2 TeV Walking Technirho at LHC?

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Based on

arXiv:1506.03751, H.S.F, M.Kurachi, S.Matsuzaki, K.Terashi and K.Yamawaki
arXiv:1507.03428, H.S.F, S.Matsuzaki and K.Yamawaki

@IPMU/Durham/KIAS workshop
"New Particle Searches Confronting the first LHC Run-2 Data"

08.Sep.2015

1. Background and Introduction (1/8) : Diboson-excess @ ATLAS

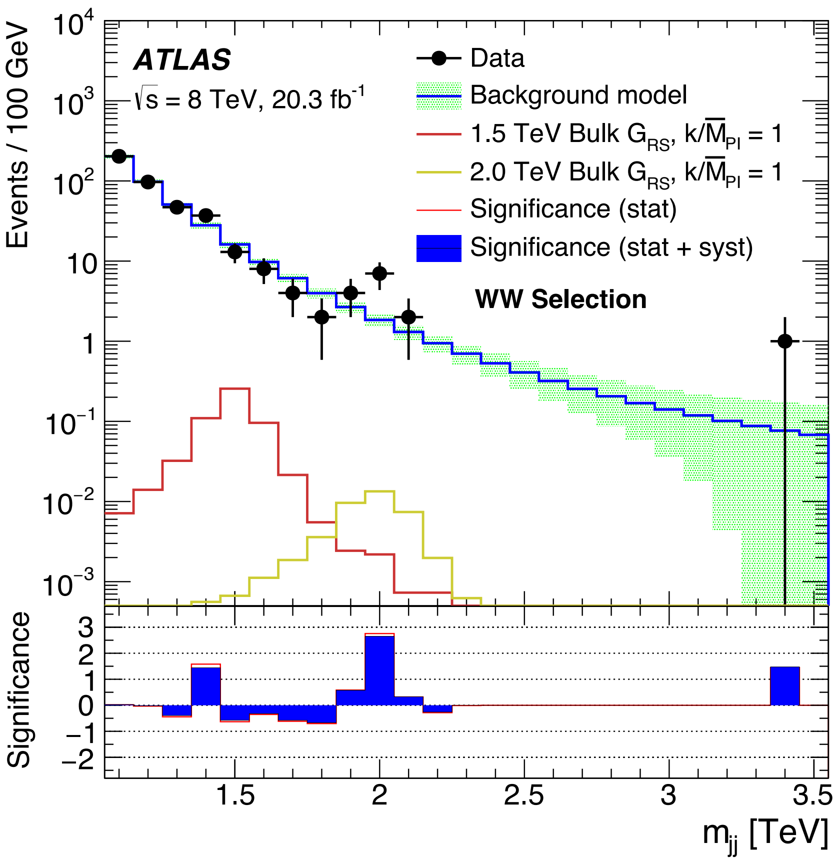
The ATLAS collaboration has reported an excess

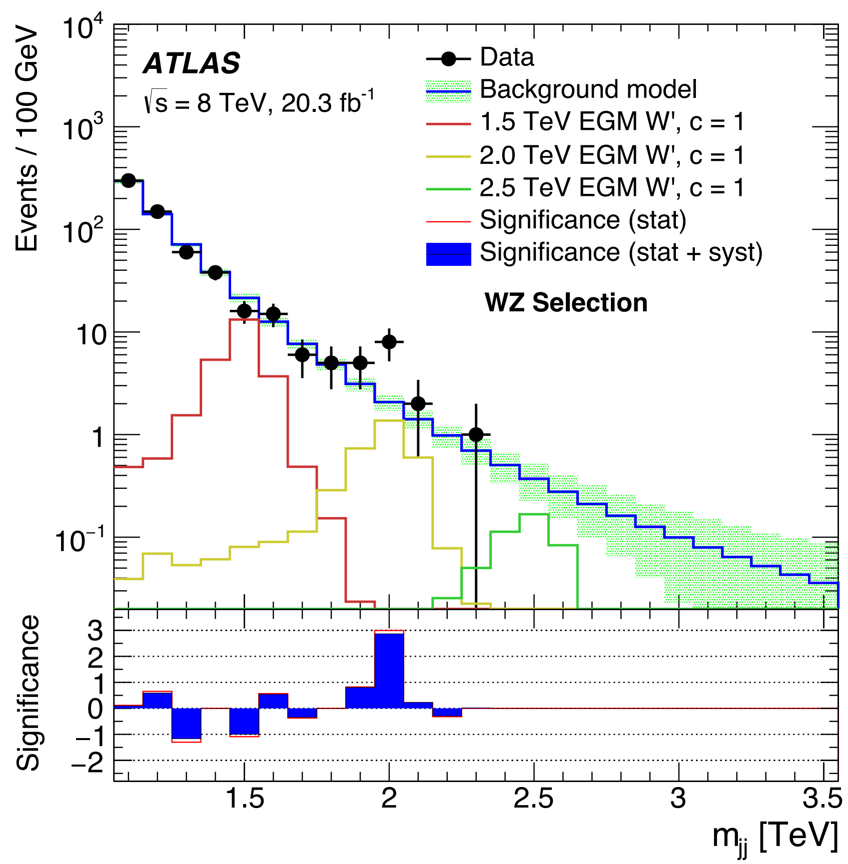
in full hadronic channel.

