A Basic Guide to New Vector Bosons at the LHC

Manuel Pérez-Victoria

University of Granada & CAFPE

Implications of LHC results for TeV-scale physics, CERN 2011

New Vector Bosons

- New spin 1 particles (often gauge bosons, but no necessarily)
- Some of them easy to spot at LHC $\longrightarrow$ Strong constraints already!
- Appear in many BSM theories: GUT, Xdims, Technicolor, Little Higgs, ...

Here, model independent

New Vector Bosons

Model independent description

del Aguila, de Blas, MPV, 2010

Organizing Principle:
SU(3)xSU(2)xU(1)
gauge invariance

→

Simple, general
and convenient
parameterization

Only *requirement* in this talk:
Single production is possible

Basis of Extra Vectors

Color	**1**					**8**		
Isospin	**1**		**2**	**3**		**1**		**3**
Hypercharge	0	1	$-\frac{3}{2}$	0	1	0	1	0
Symbol	$\mathcal{B}$	$\mathcal{B}^1$	$\mathcal{L}$	$\mathcal{W}$	$\mathcal{W}^1$	$\mathcal{G}$	$\mathcal{G}^1$	$\mathcal{H}$

Color	**3**					$\mathbf{\bar{6}}$	
Isospin	**1**		**2**		**3**	**2**	
Hypercharge	$\frac{2}{3}$	$\frac{5}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$	$\frac{2}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$
Symbol	$\mathcal{U}^2$	$\mathcal{U}^5$	$\mathcal{Q}^1$	$\mathcal{Q}^5$	$\mathcal{X}$	$\mathcal{Y}^1$	$\mathcal{Y}^5$

Basis of Extra Vectors

Color	**1**					**8**		
Isospin	**1**		**2**	**3**		**1**		**3**
Hypercharge	0	1	$-\frac{3}{2}$	0	1	0	1	0
Symbol	$\mathcal{B}$	$\mathcal{B}^1$	$\mathcal{L}$	$\mathcal{W}$	$\mathcal{W}^1$	$\mathcal{G}$	$\mathcal{G}^1$	$\mathcal{H}$
Charges	0	± 1	$\pm 1, 2$	$0, \pm 1$	$\pm 0, 1, 2$	0	± 1	$0, \pm 1$

Color	**3**					$\mathbf{\bar{6}}$	
Isospin	**1**		**2**		**3**	**2**	
Hypercharge	$\frac{2}{3}$	$\frac{5}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$	$\frac{2}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$
Symbol	$\mathcal{U}^2$	$\mathcal{U}^5$	$\mathcal{Q}^1$	$\mathcal{Q}^5$	$\mathcal{X}$	$\mathcal{Y}^1$	$\mathcal{Y}^5$
Charges	$\pm\frac{2}{3}$	$\pm\frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$	$\pm\frac{1}{3}, \frac{2}{3}, \frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$

Basis of Extra Vectors

Color	1					8		
Isospin	1		2	3		1		3
Hypercharge	0	1	$-\frac{3}{2}$	0	1	0	1	0
Symbol	$\mathcal{B}$	$\mathcal{B}^1$	$\mathcal{L}$	$\mathcal{W}$	$\mathcal{W}^1$	$\mathcal{G}$	$\mathcal{G}^1$	$\mathcal{H}$
Charges	0	± 1	$\pm 1, 2$	$0, \pm 1$	$\pm 0, 1, 2$	0	± 1	$0, \pm 1$

W′

Z′

Gluon′

Color	3					$\bar{6}$	
Isospin	1		2		3	2	
Hypercharge	$\frac{2}{3}$	$\frac{5}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$	$\frac{2}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$
Symbol	$\mathcal{U}^2$	$\mathcal{U}^5$	$\mathcal{Q}^1$	$\mathcal{Q}^5$	$\mathcal{X}$	$\mathcal{Y}^1$	$\mathcal{Y}^5$
Charges	$\pm\frac{2}{3}$	$\pm\frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$	$\pm\frac{1}{3}, \frac{2}{3}, \frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$

