Electroweak constraints on Alternative E_6 models

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

Universidad de Antioquia, Medellin, Colombia,
COMHEP

6 de Diciembre del 2016, Universidad Nacional de Colombia

Anomaly cancellation and E_6

$$\sum_{\text{left}} \mathrm{Tr}\left(T^a\{T^b, T^c\}\right) - \sum_{\text{right}} \mathrm{Tr}\left(T^a\{T^b, T^c\}\right) = 0 \qquad (1)$$

- $SU(3)_c^2 U(1)_{z'}$ $\qquad SU(2)_w^2 U(1)_{z'}$
- $U(1)_Y^2 U(1)_{z'}$ $\qquad U(1)_Y U(1)_{z'}^2$
- $U(1)_{z'}^3$
- $1^2 U(1)_{z'}$

For the fermion content of the SM (*i.e.*, without right handed neutrinos) and requiring universality it is not posible to solve the anomaly constraints for the charges of an additional $U(1)$ gauge symmetry.
[Appelquist,Bogdan,Dobrescu and Hopper: 2002]

Why E_6?

- All representations of the E_6 gauge group Gursey:1975,Achiman:1978 are anomaly-free and the fundamental **27**-dimensional representation is chiral and can accommodate a full SM fermion generation.
- Some of the E_6 subgroups, such as the original unification groups, $SU(5)$ (Georgi-Glashow) and $SO(10)$, flipped $SU(5)$ and the gauge group of left-right models (Pati-Salam), $SU(4) \times SU(2)_L \times SU(2)_R$, Trinification,...,etc play central roles in some of the best motivated extensions of the SM.
- Furthermore, the complete E_6-motivated Z' family of models appears in a supersymmetric bottom-up approach exploiting a set of widely accepted theoretical and phenomenological requirements [J. Erler:2000].

Are there new embedding of the SM fermions in the multiplets of the E_6 subgroups?

In Reference E.R and J. Erler:2015 was presented the classification of all the embeddings of the Standard Model fermions in all possible decompositions of the fundamental representation of E_6 under its maximal subgroups.
However, a dedicate study of the phenomenology of the alternative embeddings models has not yet been made.
Our work represent a first step in this direction.

$SO(10)$ parameterization

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

Z's appear naturally in extension models [Robinett1981,Robinett1982,Langacker1984]

$$SO(10) \longrightarrow SU(5) \times U(1)_{\chi}, \tag{2}$$

or

$$E6 \longrightarrow SO(10) \times U(1)_{\psi}. \tag{3}$$

In general we consider models of the form [Erler and Langacker: 2002]

$$Z' = \cos\alpha \cos\beta Z_{\chi} + \sin\alpha \cos\beta Z_{Y} + \sin\beta Z_{\psi} \tag{4}$$

Neutral current Lagrangian in E_6

$$-\mathcal{L}_{NC} = gJ^{\mu}_{3L}A_{3L\mu} + g_aJ^{\mu}_{a}A_{a\mu} + g_bJ^{\mu}_{b}A_{b\mu} + g_cJ^{\mu}_{c}A_{c\mu} \ . \tag{5}$$

$$J_Y = \sqrt{\frac{5}{3}}J_Y^{E_6} = k_aJ_a + k_bJ_b + k_cJ_c \ . \tag{6}$$

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

$$
g_{Z'} J_{Z'} = g_{Z'}(\cos\alpha \cos\beta J_\chi + \sin\alpha \cos\beta J_Y + \sin\beta J_\psi) =
$$

$$
g_Y \left(-\frac{k_a J_a^\mu + k_b J_b^\mu}{\hat{\alpha}_c} + \hat{\alpha}_c k_c J_c^\mu \right) S_\theta + \frac{g_c}{k_c \hat{\alpha}_c} \left(\frac{k_a J_b^\mu}{\hat{\beta}} - \hat{\beta} k_b J_a^\mu \right) C_\theta
$$