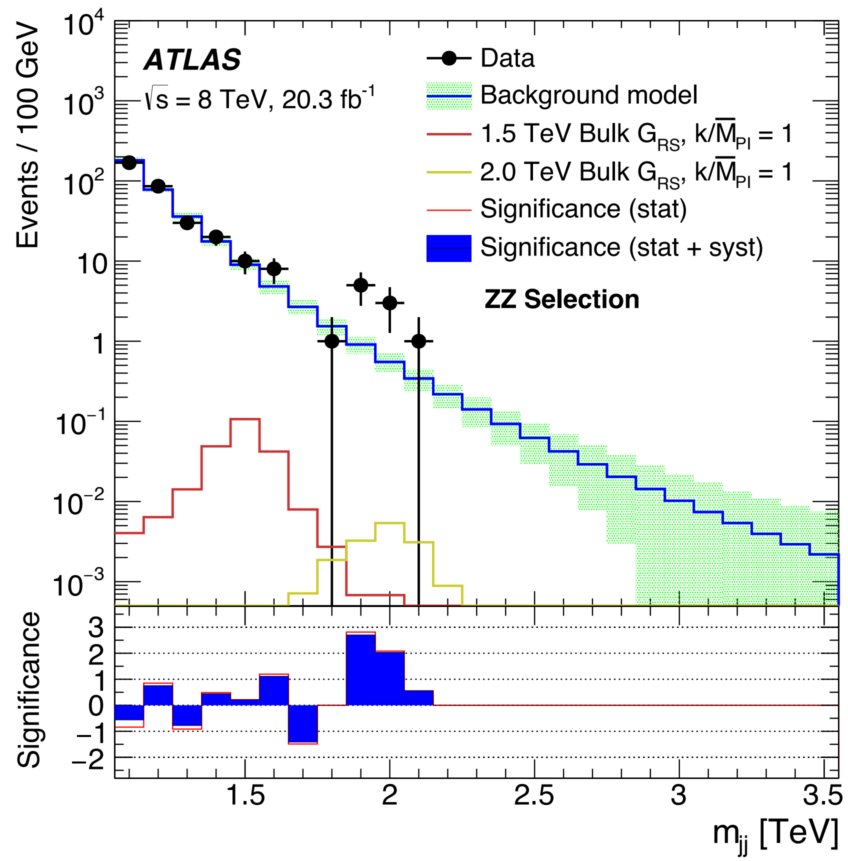
Narrow resonance decaying into WW/WZ/ZZ

arXiv: 1506.00962

$$M \simeq 2\,\mathrm{TeV}\,,\quad \Gamma \lesssim 100\,\mathrm{GeV}$$







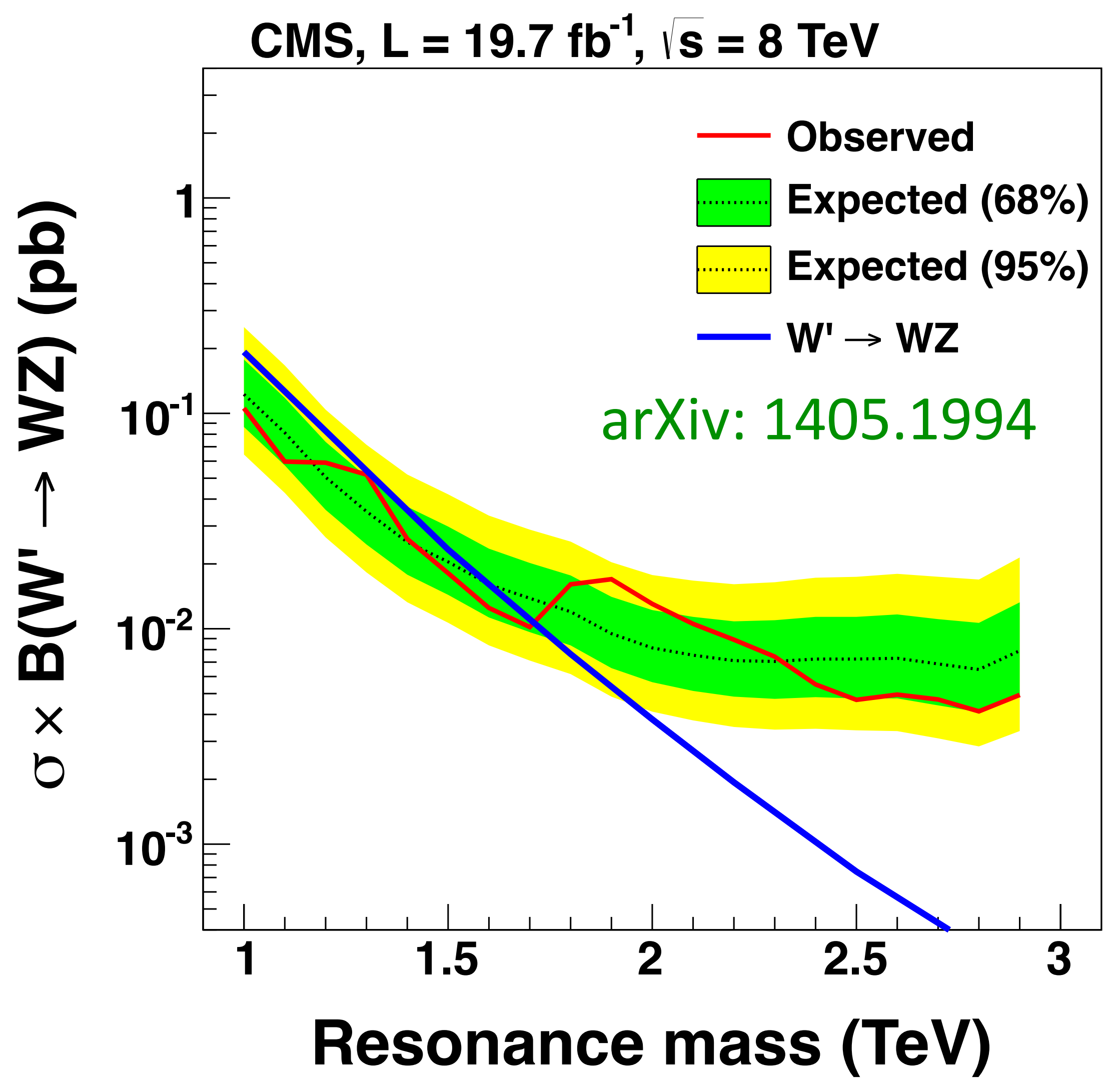
~3 sigma excesses

1. Background and Introduction (2/8) : Diboson results (hadronic)

Diboson resonance in full hadronic channel
has been searched at the CMS.

However

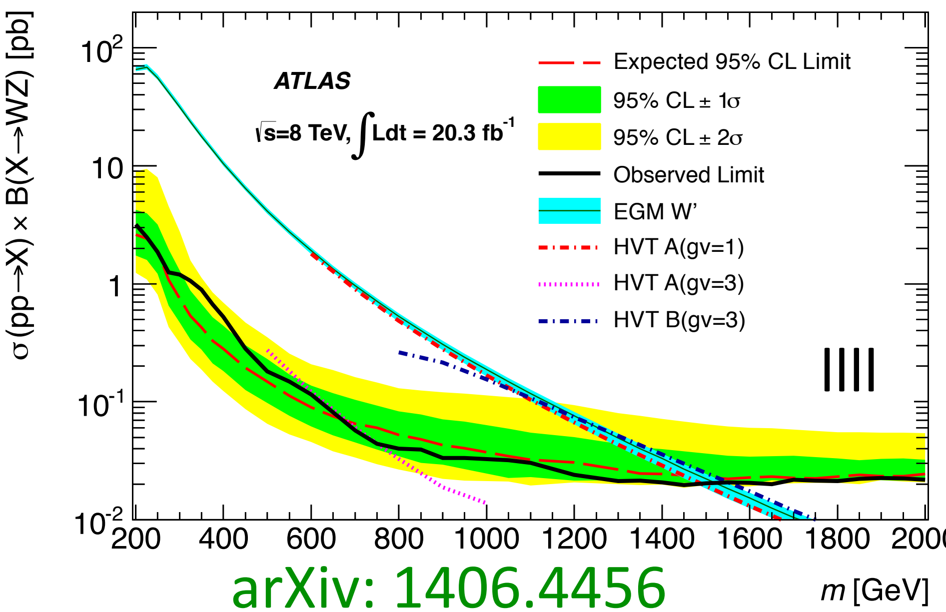
“ No significant excess has been observed ”



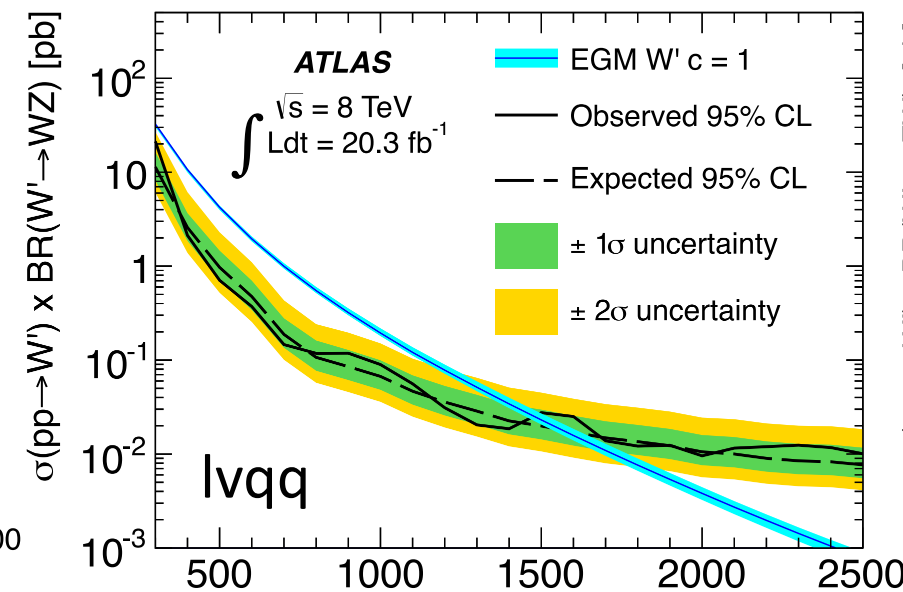
1. Background and Introduction (3/8) : Diboson results