Basis of Extra Vectors

Hadrophobic Fermiophobic

Color	1					8		
Isospin	**1**		**2**	**3**		**1**		**3**
Hypercharge	0	1	$-\frac{3}{2}$	0	1	0	1	0
Symbol	$\mathcal{B}$	$\mathcal{B}^1$	$\mathcal{L}$	$\mathcal{W}$	$\mathcal{W}^1$	$\mathcal{G}$	$\mathcal{G}^1$	$\mathcal{H}$
Charges	0	± 1	$\pm 1, 2$	$0, \pm 1$	$\pm 0, 1, 2$	0	± 1	$0, \pm 1$

Leptoquarks Leptophobic

Color	3					$\bar{\mathbf{6}}$	
Isospin	**1**		**2**		**3**	**2**	
Hypercharge	$\frac{2}{3}$	$\frac{5}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$	$\frac{2}{3}$	$\frac{1}{6}$	$-\frac{5}{6}$
Symbol	$\mathcal{U}^2$	$\mathcal{U}^5$	$\mathcal{Q}^1$	$\mathcal{Q}^5$	$\mathcal{X}$	$\mathcal{Y}^1$	$\mathcal{Y}^5$
Charges	$\pm\frac{2}{3}$	$\pm\frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$	$\pm\frac{1}{3}, \frac{2}{3}, \frac{5}{3}$	$\pm\frac{1}{3}, \frac{2}{3}$	$\pm\frac{1}{3}, \frac{4}{3}$

Dileptons

Neutral vector boson Z' coupling to quarks and leptons.
Can be inside one of these multiplets:

$\mathcal{B}$ $(1,1)_0$ ⟵ Usual Z' boson from extra U(1)

$\mathcal{W}$ $(1,3)_0$ ⟵ $Z_L{}'$ (comes with W′)

~~$\mathcal{W}^1$ $(1,3)_1$~~ ⟵ mixing-suppressed production

Dileptons

$\mathcal{B}$ $(1,1)_0$ ⟵ Usual Z' boson from extra U(1)

$\mathcal{W}$ $(1,3)_0$ ⟵ $Z_L{}'$ (comes with W′)

~~$\mathcal{W}^1$ $(1,3)_1$~~ ⟵ mixing-suppressed production

A sequential Z'_{SM} cannot be any of these!
(it breaks $SU(2)_L$ gauge invariance)

Does it make any sense?

Dileptons

$\mathcal{B}$ $(1,1)_0$ ⟵ Usual Z' boson from extra U(1)

$\mathcal{W}$ $(1,3)_0$ ⟵ Z_L' (comes with W′)

~~$\mathcal{W}^1$ $(1,3)_1$~~ ⟵ mixing-suppressed production

Yes: Z'_{SM} is a mixture of $\mathcal{B}$ and neutral component of $\mathcal{W}$

$\Downarrow$

Sequential Z' comes necessarily with a γ' and a W'

Dileptons

Parametrization of Z' (family universal)

$\mathcal{B}$

- 5 couplings to fermions $g_l,\ g_e,\ g_q,\ g_u,\ g_d$
- 1 coupling to scalar $g_\phi \longrightarrow$ mixing with Z

$Z_L{}'$

- 2 couplings to fermions $g_l,\ g_q$
- 1 coupling to scalar $g_\phi \longrightarrow$ mixing with Z

Z′ Drell-Yan:

Carena, Daleo, Dobrescu, Tait, 2004

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

(narrow width, no interference)