where $S_\theta = \sin\theta$ parameterize the mixing between the neutral currents and

$$
\hat{\alpha}_c = \frac{\sqrt{k_b^2 g_a^2 + k_a^2 g_b^2}\, g_c}{g_b g_a k_c} = \sqrt{\frac{k_a^2}{g_a^2} + \frac{k_b^2}{g_b^2}}\, \frac{g_c}{k_c}
$$

$$
= \frac{1}{k_c} \sqrt{\frac{g_c^2}{g^2} \cot^2\theta_W - k_c^2}, \quad \hat{\beta} = \frac{g_a}{g_b}
$$

Coupling strengths at the electroweak scale

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

Fron the 1-loop renormalization group equations it is possible to define the unification mass scales and the values of the coupling strengths at the electroweak scale.

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.
UNIVERSIDAD DE ANTIOQUIA
FACULTAD DE COMUNICACIONES

chain of subgroups

E_6 →

$SO(10) \otimes U(1)_{42X}$	A
$SU(2)_X \otimes SU(6)$	B
$SU(2)_L \otimes SU(6)$	C
$SU(3)_C \otimes SU(3)_L \otimes SU(3)_R$	D
F_4	E

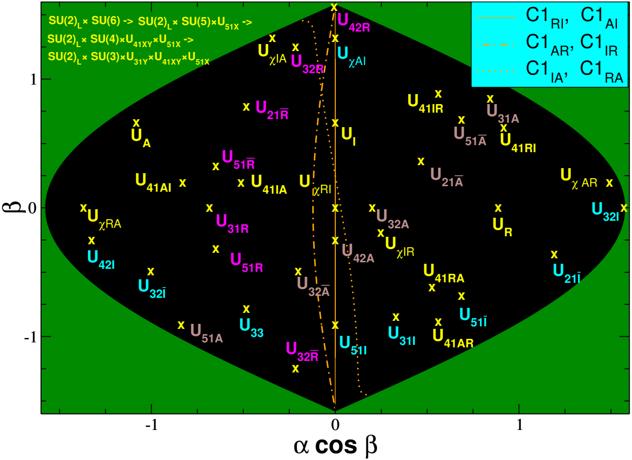
E_6 maximal subgroups Slansky:1981

E_6 benchmark models

Z'	Z_R [RR82]	$Z_{\not d}$ [ELMR11]	$-Z_I$ [RR82]	$-Z_{L_1}$ [RR82]	$-Z_{R_1}$ [RR82]	$Z_{\not p}$ [ELMR11]
RR Q^l_{nm}	U_R Q^1_{R00}	U_A Q^1_{A00}	U_I $-Q^1_{I00}$	U_{33} Q_{X-10}	$U_{21\overline{R}}$ Q_{R0-1}	$U_{21\overline{A}}$ Q_{A01}
Z'	$-Z_{\not n}$ [SPM01, ELMR11]	$-Z_{B-L}$ [PS74]	Z_{ALR} [Ma87]	$-Z_{\not L}$ [BKMR96]	Z_ψ [RR82]	Z_χ [RR82]
RR Q^l_{mn}	$U_{21\bar{I}}$ Q_{I0-1}	U_{31R} Q_{R-1-1}	U_{31A} Q_{A11}	U_{31I} Q_{I-1-1}	U_{42R} Q_{R1-1}	$U_{\chi RI}$ Q^1_{A-23}
Z'	Z_N [Ma96, KMN06]	Z_{χ^*} [flipped $-$ $SU(5)$][Bar82]	Z_η [Wit85]	Z_Y [Gla61, Wei67]	Z_S [ELL02, KLLL05]	—
RR Q^l_{mn}	$U_{\chi AI}$ $-Q^{-1}_{R-23}$	$U_{\chi RA}$ $-Q^{-1}_{I-23}$	U_{51I} Q_{I-2-1}	U_{32I} Q_{I1-2}	— Q^3_{A-14}	— —