No significant excess has been observed

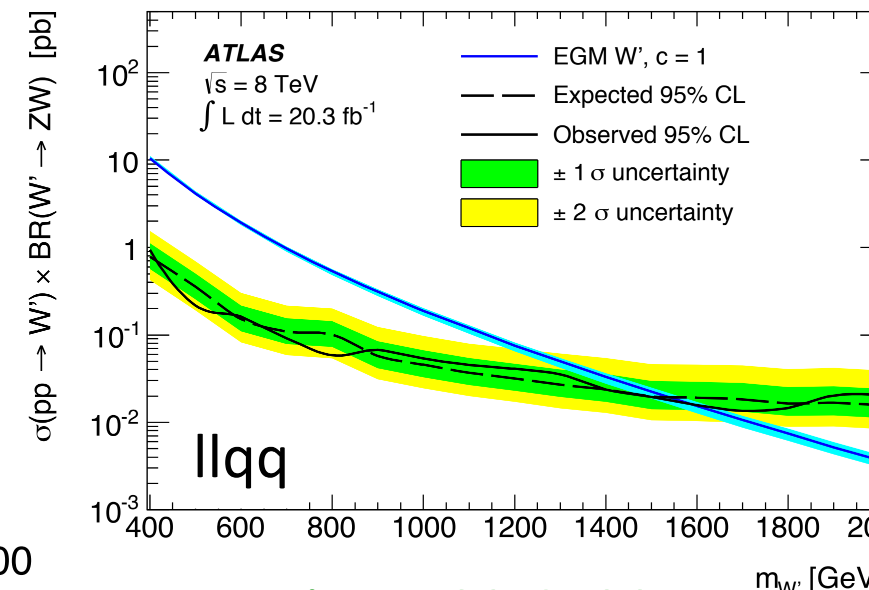
in leptonic channel.



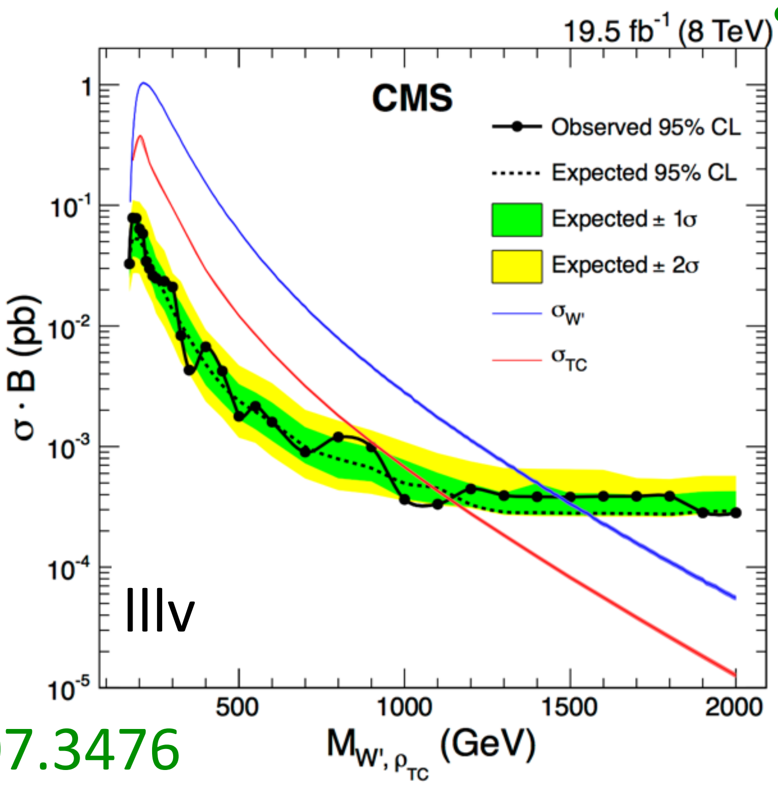
arXiv: 1406.4456



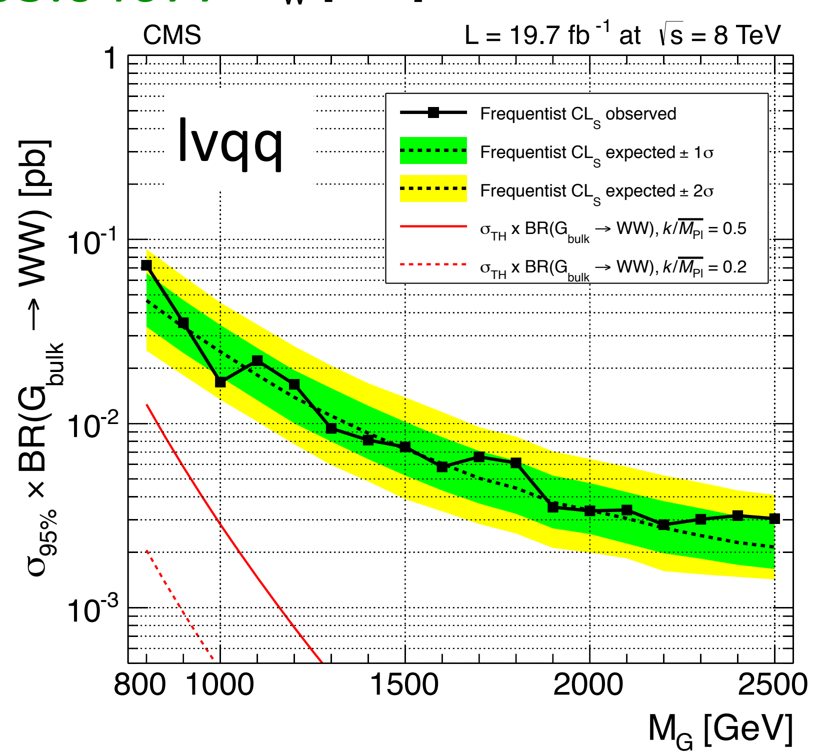
arXiv: 1503.04677



arXiv: 1409.6190



arXiv: 1407.3476



arXiv: 1405.3447

1. Background and Introduction (4/8) : Can we explain it?

Q:

Can we explain ATLAS diboson excess without conflicting with other diboson results?

A: YES we can do it.

I) Spin-0 massive resonance

arXiv: 1507.02483[Chiang et.al.], 1507.03098 [Cacciapaglia et.al.], ...

My talk

II) **Spin-1 massive resonance**

Many papers including our works arXiv:1506.03751,1507.03428

III) Spin-2 massive resonance

arXiv: 1507.06312[Kim et.al.], ...

1. Background and Introduction (5/8) :Spin-1 candidates

In the market,

a high mass spin-1 resonance is described

I) based on an elementary scenario

e.g. SU(2)L x SU(2)R x U(1) model

1506.06736 [Dobrescu et.al.],
1507.01185 [Abe et.al.], 1507.01681 [Abe et.al.], …

II) based on a composite scenario

My talk

I. **Walking Technicolor**

1506.03751 [Fukano et.al.], 1507.03428 [Fukano et.al.]

II. SU(2) triplet model

1506.04392 [Franzosi et.al.], 1506.08688 [Thamm et.al.]

III. Composite Higgs model

1507.01914 [Carmona et.al.], 1507.07557 [Low et.al.]

