2 TeV Walking Technirho at LHC?

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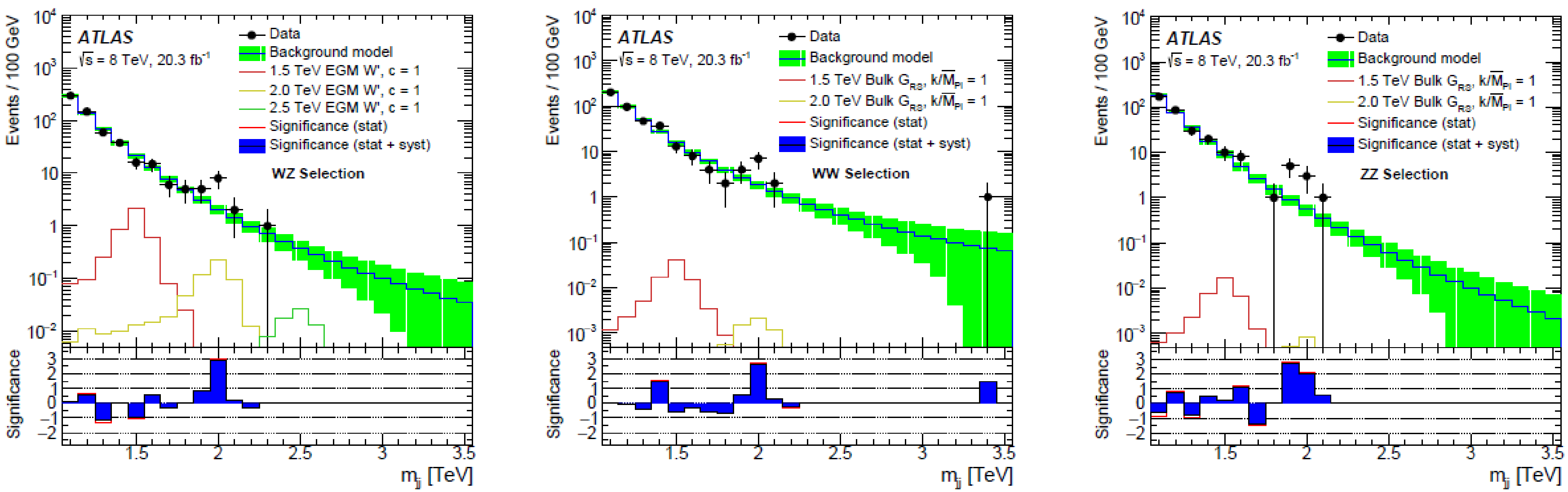
Based on
arXiv: 1506.03751 (to appear in PLB) *H.S.Fukano, M.Kurachi, S.M, K.Terashi, K.Yamawaki*
arXiv: 1507.03428 *H.S.Fukano, S.M., K.Yamawaki*

PPP
09/15/2015

☆ Introduction

arXiv: 1506.00962

ATLAS Collaboration reported ~ 3 sigma excesses at around 2 TeV in diboson channels



New Resonance, hint for BSM?