Table: Generalized Robinett and Rosner notation for various E_6-motivated Z' bosons. All of them appear in the literature. The $Z_{\not p}$ and the $Z_{\not n}$ are bosons which do not couple — at vanishing momentum transfer and at the tree level — to protons and neutrons, respectively. Similarly, the $Z_{\not L}$, Z_I, and $Z_{\not d}$ bosons are blind, respectively, to SM leptons, up-type quarks, and down-type quarks. For convenience the models with the same multiplet structure of the Z_χ are referred to as $U_{\chi XY}$.

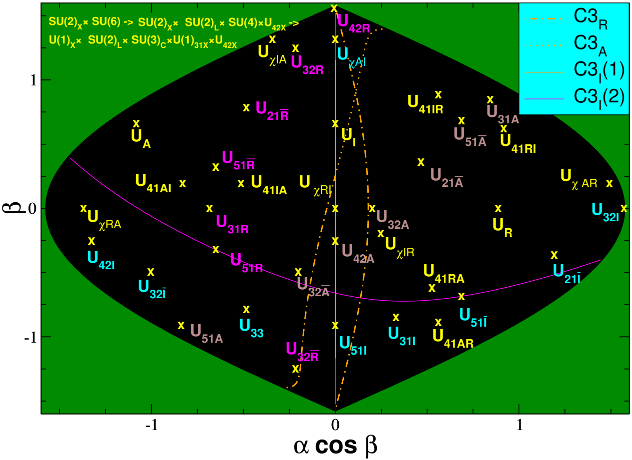
Z' couplings at low energies in the sanson flamsteed-projection



$$Q_{Z'} = (\cos\alpha\cos\beta Q_\chi + \sin\alpha\cos\beta Q_Y + \sin\beta Q_\psi)$$

Z' couplings at low energies in the sanson flamsteed-projection for the Pati-Salam model embedded in E_6 and its alternative versions.

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.



$$Q_{Z'} = (\cos\alpha\cos\beta\, Q_\chi + \sin\alpha\cos\beta\, Q_Y + \sin\beta\, Q_\psi)$$

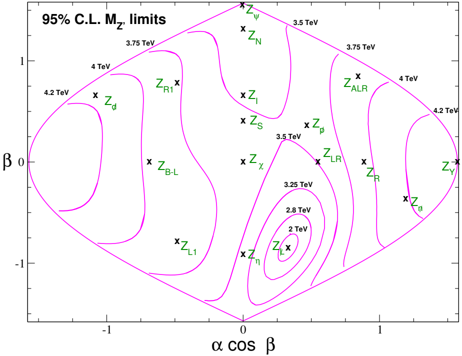
Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

LHC constraints on E_6 inspired Z' models

Z' model	Z_χ	Z_ψ	Z_η	Z_{LR}	Z_R	Z_N	Z_S	Z_I	Z_{B-L}	$Z_{\not{d}}$	Z_{SSM}
$M_{Z'}$ (TeV)	3.62	3.35	3.43	3.77	3.92	3.38	3.54	3.47	3.95	4.15	4.05
ATLAS	3.66	3.36	3.43	—	—	3.41	3.62	3.55	—	—	4.05

95% CL lower mass limits (in TeV) for E_6 inspired Z' models and the sequential standard model SSM. These constraints come from the 13.3 fb^{-1} of proton-proton collision data [col16], collected at $\sqrt{s} = 13$ TeV by the ATLAS experiment at the LHC.

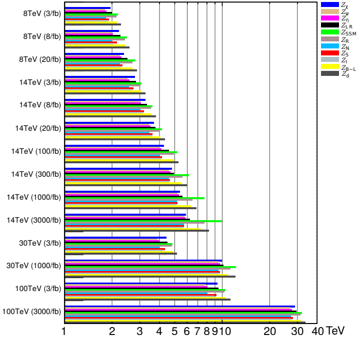
Z' couplings at low energies in the sanson flamsteed-projection for the Pati-Salam model embedded in E_6 and its alternative versions.