1. Background and Introduction (6/8) : Vector meson in my talk

1506.03751 and 1507.03428

"2 TeV diboson resonance" in my talk

= **Vector meson** generated

not by technicolor(=QCD-like dynamics)

but by

Walking technicolor

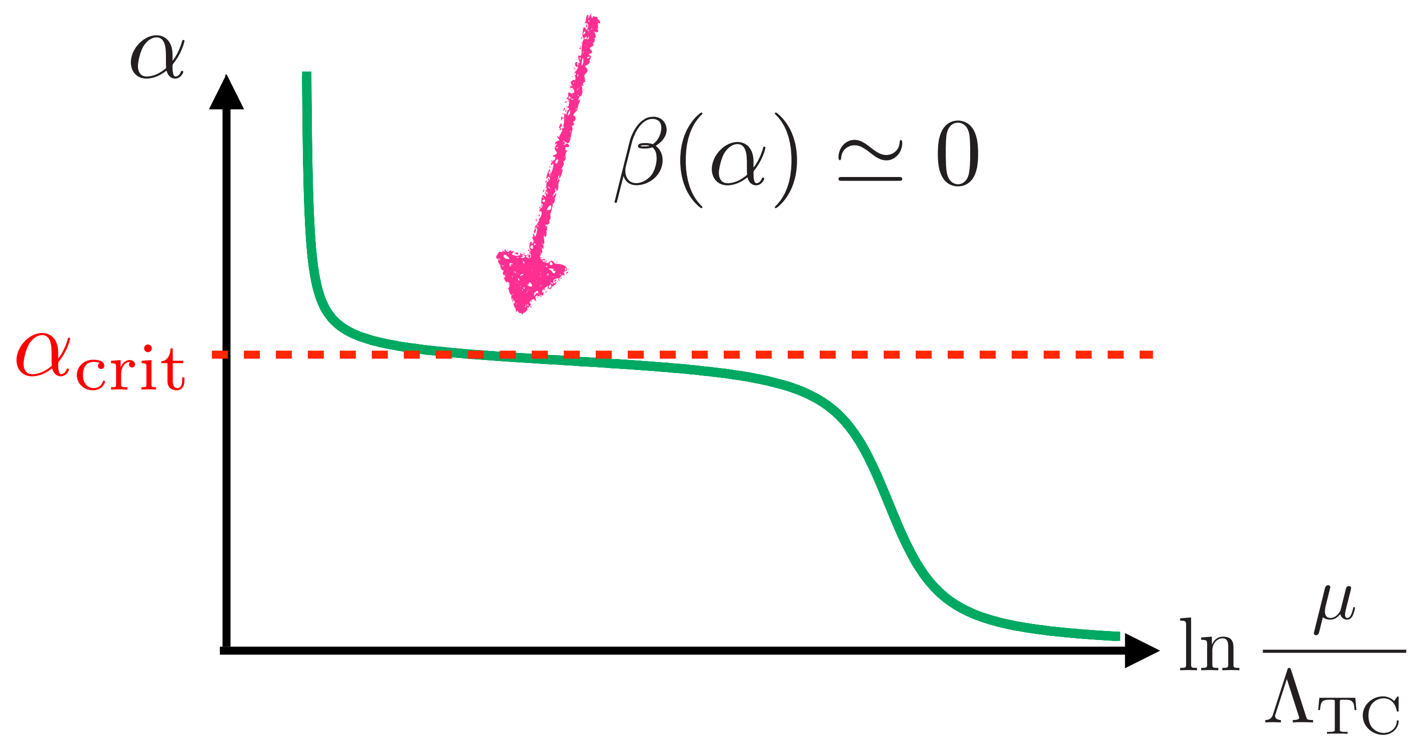
(=near conformal dynamics)

1. Background and Introduction (7/8) : walking technicolor

Walking Technicolor (WTC) Holdom (1985); Yamawaki et.al. (1986); Bando et.al. (1986);Akiba et.al.(1986); Appelquist et.al.(1986)

(i) gives dynamical explanation for origin of mass and EWSB by technifermion condensation $\langle \bar{F}F \rangle \neq 0$

(ii) is based on the almost scale invariant (="walking") dynamics



(iii) is realized by SU(4) gauge theory with 8 flavors

Matsuzaki et.al. (2012,2013)

1. Background and Introduction (8/8) : Walking TC hadrons

Low-lying spectra in SU(4) with 8 flavors (=**1 Family WTC**):

(I) Technidilaton = 125 GeV Higgs

Matsuzaki et.al. (2012,2013,2015)

Due to walking feature

(II) Techni-Pion = few TeV scale mass

60 [pNGBs] = 63 [NGBs] - 3[eaten by W/Z]

Jia et.al. (2012); Kurachi et.al.(2014)

(III) **Techni-vector meson**

lightest isotriplet vector meson

→ Just Fit to 2 TeV

supported by BS, lattice and holography

Harada et.al. (2003); LatKMI (2015);
Haba et.al. (2010); Matsuzaki et.al.(2012)

2. Conformal Barrier (1/2) : TC dilaton + vector mesons

The low-lying spectra are described by

scale invariant Hidden Local Symmetry (sHLS).

arXiv:1506.03751,1507.03428

After integrating out heavy Techni-Pions

and taking Unitary gauge, the sHLS Lagrangian becomes

$$\mathcal{L}_{\rm sHLS} = \mathcal{L}_{\rm kin}(V_\mu^a, W_\mu^a) + F_\pi^2 \underline{\left(1 + \frac{2\phi}{F_\phi}\right)} \left[(W_\mu^a)^2 + a \cdot (\underline{W_\mu^a - V_\mu^a})^2\right] + \cdots$$

mass mixing

$$F_\pi^2 = \frac{v^2}{4}$$

scale symmetry is realized nonlinearly

mass diagonalization

$$\mathcal{L}_{\rm sHLS} = \mathcal{L}_{\rm kin}(\tilde{V}_\mu^a, \tilde{W}_\mu^a) + F_\pi^2 \underline{\left(1 + \frac{2\phi}{F_\phi}\right)} \left[(\tilde{W}_\mu^a)^2 + a \cdot (\underline{\tilde{V}_\mu^a})^2\right] + \cdots$$

No off-diagonal coupling to dilaton !!

arXiv:1507.03428

2. Conformal Barrier (2/2): Features of walking TC-rho

The **vector meson (= walking TC-rho)** has a distinct nature:

" Conformal Barrier "

arXiv:1507.03428

No off-diagonal coupling to dilation (=Higgs) due to scale/conformal invariance

$$g[\tilde{\rho}_{\Pi}^{\mp} - \tilde{W}^{\pm} - \phi] = 0\,, \quad g[\tilde{\rho}_{\Pi}^{0} - \tilde{Z} - \phi] = 0$$

"Conformal Barrier" means

$$\mathrm{Br}(\rho^{\pm} \to W^{\pm} Z) \simeq 100\%\,, \quad \mathrm{Br}(\rho^{0} \to W^{\pm} W^{\mp}) \simeq 100\%$$

in sharp contrast to other vector resonance model where

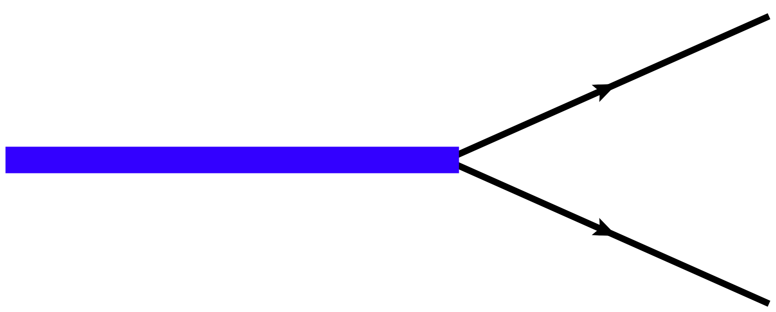
$$\mathrm{Br}(W' \to W^{\pm} Z) \simeq \mathrm{Br}(W' \to Wh) \simeq 50\%$$