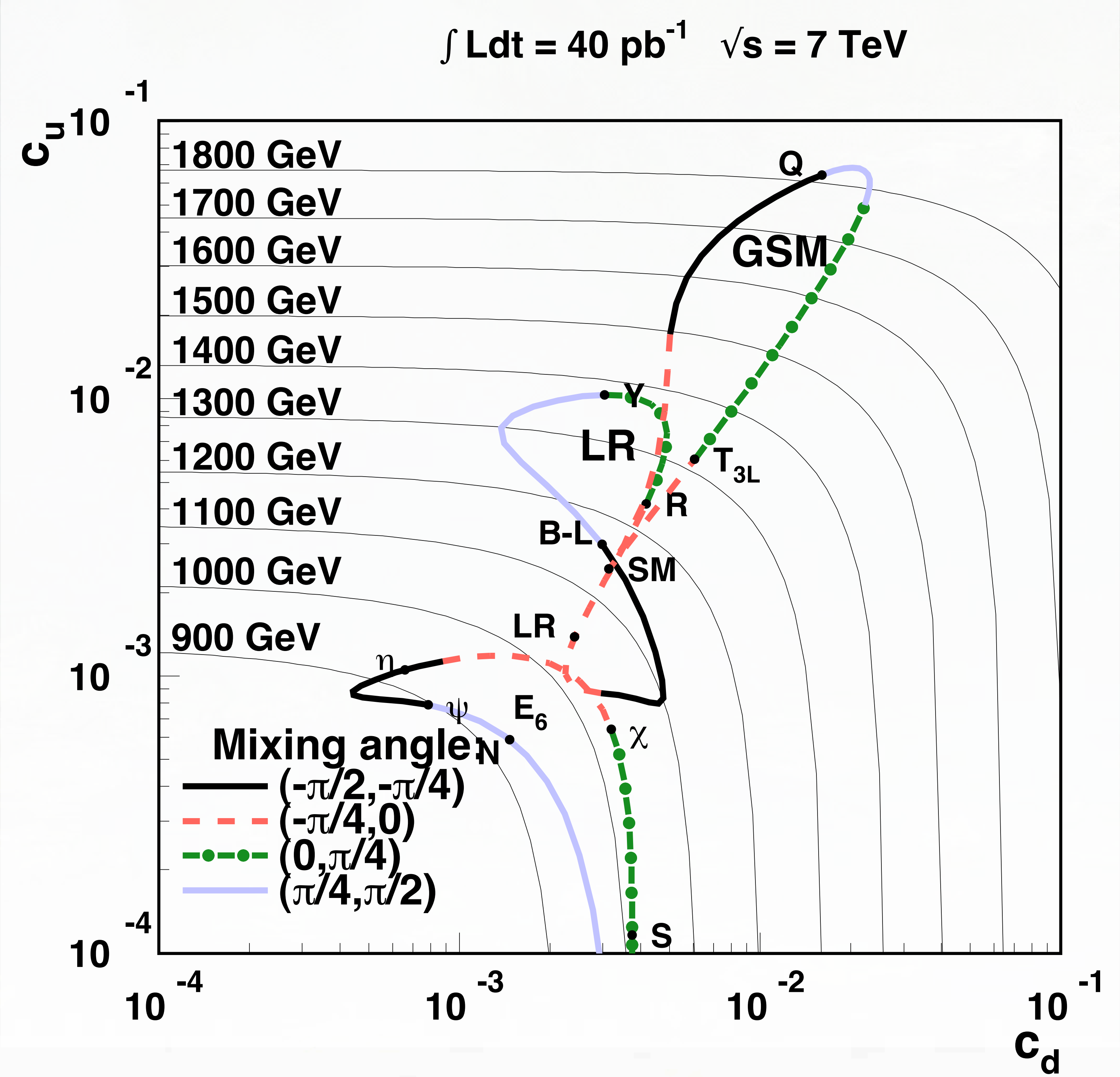
$$c_{u,d} = \left(g_q^2 + g_{u,d}^2\right)\ \left(g_l^2 + g_e^2\right) \frac{M_{Z'}}{24\pi\Gamma_{Z'}(g_i)}$$

(vanishing mixing)