The resonance property -- read off from ATLAS data

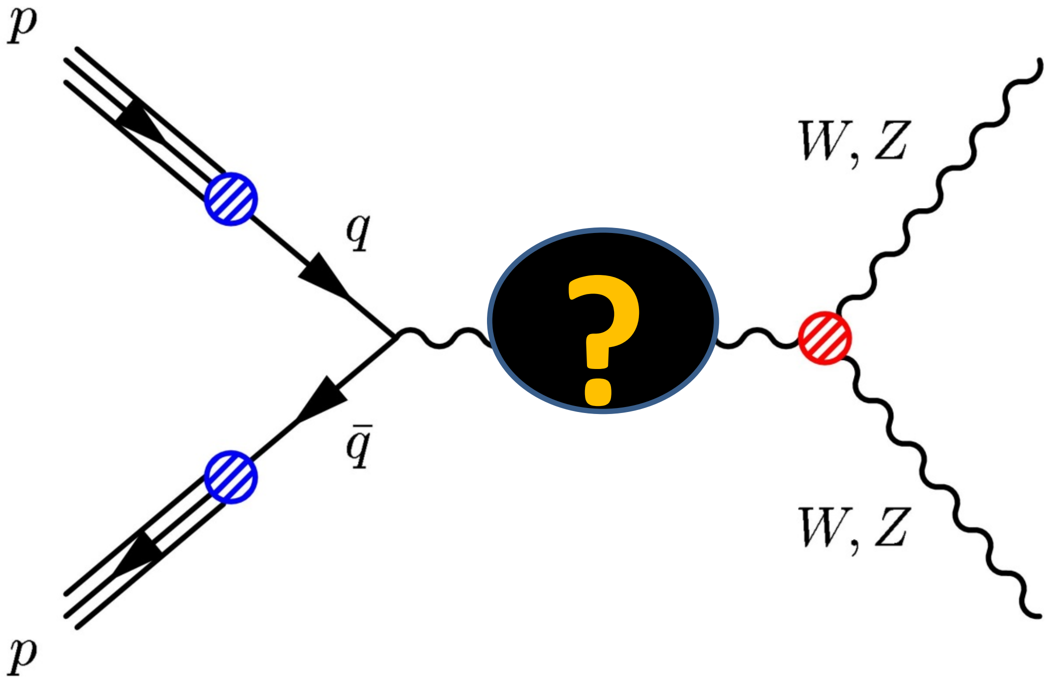
arXiv: 1506.00962

i) resonance width < 100 GeV

ii) reconstructed X-> diboson cross section via DY
@ 8TeV and L = 20.3/fb

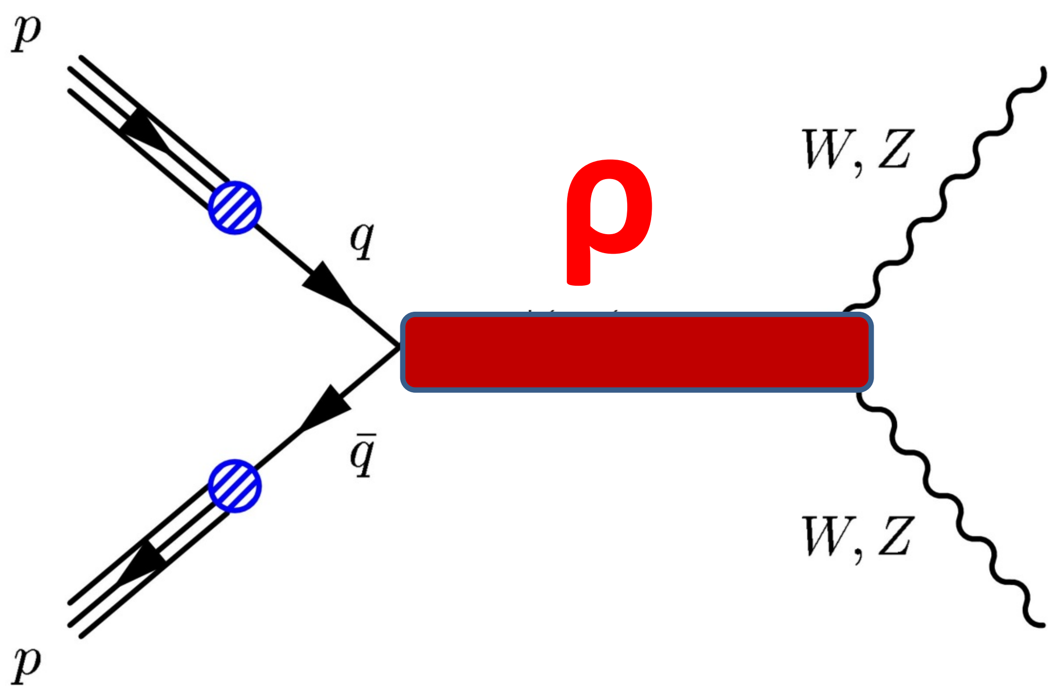
$\sigma(pp \to X \to WZ/WW)$ = about 14 fb

What is the new resonance, if it is there?



What is the new resonance, if it is there?

In this talk

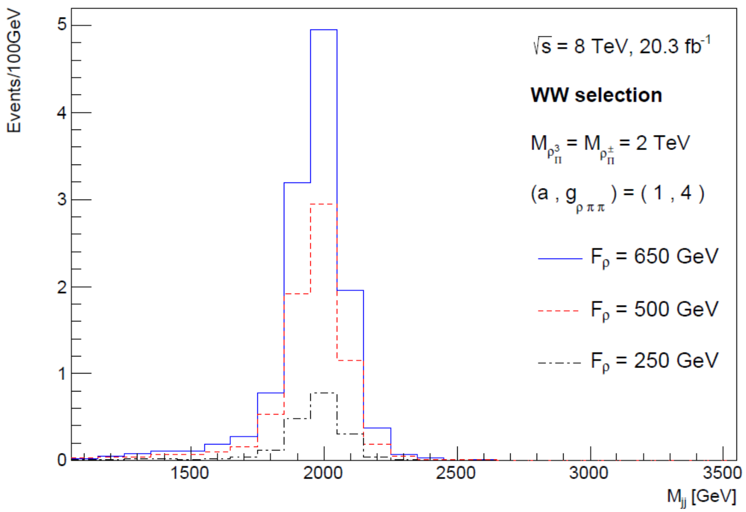


2 TeV Technirho!?

in Walking TC

☆ Quick view of main result

H.S.Fukano, M.Kurachi,
S.M, K.Terashi, K.Yamawaki



Walking technirho can explain the excesses!!