3. Phenomenologies (1/7): Possible decay mode of TC-rho

Thanks to **"Conformal Barrier"** ,

decay channels of TC-rho meson are divided into two types:

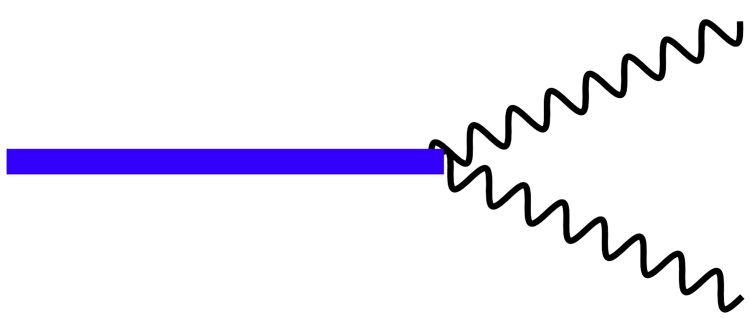
I. to SM fermions: controlled by F_ρ



$$\mathcal{L}_{\rho f f} = -\left(\sqrt{\frac{N_f}{2}}\frac{F_\rho}{M_\rho}\right) \times \tilde{\rho}_\mu J^\mu$$

$$N_f = 8$$

II. to EW gauge bosons: controlled by $g_{\rho\pi\pi}$



$$\mathcal{L}_{\rho VV} = -i\left(\sqrt{\frac{2}{N_f}}\, g_{\rho\pi\pi}\right) \times (\partial_\mu \tilde{\rho}_\nu - \partial_\nu \tilde{\rho}_\mu) V^\mu V^\nu$$

3. Phenomenologies (2/7): Total width of TC-rho

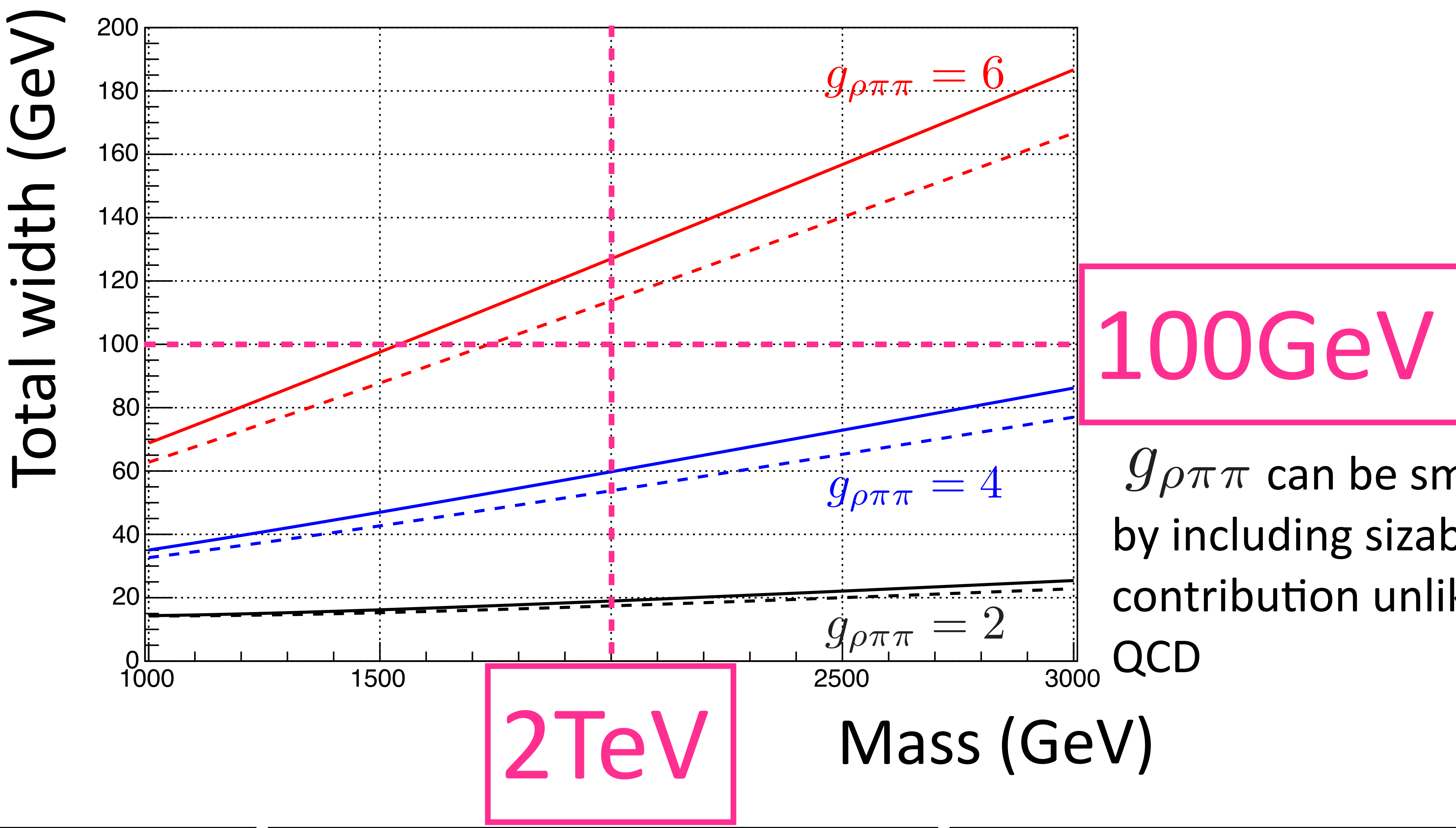
ATLAS results imply narrow width resonance with $\Gamma \lesssim 100\,\mathrm{GeV}$

Width is suppressed in **1FMWTC** compared with scale-up QCD:

$$N_f = 8 \qquad \frac{\Gamma_\rho[\mathrm{1FMWTC}]}{\Gamma_\rho[\mathrm{QCD}]} \simeq \frac{2}{N_f}$$