$c_u = c_d$ for $Z_L{}'$

Dileptons

Limits on (narrow) Z′



CMS

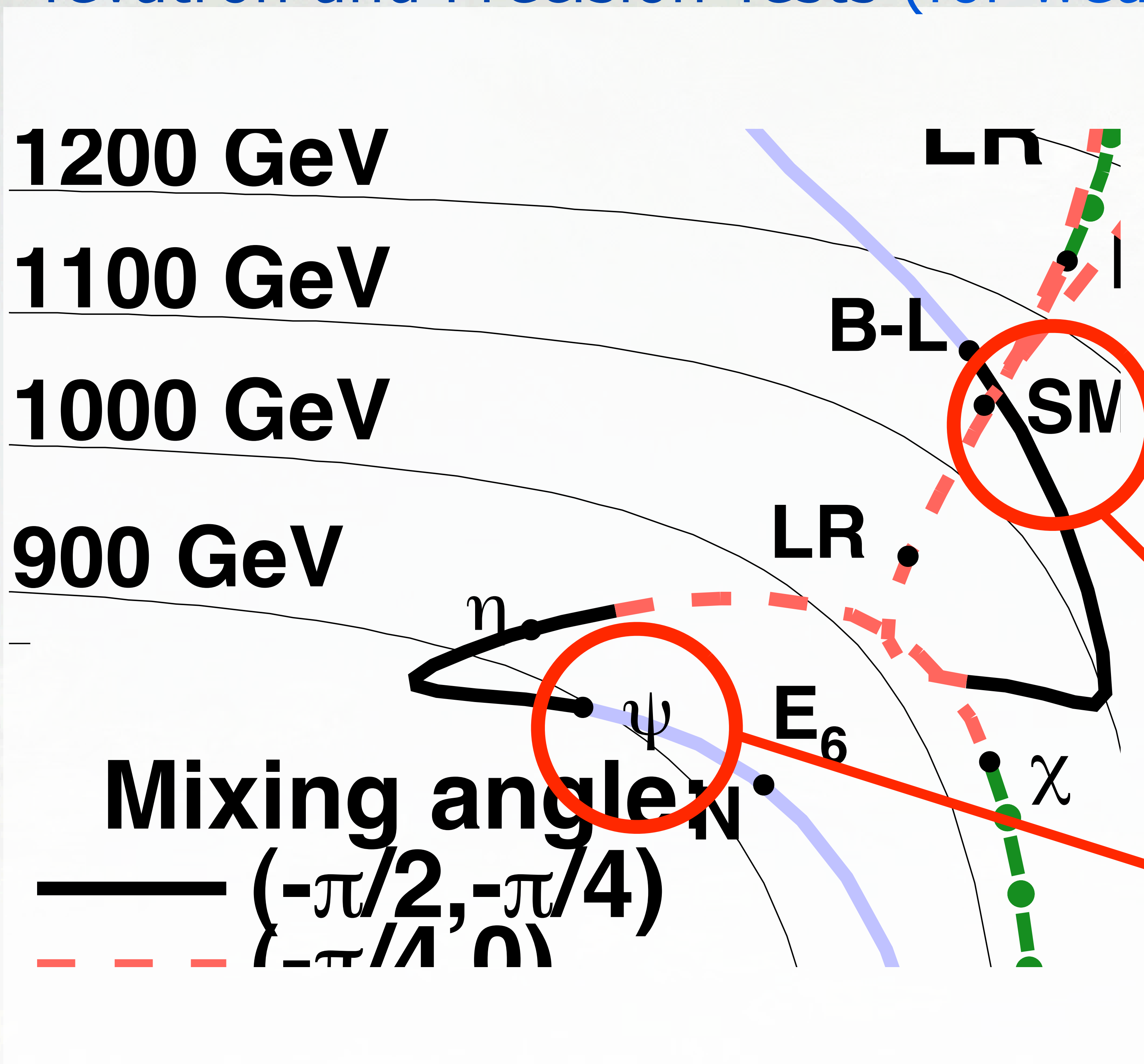
arXiv:1103.0981

(LHC theoretical analysis by Accomando et al., 2010)

Dileptons

Limits on (narrow) Z′

Limits from LHC already stronger than those from Tevatron and Precision Tests (for weak couplings)