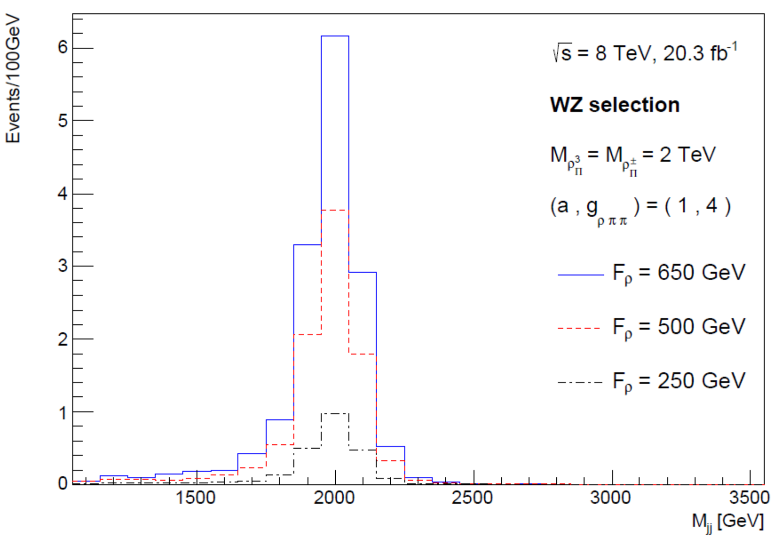
w/ Γ = about 60 GeV

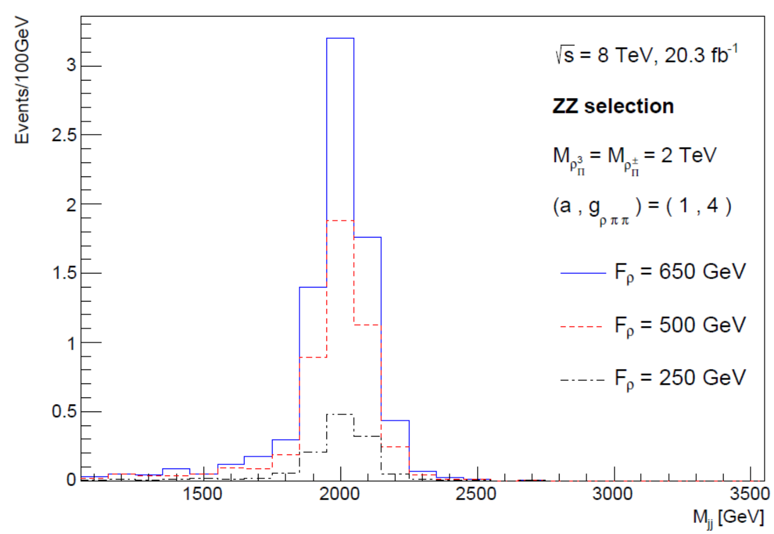
Observed excesses

WW/WZ selection: 5 – 6 events/bin

***ZZ selection : 2 – 3 events/bin**

* *contamination from WW&WZ modes*





Contents

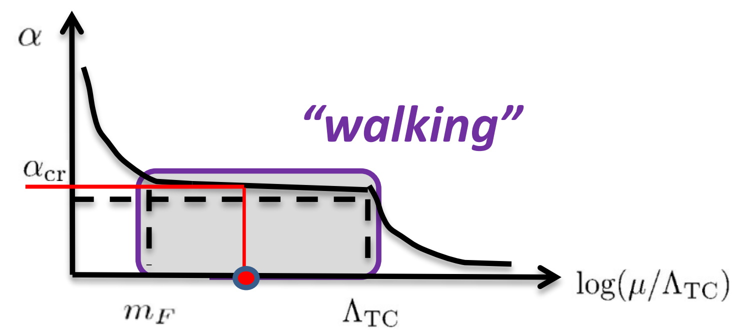
1. Walking TC

Walking Technicolor (WTC)

--- gives dynamical explanation for origin of mass/EW symmetry breaking
by technifermion condensate $\langle \bar{F}F \rangle \neq 0$, just like $\langle \bar{q}q \rangle \neq 0$ in QCD

--- almost scale inv./ ``**walking**” dynamics

$$\beta(\alpha) \simeq 0$$



--- can be realized by large Nf/many flavor QCD

Lattice simulation has observed
large Nf walking signal: say, Nf=8

LatKMI collaboration, ‘13

Viable candidate: **One-family model of WTC w/ Nf=8**

☆ Is light (125GeV) Higgs there?

One-family model (1FM) of Walking Technicolor (WTC)

--- (approximate) scale-inv. : spontaneously broken by $\langle \bar{F} F \rangle \neq 0$

--- predicts a light composite Higgs, $\phi \sim \bar{F} F$
pNGB for the scale symmetry

Yamawaki et al ('86);
Bando et al ('86)

Technidilaton (TD)

M.Kurachi, S.M., K.Yamawaki (2014);
S.M., talk at SCGT15 (2015);
S.M., K.Yamawaki (2015)

☆The lightness is ensured by

i) $\beta(\alpha) \simeq 0$

ii) Large Nf nature (``anti-Veneziano limit")

$$M_\phi^2 \simeq \left(\frac{v_{\rm EW}}{2}\right)^2 \cdot \left(\frac{5 v_{\rm EW}}{F_\phi}\right)^2 \cdot \left(\frac{8}{N_{\rm TF}}\frac{4}{N_{\rm TC}}\right)$$

Amazingly,

**** 125 GeV TD signatures, in 1FM w/ N_{TC}=4,***
are consistent with current LHC Higgs data

S.M. and K. Yamawaki, PRD85,86 ('12), PLB719 ('13); S.M. 1304.4882; talk at SCGT15