95% CL lower mass limits (in TeV) for E_6 inspired Z' models and the sequential standard model SSM. These constraints come from the 13.3 fb^{-1} of proton-proton collision data [col16], collected at $\sqrt{s} = 13$ TeV by the ATLAS experiment at the LHC.

Z' couplings at low energies in the sanson flamsteed-projection for the Pati-Salam model embedded in E_6 and its alternative versions.

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.



Projected 95% CL exclusion limits on $M_{Z'}$ for several E_6-motivated Z' models and the SSM by using our statistical methods.

Conclusions

- In the present work we have reported a general expression for the Z' charges of the E_6 inspired Z' models, as a function of the neutral current mixing angle.
- By using ATLAS data from the Drell-Yang process $pp \to Z, \gamma \to l^+ l^-$ we set 95% CL lower limits for the Z' mass in every one of this models. Our results are in accordance with the ATLAS reported lower mass limits.
- We have identified the preferred parameter space for unification models and its alternative versions in E_6.

Eduardo Rojas Peña
In collaboration with: W. A. Ponce, R. H. Benavides, L. Muñoz and O. Rodriguez.

Gracias

bibliography I

Stephen M. Barr.
A New Symmetry Breaking Pattern for SO(10) and Proton Decay.
Phys. Lett., 112B:219–222, 1982.

K. S. Babu, Christopher F. Kolda, and John March-Russell.
Leptophobic U(1) s and the R(b) - R(c) crisis.
Phys. Rev., D54:4635–4647, 1996.

The ATLAS collaboration.
Search for new high-mass resonances in the dilepton final state using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector.
2016.

bibliography II

Jens Erler, Paul Langacker, and Tian-jun Li.
The Z - Z' mass hierarchy in a supersymmetric model with a secluded U(1) -prime breaking sector.
Phys. Rev., D66:015002, 2002.

Jens Erler, Paul Langacker, Shoaib Munir, and Eduardo Rojas.
Z' Bosons at Colliders: a Bayesian Viewpoint.
JHEP, 11:076, 2011.

S. L. Glashow.
Partial Symmetries of Weak Interactions.
Nucl. Phys., 22:579–588, 1961.

bibliography III

Junhai Kang, Paul Langacker, Tian-jun Li, and Tao Liu.
Electroweak baryogenesis in a supersymmetric U(1)-prime model.
Phys. Rev. Lett., 94:061801, 2005.

S. F. King, S. Moretti, and R. Nevzorov.
Theory and phenomenology of an exceptional supersymmetric standard model.
Phys. Rev., D73:035009, 2006.

Ernest Ma.
Particle Dichotomy and Left-Right Decomposition of E(6) Superstring Models.
Phys. Rev., D36:274, 1987.

bibliography IV

Ernest Ma.
Neutrino masses in an extended gauge model with E(6) particle content.
Phys. Lett., B380:286–290, 1996.

Jogesh C. Pati and Abdus Salam.
Lepton Number as the Fourth Color.
Phys. Rev., D10:275–289, 1974.
[Erratum: Phys. Rev.D11,703(1975)].

R. W. Robinett and Jonathan L. Rosner.
Mass Scales in Grand Unified Theories.
Phys. Rev., D26:2396, 1982.

bibliography V

Luis A. Sanchez, William A. Ponce, and R. Martinez.
SU(3) (c) x SU(3) (ℓ) x U(1) (X) as an E(6) subgroup.
Phys. Rev., D64:075013, 2001.

Steven Weinberg.
A Model of Leptons.
Phys. Rev. Lett., 19:1264–1266, 1967.

Edward Witten.
Symmetry Breaking Patterns in Superstring Models.
Nucl. Phys., B258:75, 1985.