CMS
arXiv:1103.0981

Atlas $\sim 1 fb^{-1}$
arXiv:1108.1582

≥ 1.83 TeV

≥ 1.49 TeV

Lepton+MET

Charged vector boson W' coupled to quarks and LH leptons.
Can be inside one of these multiplets:

$\mathcal{W}$ $(1,3)_0$

$\mathcal{W}^1$ $(1,3)_1$

$\mathcal{B}^1$ $(1,1)_1$

Lepton+MET

Charged vector boson W' coupled to quarks and LH leptons.
Can be inside one of these multiplets:

$\mathcal{W}$ $(1,3)_0$

~~$\mathcal{W}^1$ $(1,3)_1$~~ ⟵ mixing-suppressed production

~~$\mathcal{B}^1$ $(1,1)_1$~~ ⟵ mixing-suppressed coupling to leptons (mixing strongly constrained by EWPT)

Other signals: Grojean, Salvioni, Torre, '11
Schmaltz, Spethmann, '11, with light RH neutrinos

Lepton + MET

Parametrization of W′ (family universal)

$\mathcal{W}$ $(1,3)_0$ { Charged $W'^{\pm}$ / Neutral Z' } — Nearly degenerate!

$$\mathcal{W}^a_\mu \left[g_l \bar{l}_L \gamma^\mu \tau_a l_L + g_q \bar{q}_L \gamma^\mu \tau_a q_L + g_\phi (\phi^\dagger \tau_a i D^\mu \phi + h.c.) \right]$$

g_ϕ → mixing with W

W′ charged Drell-Yan:

$$\sigma(pp \to W' \to l\nu) = \frac{\pi}{48s} c_{ud} w_{ud}(s, M_{Z'})$$

(narrow width, no interference)

$$c_{ud} = g_q^2 \; g_l^2 \; \frac{M_{W'}}{24\pi \Gamma_{W'}(g_i)}$$

(vanishing mixing)

Lepton + MET

Parametrization of W' (family universal)

$\mathcal{W}$ $(1,3)_0$ { Charged $W'^{\pm}$ / Neutral Z' — Nearly degenerate!

$$\mathcal{W}^a_\mu \left[g_l \bar{l}_L \gamma^\mu \tau_a l_L + g_q \bar{q}_L \gamma^\mu \tau_a q_L + g_\phi (\phi^\dagger \tau_a i D^\mu \phi + h.c.) \right]$$

Z' has same couplings as W' ⟹ Z_L' model

Lepton + ME$_T$ from W' implies Dilepton from Z_L'

