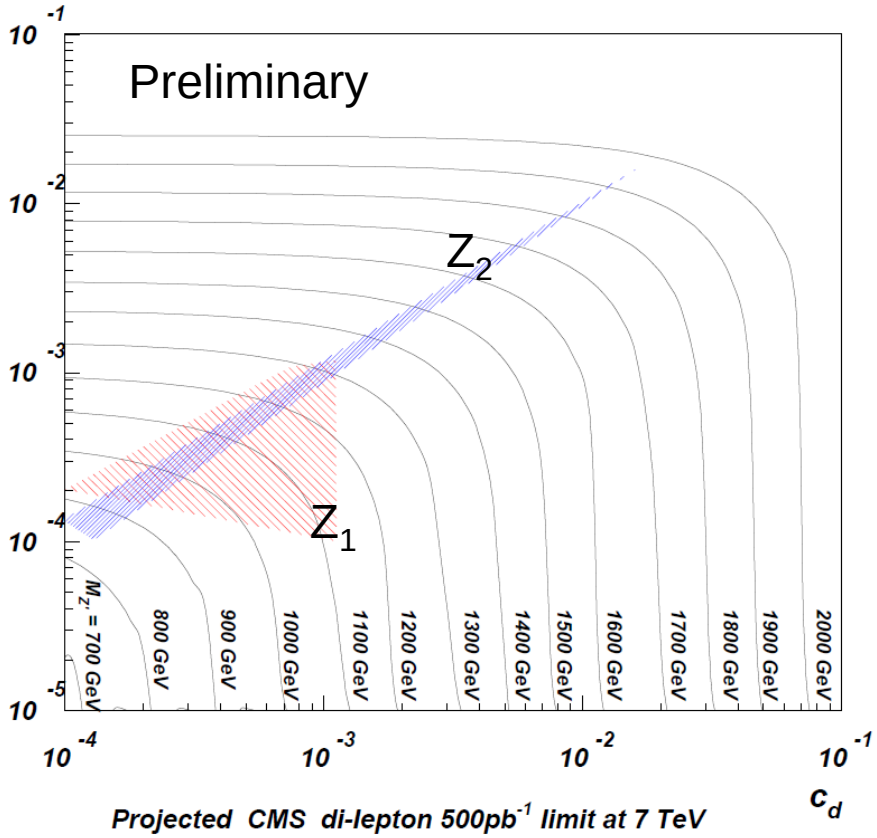
$b_{1,2}$ are direct couplings of delocalized SM fermions to $SU(2)_{1,2}$

4-site Higgsless Model

Tevatron $p\bar{p}$ $\sqrt{s} = 1.8\ TeV$



LHC pp $\sqrt{s} = 7\ TeV$



Conclusion

- Z' is very easy to discover in the first LHC run @7 TeV
- Z' is also predicted by 100s of models
- It seems plausible that a Z' could be first LHC discovery
- Preliminary results indicate that the Z' mass limits in the c_u-c_d plane for LHC@7 TeV are significantly stronger than the existing Tevatron limits
  e.g. E_6 limits: 750-900 GeV @Tevatron
  → 1200-1400 @LHC with 7 TeV
- E_6 models also predict "other stuff" e.g. E_6SSM
- Higgless/WTC models predict multiple Z's and Ws providing a distinctive signature