☆ Other low-lying spectra in 1FM w/ Nc=4,NF=8

i) **Technipions**

$\langle \bar{F}F \rangle \neq 0$ breaks scale & chiral SU(8)L x SU(8)R symmetries

--- 63 NGBs (3 ← eaten by W&Z)

60 become pseudo (**technipions**)
via SM gauge int. & extended TC

--- the mass is lifted up to the order of a few TeV

J.Jia, S.M. K.Yamawaki (2012);
M.Kurachi, S.M., K.Yamawaki (2014)

$m_{TP} \sim \mathcal{O}(\text{a few TeV})$ due to the walking feature

ii) **Technirho/a1**

$$\frac{M_\rho}{F_\pi} \simeq \frac{M_{a_1}}{F_\pi} \sim \mathcal{O}(10)$$

from nonperturbative estimate
and holographic estimate

M.Harada, et al (2003);
K.Haba, S.M., K.Yamawaki (2010);
S.M., K.Yamawaki (2012);
LatKMI , talk at SCGT15

* 63 vector mesons in a way similar to Technipions

Techni-rho meson	color	isospin	Coupling to WW/WZ
$\rho^i_{\theta_a}$	octet	triplet	No
$\rho^0_{\theta_a}$	octet	singlet	No
$\rho^i_{T_c}\,(\bar{\rho}^i_{T_c})$	triplet	triplet	NO
$\rho^0_{T_c}\,(\bar{\rho}^0_{T_c})$	triplet	triplet	NO
ρ^i_P	singlet	triplet	NO (orthogonality)
ρ^0_P	singlet	singlet	YES (very weakly: via isospin violation)
ρ^i_Π	singlet	triplet	YES (strongly)

2. Low-energy eff. Theory for 1FM of WTC

M.Kurachi, S.M., K.Yamawaki (2014);
H.S.Fukano, S.M., K.Yamawaki (2015)

1FM w/ Nc=4,NF=8

reflecting spontaneous breaking of scale & chiral symmetries

--- **scale inv. Hidden local symmetry (sHLS)**

Refs. for original HLS
*Bando, et al. PRL**54** ('85);*
*Bando, et al, NP**B259** ('85);*
*Bando, et al, PTP**79** ('88);*
*Bando, et al, PR**164** ('88)*

* nonlinear realization for the chiral part:

$$\underline{SU(8)_L \times SU(8)_R} \times \underline{[SU(8)_V]_{\rm HLS}}/SU(8)_V$$

SM gauges (W, B, G)
in part embedded

Techni-ρ gauge bosons
(# = 63)

* nonlinear realization for the scale part:

introduces ``conformal/scale compensator"

$$\chi(\phi) = e^{\phi/F_\phi}$$

Technidilaton, Φ

3. Pheno. of walking technirho -- "Conformal Barrier"

arXiv: 1507.03428 [hep-ph]

H.S.Fukano, S.M., K.Yamawaki

* That's astonishing, crazy ``*handicap*" for new vector bosons!!

--- look at the vector boson mass terms in sHLS (w/ hypercharge turned off)

$$\mathcal{L}_{\rm sHLS} \ni (W_\mu)^2 + a \cdot \underline{(W_\mu - \rho_\mu)^2}$$

mass mixing arises
due to the SM gauges x HLS -> U(1)em

--- consider dilaton coupling to this part in scale-inv. manner

$$\mathcal{L}_{\rm sHLS} \ni \chi^2(\phi)[(W_\mu)^2 + a \cdot (W_\mu - \rho_\mu)^2]$$

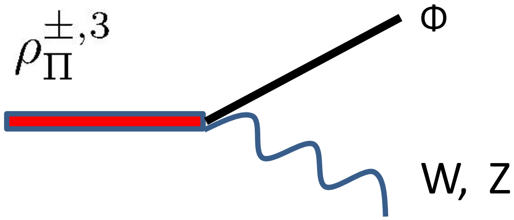
Diagonalized into mass-basis

$$\mathcal{L}_{\rm sHLS} \ni \chi^2(\phi)[(\tilde{W}_\mu)^2 + \tilde{a} \cdot (\tilde{\rho}_\mu)^2]$$

No off-diagonal coupling to dilaton, (ρ-W-Φ = 0) required by scale/conformal inv.

"Conformal Barrier"

* Phenomenological consequence of CB



$$\rho_{\Pi}^{\pm,3} = 0$$

Conformal Barrier!!

i.e., $$\mathrm{Br}[\rho \to W_L W_L / W_L Z_L] \simeq 100\%$$

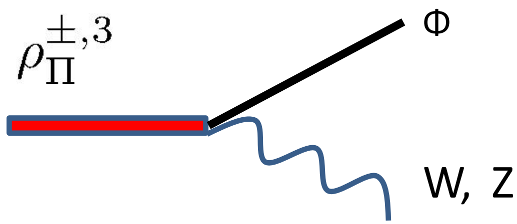
in sharp contrast to other new vector bosons!!

--- incompatible w/ widely believed "Equivalence Theorem"

$$\mathrm{Br}[V' \to VV] \simeq \mathrm{Br}[V' \to VH] \simeq 50\%$$

Walking technirho: salient nature,
Smoking-gun = absence of V'→ VH signal!