Possible to combine searches/limits

Resonant Signals of Vector Bosons at LHC

Dilepton

$\mathcal{B}$ $\mathcal{W}$ $\mathcal{W}^1$

Lepton + ME$_T$

$\mathcal{B}^1$ $\mathcal{W}$ $\mathcal{W}^1$

Dijet

$\mathcal{B}$ $\mathcal{W}$ $\mathcal{B}^1$ $\mathcal{W}^1$

$\mathcal{G}$ $\mathcal{G}^1$ $\mathcal{H}$

$\mathcal{Q}^1$ $\mathcal{Q}^5$ $\mathcal{Y}^1$ $\mathcal{Y}^5$

$t\,\bar{t}$

$\mathcal{B}$ $\mathcal{W}$ $\mathcal{W}^1$

$\mathcal{G}$ $\mathcal{H}$

$t\,t$

$\mathcal{Q}^5$ $\mathcal{Y}^5$

Z H

$\mathcal{B}$ $\mathcal{W}$ $\mathcal{W}^1$

W Z/γ

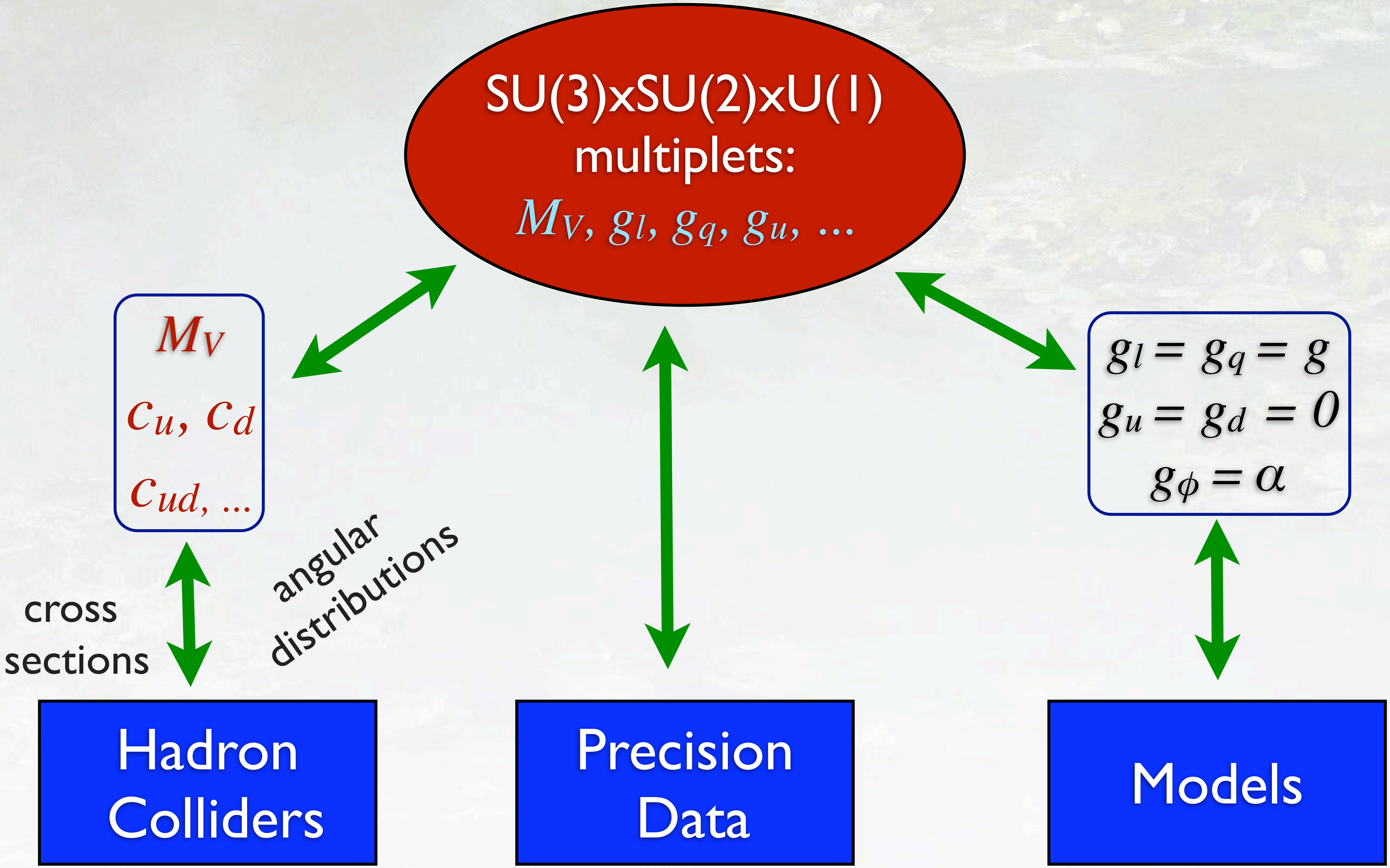
$\mathcal{B}^1$ $\mathcal{W}$ $\mathcal{W}^1$