$\Gamma_\rho[\mathrm{QCD}] \simeq 480\,\mathrm{GeV}$

for $g_{\rho\pi\pi} \simeq 6$, $M_\rho = 2\,\mathrm{TeV}$



$g_{\rho\pi\pi}$ can be small by including sizable a1 contribution unlike QCD

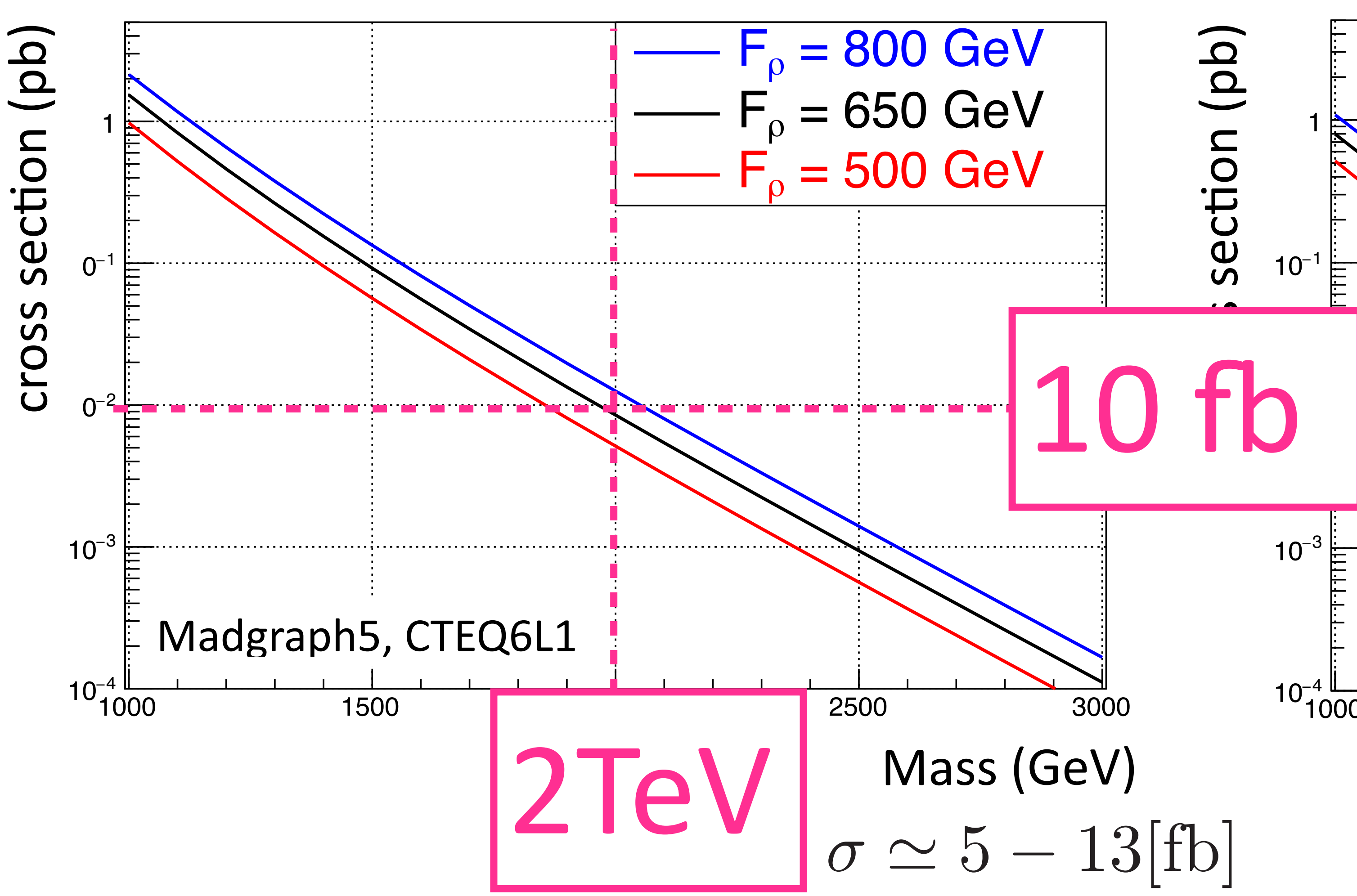
3. Phenomenologies (3/7): Diboson channel @ 8TeV

Cross section: $\sigma_{\rm DY}(pp \to \tilde{\rho} \to VV)$ @ 8TeV for $g_{\rho\pi\pi} = 4$:

Thanks to **"Conformal Barrier"**,

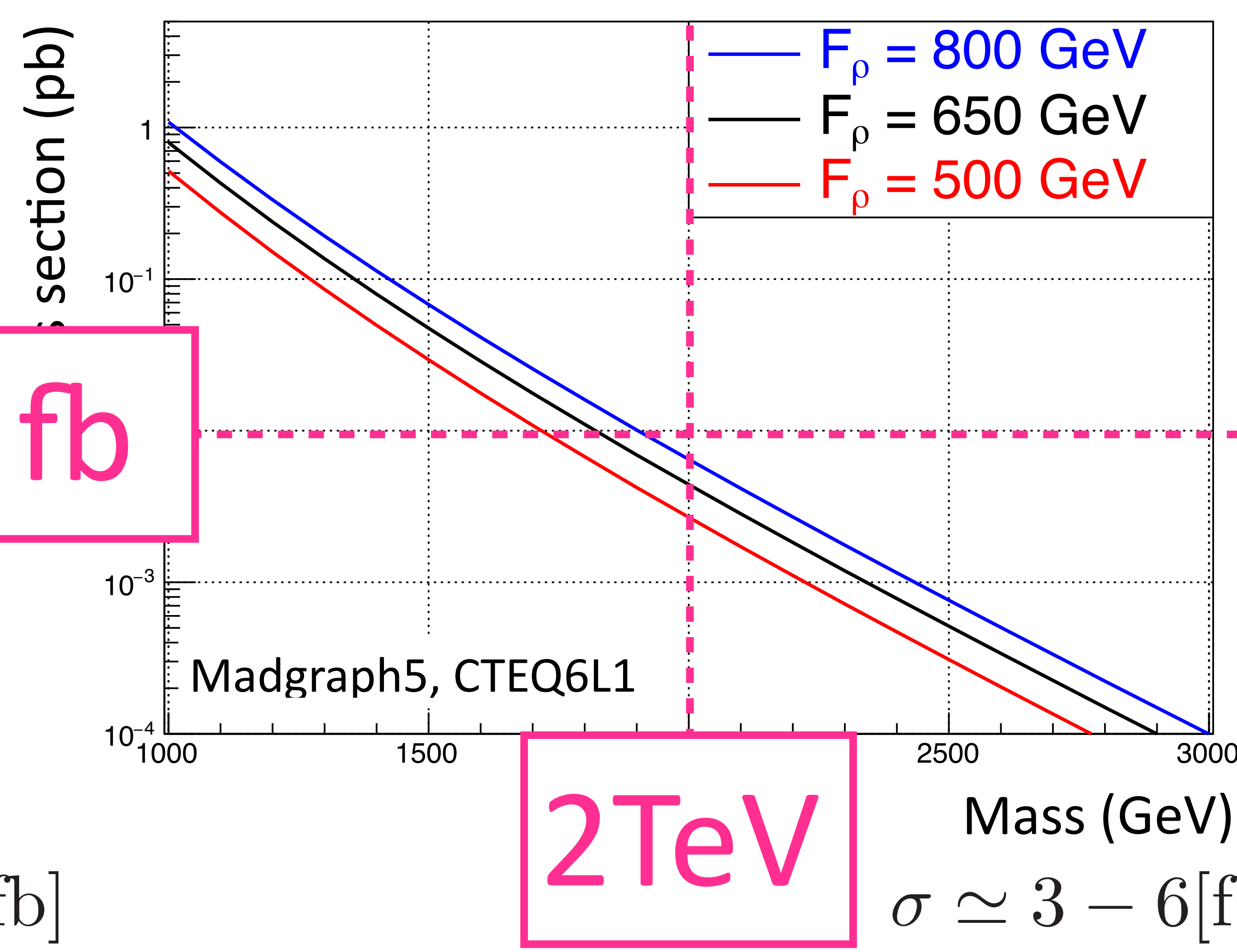
$$\sigma(pp \to \tilde{\rho} \to VV) \simeq 10 - 20[\mathrm{fb}] \text{ for } M_{\tilde{\rho}^0} = M_{\tilde{\rho}^\pm} = 2\,\mathrm{TeV}$$