* Phenomenological consequence of CB



= 0

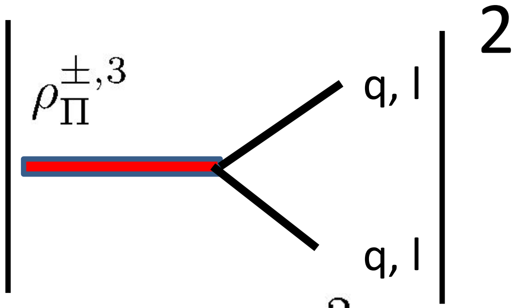
Conformal Barrier!!

i.e., $$\mathrm{Br}[\rho \to W_L W_L / W_L Z_L] \simeq 100\%$$

Diboson cross section easily reaches O(10 fb – 20fb) necessary to account for the reported excesses!!

*possible decay modes of 2 TeV walking technirhos

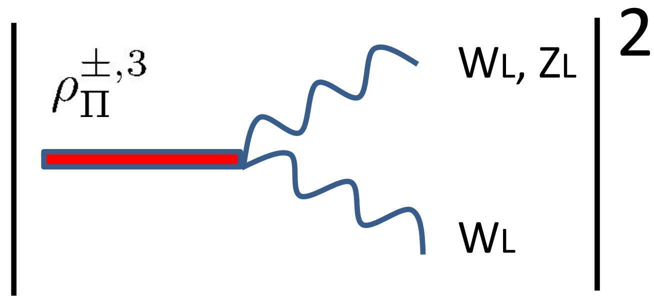
To SM fermions



$$\propto \left(\frac{F_\rho}{M_\rho}\right)^2$$

controls DY cross section

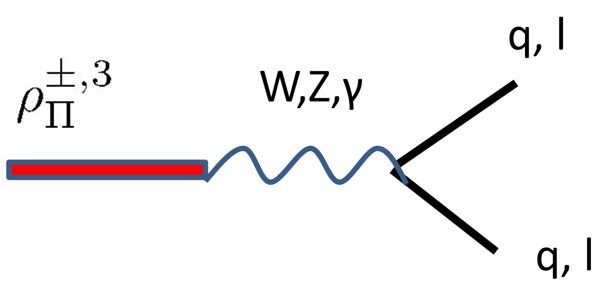
To diboson (W, Z)



$$\propto (g_{\rho\pi\pi})^2$$

controls total width

arises from VMD



c.f. ATLAS data favor

$$\Gamma \lesssim 100 \text{ GeV}$$

arXiv: 1506.00962

☆ Width < 100 GeV??
How can rho be so narrow resonance?

Recall QCD rho meson (made of lightest flavors)

$$\Gamma_\rho^{\rm QCD} \simeq \Gamma[\rho \to \pi\pi]\Big|_{\rm QCD} \simeq \frac{|g_{\rho\pi\pi}|^2}{48\pi} M_\rho$$

w/ rho coupling

$$g_{\rho\pi\pi} \simeq 6$$

$$\Gamma_\rho^{\rm QCD} \simeq 477 \text{ GeV for } M_\rho = 2 \text{ TeV}$$

Too large!!

☆ Width < 100 GeV??
How can rho be so narrow resonance?

$$\mathcal{L}_{\rho\Pi W_L W_L/W_L Z_L} = \frac{1}{\sqrt{N_D}} g_{\rho\pi\pi} i \Bigg[\partial^\mu \pi_W^+ \pi_W^- \rho^3_{\Pi\mu} + (\partial^\mu \pi_W^- \pi_Z - \partial^\mu \pi_Z \pi_W^-) \rho^+_{\Pi\mu} \Bigg] + \text{h.c.}\,,$$

But, it's NOT the case for 1FM w/ Nf=8 (N_D = 4) and Nc=4!!

$$\Gamma_\rho \simeq \Gamma[\rho \to W_L W_L / W_L Z_L] \simeq \frac{|g_{\rho\pi\pi}|^2}{48\pi} \left(\frac{1}{N_D}\right) M_\rho$$

Large Nc scaling

$$g_{\rho\pi\pi} \sim \sqrt{\frac{3}{N_c}} g_{\rho\pi\pi}|_{\rm QCD} \quad \sim 5$$

Flavor-dependence

☆ Width < 100 GeV??
How can rho be so narrow resonance?

$$\mathcal{L}_{\rho\Pi W_L W_L/W_L Z_L} = \frac{1}{\sqrt{N_D}} g_{\rho\pi\pi} i \Big[\partial^\mu \pi_W^+ \pi_W^- \rho^3_{\Pi\mu} + (\partial^\mu \pi_W^- \pi_Z - \partial^\mu \pi_Z \pi_W^-) \rho^+_{\Pi\mu} \Big] + \text{h.c.}\,,$$

But, it's NOT the case for 1FM w/ Nf=8 (ND = 4) and Nc=4!!

$$\Gamma_\rho \simeq \Gamma[\rho \to W_L W_L / W_L Z_L] \simeq \frac{|g_{\rho\pi\pi}|^2}{48\pi} \left(\frac{1}{N_D}\right) M_\rho$$