Chiang,Christensen,Ding,Han '11: Drell Yan

Han, Lewis, Liu '11: Colored

Additional possibilities for non-resonant signals

Model independent analyses

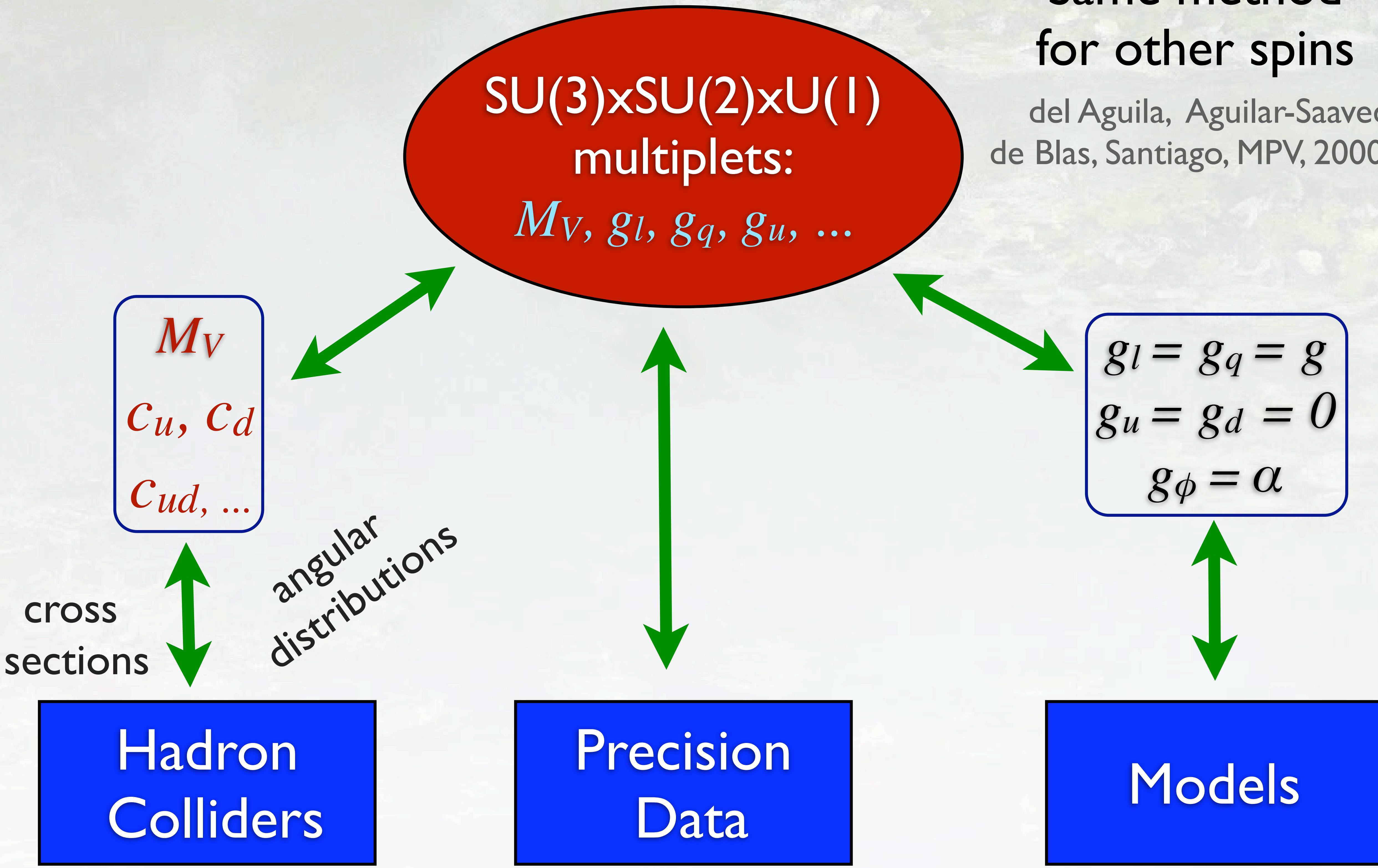


Interplay with Higgs and other new particles

Model independent analyses

Same method for other spins

del Aguila, Aguilar-Saavedra, de Blas, Santiago, MPV, 2000-2011



Interplay with Higgs and other new particles