Charged TC-rho



$\sigma \simeq 5 - 13[\mathrm{fb}]$

Neutral TC-rho



$\sigma \simeq 3 - 6[\mathrm{fb}]$

3. Phenomenologies (4/7): Other vector particle search results

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

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

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

Most stringent diboson-constraint

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

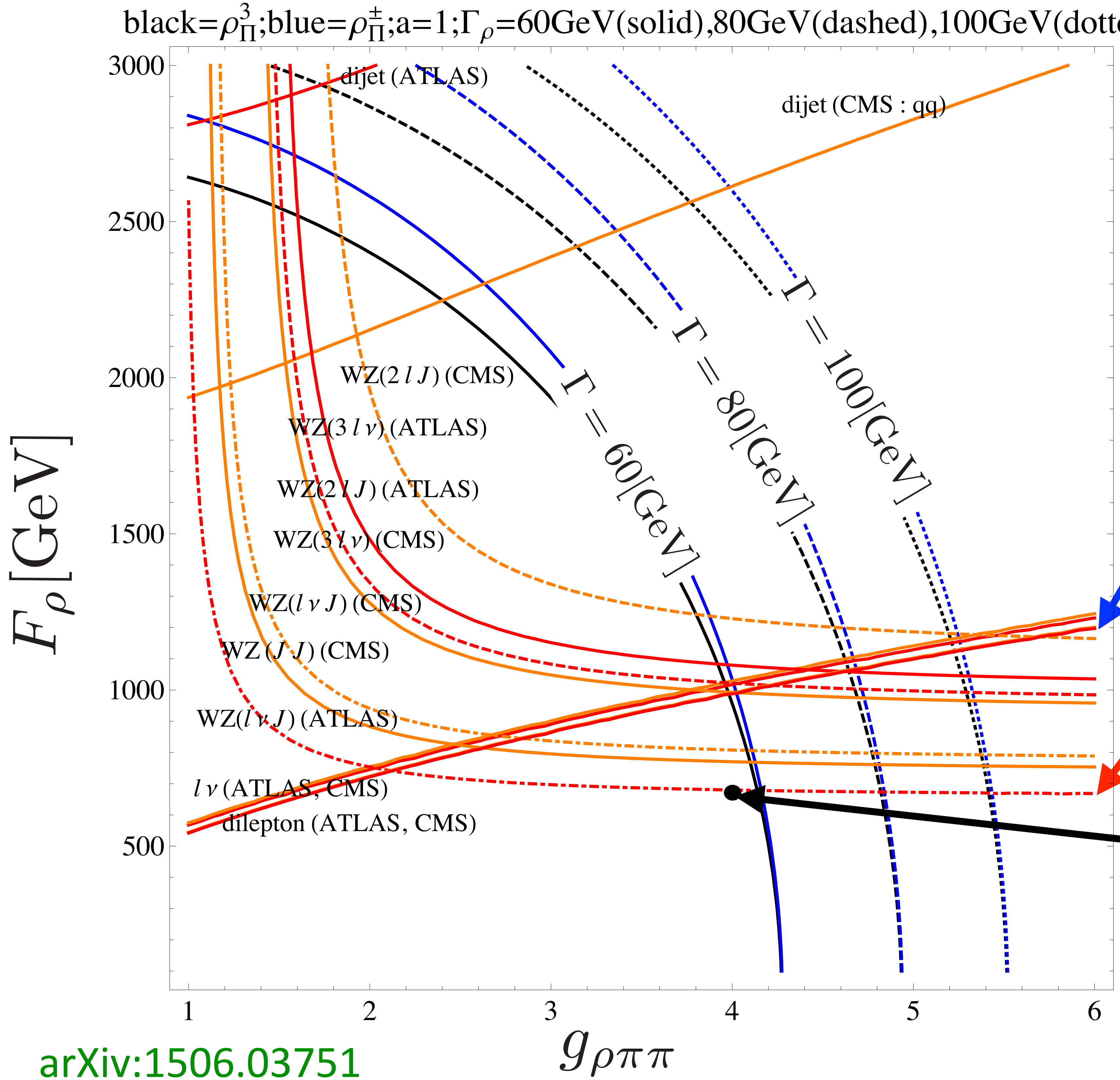
$$\sigma^{\rm ATLAS}_{l\nu}[{\rm fb}] \le 0.41\,, \qquad \sigma^{\rm CMS}_{l\nu}[{\rm fb}] \le 0.42\,,$$

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

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

Most stringent difermion-constraints

3. Phenomenologies (5/7):Coupling constraints from other results



$\sigma_{2l}^{\rm ATLAS}[\rm fb] \le 0.24\,,$

$\sigma_{2l}^{\rm CMS}\;[\rm fb] \le 0.25$

$\sigma_{WZ(l\nu J)}^{\rm ATLAS}[\rm fb] \le 9.5$

Upper bound for F_ρ :

$$F_\rho \lesssim 650[\rm GeV]$$

arXiv:1506.03751

3. Phenomenologies (6/7): Collider simulation

Signal event generation

arXiv:1506.03751

for $pp \to \tilde{\rho} \to VV \to JJ$ (J=CA12 jet):

* FeynRules2 + Madgraph5
* Pythia8
* FastJet3
* smearing for jet momentum/energy/mass to account for migration due to ATLAS detector resolution

Event selection following ATLAS analysis:

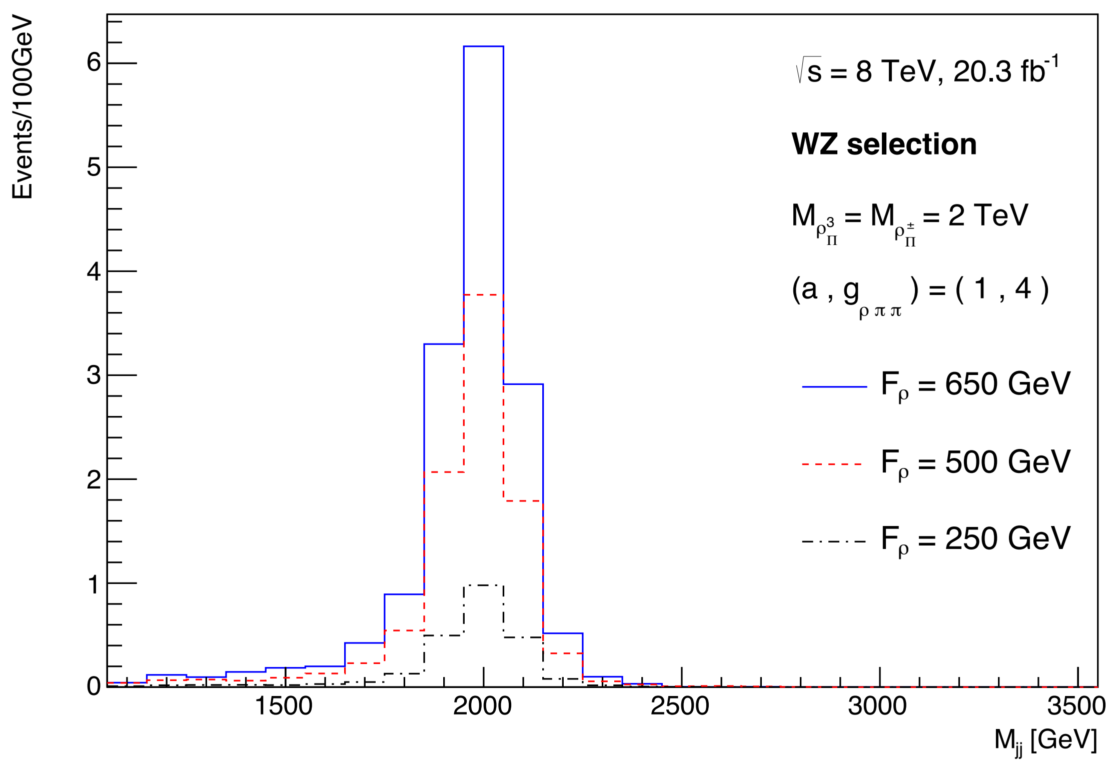
Cut 1: $p_{T_{1,2}} \geq 540\,\mathrm{GeV}$, $|\eta_{1,2}| \leq 2$ and $|y_1 - y_2| \leq 1.2$,