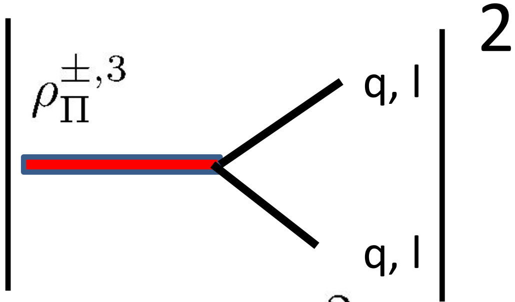
Support from holographic estimate
= 3 – 4 (significant techni-a1 contribution)

S.M., et al, in preparation

~ 80 GeV or less

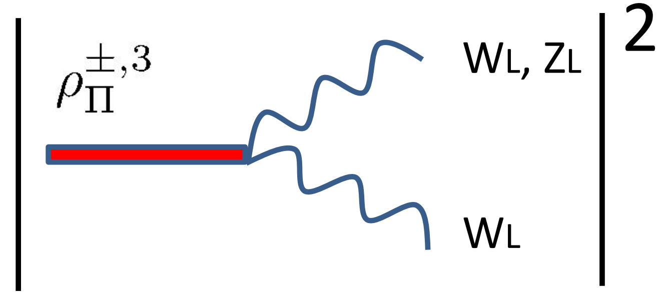
* LHC constraints on couplings?

To SM fermions



$$\propto \left(\frac{F_\rho}{M_\rho}\right)^2$$

To diboson (W, Z)



$$\propto \left(g_{\rho\pi\pi}\right)^2$$

Current LHC limits on 2 TeV W'/Z' candidate

diboson

$$\sigma^{\text{ATLAS}}_{WZ(3l\nu)}\,[\text{fb}] \le 22\,, \qquad \sigma^{\text{CMS}}_{WZ(3l\nu)}\,[\text{fb}] \le 19$$

$$\sigma^{\text{ATLAS}}_{WZ(2lJ)}\,[\text{fb}] \le 20\,, \qquad \sigma^{\text{CMS}}_{WZ(2lJ)}\,[\text{fb}] \le 27$$

$$\sigma^{\text{ATLAS}}_{WZ(l\nu J)}\,[\text{fb}] \le 9.5\,, \qquad \sigma^{\text{CMS}}_{WZ(l\nu J)}\,[\text{fb}] \le 13$$

$$\sigma^{\text{CMS}}_{WZ(JJ)}\,[\text{fb}] \le 12$$

*J = fat-dijet

leptons

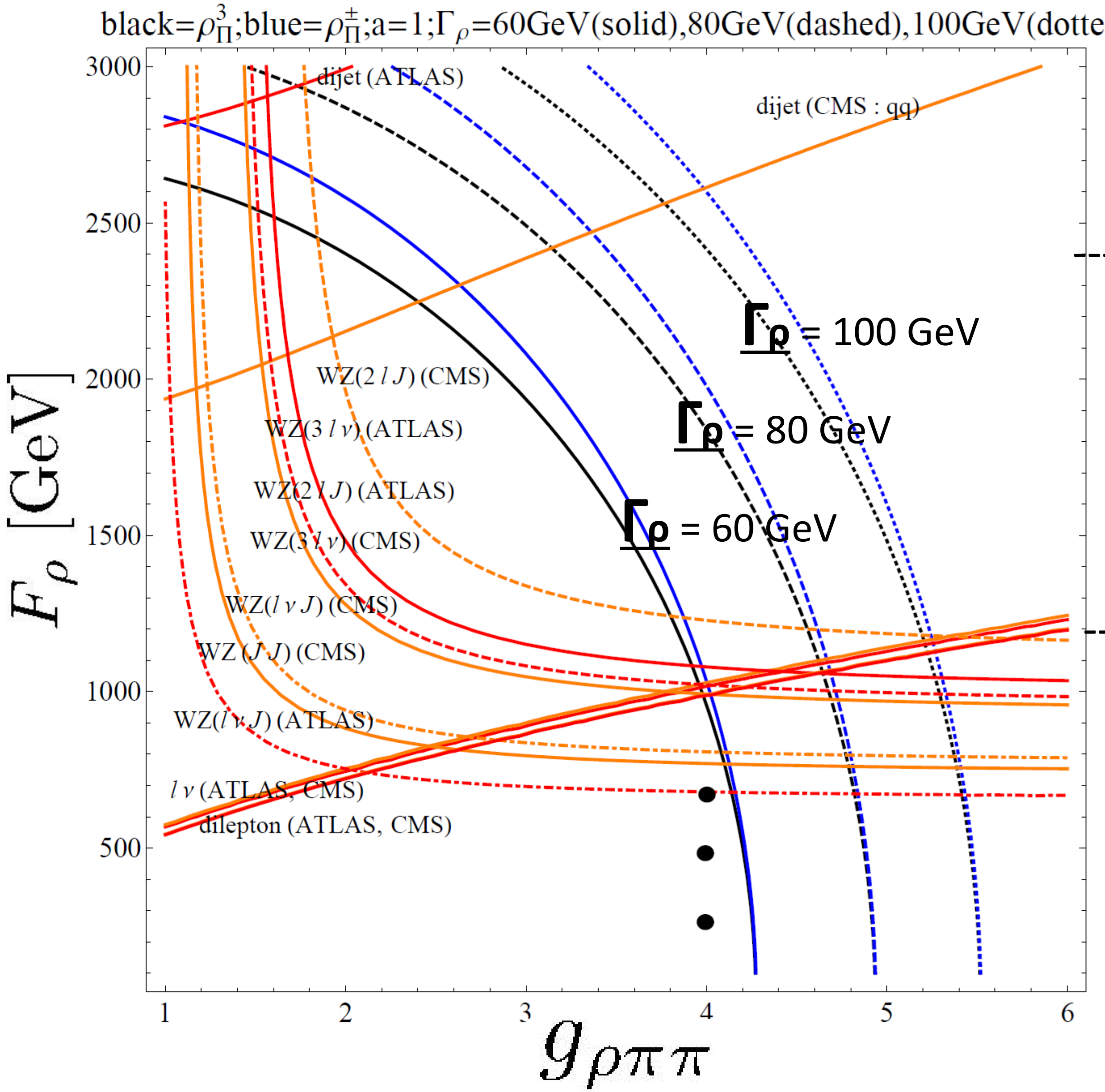
$$\sigma^{\text{ATLAS}}_{l\nu}\,[\text{fb}] \le 0.41\,, \qquad \sigma^{\text{CMS}}_{l\nu}\,[\text{fb}] \le 0.42$$

$$\sigma^{\text{ATLAS}}_{2l}\,[\text{fb}] \le 0.24\,, \qquad \sigma^{\text{CMS}}_{2l}\,[\text{fb}] \le 0.25$$

dijet

$$\sigma^{\text{ATLAS}}_{2j}\,[\text{fb}] \le 130\,, \qquad \sigma^{\text{CMS}}_{2j(qq)}\,[\text{fb}] \le 58$$

☆ Constraining rho couplings F_ρ and $g_{\rho\pi\pi}$



--- Current LHC limits constrain coupling to fermions

$$\frac{F_\rho}{M_\rho} \lesssim \frac{650\,\text{GeV}}{2000\,\text{GeV}} \simeq 0.33$$

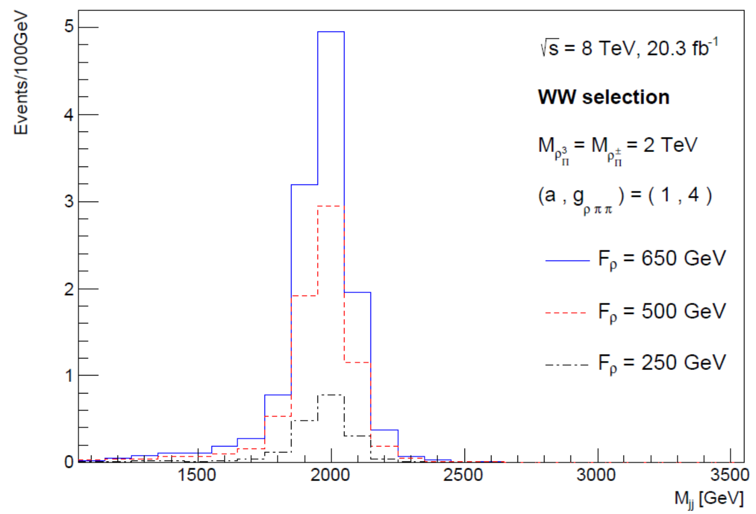
--- Take **Γρ** = 60 GeV

$$g_{\rho\pi\pi} = 4$$

c.f. holographic estimate = 3 – 4

S.M., et al, in preparation

☆ 2 TeV walking technirho signals in diboson mass distributions



Walking technirho **w/Γ = about 60 GeV**

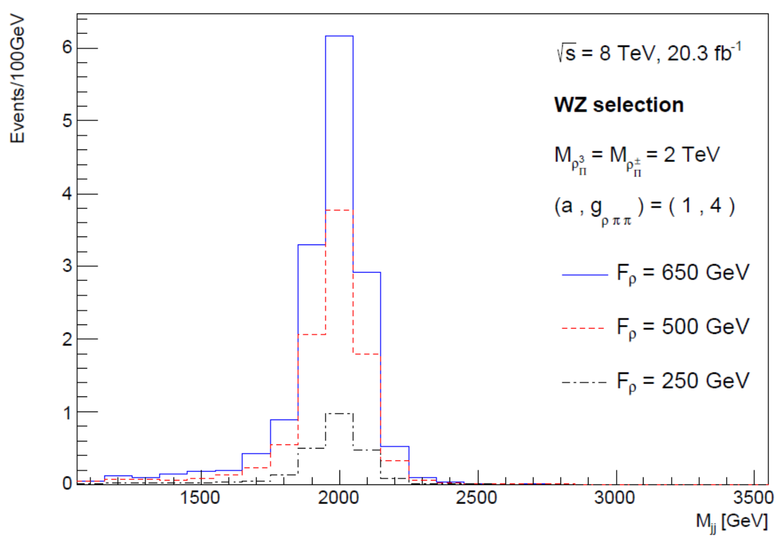
can explain the excesses!!