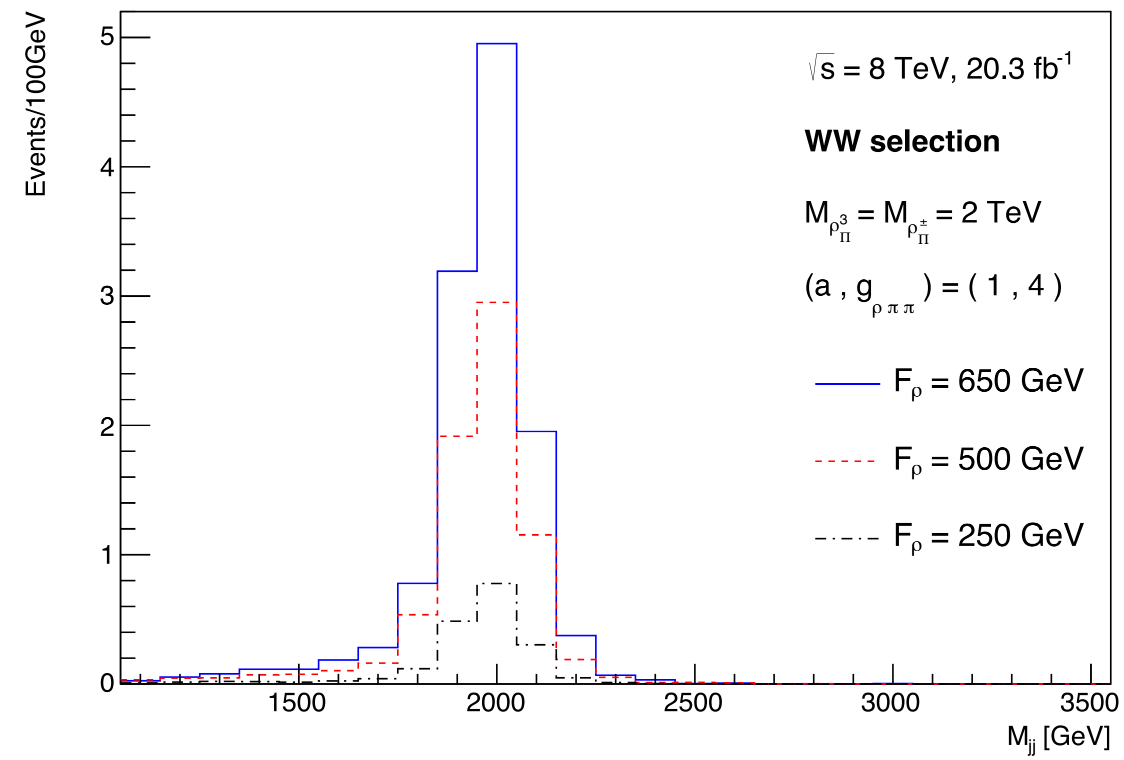
Cut 2: $(p_{T_1} - p_{T_2})/(p_{T_1} + p_{T_2}) \leq 0.15$,

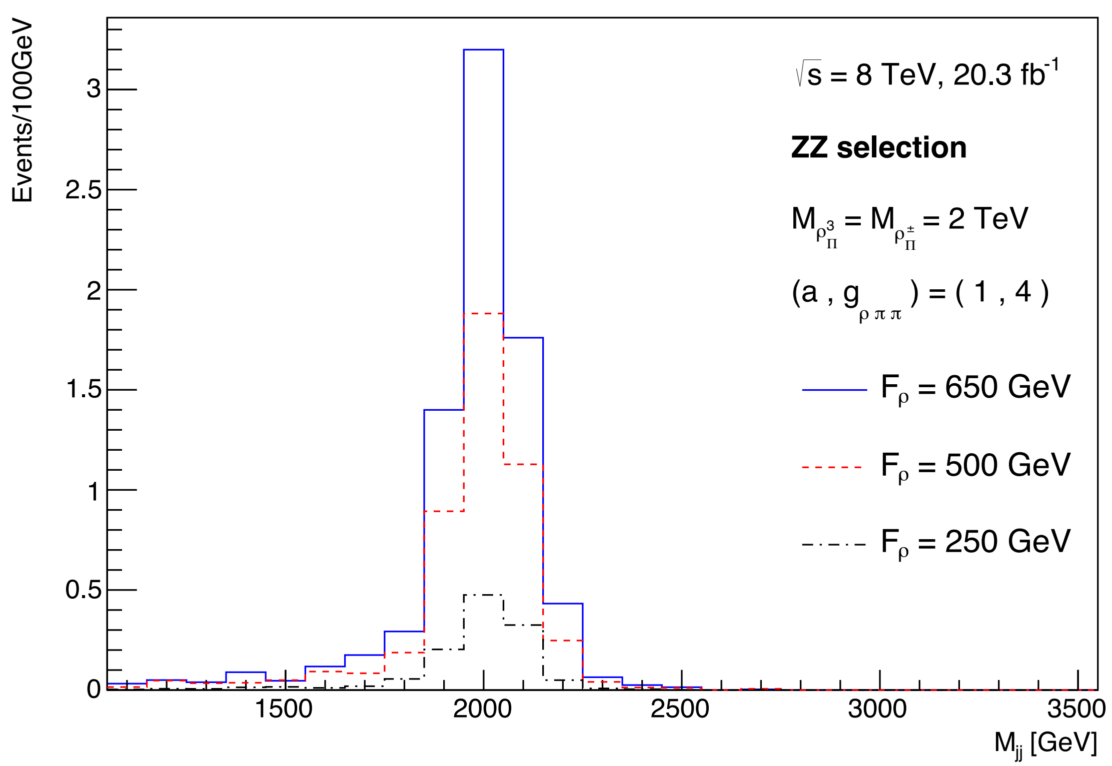
Cut 3: $\sqrt{y} \geq 0.45$, $n_{\mathrm{trk}} < 30$, $|m_j - m_V| \leq 13.0\,\mathrm{GeV}$ where $m_W = 82.4\,\mathrm{GeV}$ and $m_Z = 92.8\,\mathrm{GeV}$,

3. Phenomenologies (7/7): Results

arXiv:1506.03751







GOOD EXPLANATION !!

# @ peak	TC-rho	ATLAS
WZ	~6	~3-8
WW	~5	~3-6
ZZ	~3	~2-3

4.Summary

- **ATLAS diboson excess** may be a hint for BSM
- ATLAS excess around 2TeV in full hadronic channel
  = **Vector meson** based on **1-Family Walking technicolor**
  $$N_f = 8$$
- **Narrow width** is realized thanks to **1FMWTC**
  $$\Gamma \lesssim 100\,\mathrm{GeV}$$
- **Large cross section** is realized thanks to
  Conformal Barrier (no decay into H + W/Z)
  $$\sigma(pp \to \tilde{\rho} \to VV) \simeq 10 - 20[\mathrm{fb}]$$
- More studies on LHC signatures of TC-rhos are on-going

Thank you very much

Backup slides

Symmetry breaking in sHLS

The sHLS are nonlinear realization for

arXiv:1506.03751,1507.03428

I. scale invariance

II. chiral symmetry

$$\frac{G}{H} = \frac{SU(8)_L \times SU(8)_R \times [SU(8)_V]_{\rm HLS}}{SU(8)_V}$$

The ingredients are

Techni-dilaton, Techni-pion and Techni-vector mesons

TC-rhos from 1FMWTC

		SU(3) color	SU(2) EW
ATLAS diboson	ρ^i	singlet	triplet
No couple to W/Z	ρ^i_P	singlet	triplet
Weak couple to W/Z	ρ^0_P	singlet	singlet
No couple to W/Z	$\rho^i_{\theta_a}$	octet	triplet
	$\rho^0_{\theta_a}$	octet	singlet
No couple to W/Z	$\rho^i_{T_c}, \bar{\rho}^i_{T_c}$	triplet	triplet
	$\rho^0_{T_c}, \bar{\rho}^0_{T_c}$	triplet	singlet

$$M_\rho = 1 - 4\,\mathrm{TeV}$$