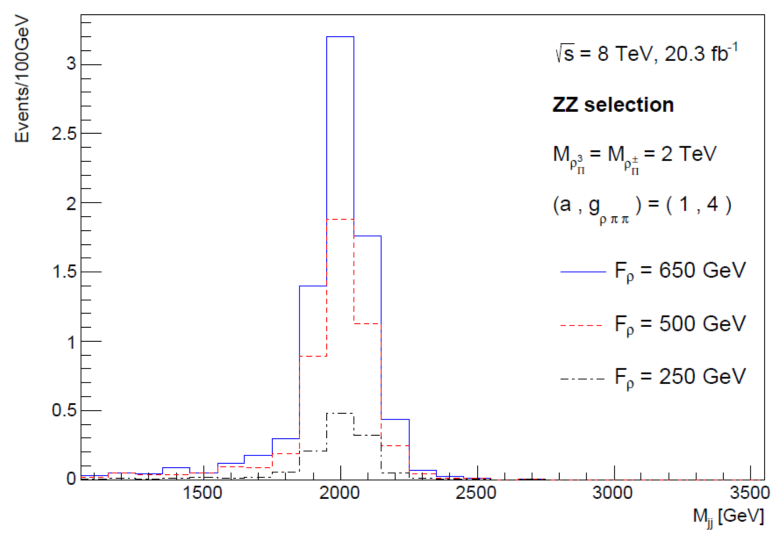
Observed excesses

WW/WZ selection: 5 – 6 events/bin

***ZZ selection : 2 – 3 events/bin**

** contamination from WW&WZ modes due to overlap b/w jet mass windows*





4. Summary

- ∗ The ATLAS diboson excesses may imply
  the walking technirho in 1FM of WTC

- ∗ The smoking-gun is the absence of decay to
  the Higgs + W/Z (``Conformal Barrier")

- ∗ More on the LHC signatures of the walking technirhos,
  in other channels (such as dilepton), is in progress.

Backup slides

☆ Implications of large F_ρ and small $g_{\rho\pi\pi}$: techni-a1

$$\mathcal{L}_{\rho\Pi ff} = -\sqrt{N_D}\frac{F_\rho}{M_{\rho\Pi}}\left[eJ_\mu^{\rm em}\rho_\Pi^{3\mu} + \frac{e(c^2-s^2)}{2sc}J_\mu^Z\rho_\Pi^{3\mu} + \frac{e}{2s}(J_\mu^{W^+}\rho_\Pi^{+\mu} + {\rm h.c.})\right]$$

S parameter

$$S|_\rho = 4\pi N_D (F_\rho/M_{\rho\Pi})^2 \simeq \mathcal{O}(10)$$

For $F_\rho = 700\ {\rm GeV}$, $N_D = 4$

Note the techni-a1 part and rho-a1 degeneracy

$$M_{\rho\Pi} \simeq M_{a_1\Pi}$$

$$S = S|_\rho + S|_{a_1} = 4\pi N_D (F_\rho/M_{\rho\Pi})^2[1-(F_{a_1}/F_\rho)^2]$$

If a1 has the same large coupling $F_{a_1} \simeq F_\rho$

like "degenerate BESS"
Casalbuoni, et al (1995)

S ~ 0 implying large DY cross section for a1

* Reference values of cross sections & BRs

$$F_\rho[\mathrm{GeV}] = (250, 500, 700)$$

$$\Gamma_{\rho^3_\Pi}\,[\mathrm{GeV}] \simeq (53, 55, 57)$$

$$\Gamma_{\rho^\pm_\Pi}\,[\mathrm{GeV}] \simeq (53, 54, 56)$$

$$\mathrm{Br}(\rho^3_\Pi \to WW)\,[\%] \simeq (99, 96, 93)$$

$$\mathrm{Br}(\rho^\pm_\Pi \to W^\pm Z)\,[\%] \simeq (99, 97, 94)$$

$$\sigma_{\mathrm{DY}}(pp \to \rho^3_\Pi)\,[\mathrm{fb}] \simeq (0.7, 2.8, 5.5)$$

$$\sigma_{\mathrm{DY}}(pp \to \rho^\pm_\Pi)\,[\mathrm{fb}] \simeq (1.4, 5.4, 11)$$

Simulation details

- PDF：CTEQ6L1
- Technirho implementation：FeynRules
- Event generation：MadGraph5_aMC@NLO
- Hadronization, parton showering：PYTHIA 8.1.86
- Jet reconstruction：FastJet 3.0.6（C/A R=1.2）

  （processed through BDRS-A algorithm ）

Simulation details

Event selection

i) # of fat-jets ≥ 2

ii) momentum balance of subjets $\sqrt{y_f} \geq 0.45$

iii) p_T cut for leading fat-jet $p_T(J_1) \geq 540$ GeV

iv) pseudo-rapidity for the two leading fat-jets ≤ 2

v) rapidity difference between the two leading fat-jets ≤ 1.2

vi) p_T asymmetry for the two leading fat-jets ≤ 0.15

vii) # of charged-particle tracks $n_{\rm tr} \leq 30$

viii) fat-jet mass range $M_W \pm 13$ GeV, $M_Z \pm 13$GeV