COST Workshop on Higgs and Flavour Physics: Present and Future

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The LHC limits on the **mass** and the **direct couplings** of the BSM **$SU(2)_{L+R}$ vector** resonance triplet

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Introduction

the problem

- BSM=?
- composite/strongly-interacting
- new resonances
- not seen yet
- mass exclusion limits

vector resonances

- Higgs + NGB = candidates for scalar resonances
- **vector resonances** … well motivated
  - CHM, TC2, ...
- effective Lagrangian: a convenient tool for pheno

Introduction

direct searches

- ATLAS+CMS
- $\leq$ 13 TeV, $\leq$ 36 fb^{-1}
- no "$pp \to R$" signal $\Rightarrow$ upper limits on "$\sigma_{prod} \times BR(R \to ab)$"
  - tailored for **narrow resonances**, $\Gamma/M \leq 10\%$
  - some attempts beyond this restriction
- vector resonances:
  - MEL's: **model dependent**

Our Goals

the vector resonance

- **$SU(2)_{L+R}$ triplet** of vector resonances
- effective description via the Hidden Local Symmetry approach
- its **mass** depends on the model's couplings
- its **total width** grows with the resonance mass
- neutral & charged vector resonances are **degenerate**
- **direct couplings to fermions:** 3rd quark generation only

particular questions:

- **MEL**'s: the impact of the resonance-to-fermions free params
- the role of the **b-quark proton contents**
- restriction by the **NWA**

tBESS model

the effective Lagrangian

- the modified BESS model
  - BESS[R. Casalbuoni et al, PLB 155, 95 (1985); NPB282, 235 (1987)]
  - a specific resonance-to-fermion interaction pattern
  - emphasizes **the role of the 3rd quark generation**
  - **avoids the EWPD low-energy limits**
- particle spectrum
  - **SM fields + vector resonance triplet**
- symmetry
  - global $\mathbf{SU(2)_L \otimes SU(2)_R \rightarrow SU(2)_{L+R}}$ (Higgs sector)
  - auxiliary $SU(2)_{HLS}$: the vector triplet as gauge bosons
  - non-linear sigma model (NGB)
  - the 125 GeV $SU(2)_{L+R}$ scalar singlet (Higgs)

tBESS model

the Lagrangian's free parameters

- the gauge couplings:
  - g … $SU(2)_L$
  - g' … $U(1)_Y$
  - g''/2 … $SU(2)_{HLS}$
- the resonance masses: $M_\rho \approx \sqrt{\alpha} g'' v/2$
- the direct vector-to-fermion couplings:

vertex	$V^3 t_L t_L$, $V^3 b_L b_L$	$V^\pm t_L b_L$	$V^3 t_R t_R$	$V^3 b_R b_R$	$V^\pm t_R b_R$
cplng	$b_L g''/2$	$b_L g''/2$	$b_R g''/2$	$p^2 b_R g''/2$	$p b_R g''/2$

- perturbativity limit: $g''/2 \leq 4\pi$
- EWPD, Higgs sector measurements, unitarity limits: $g'' > 12$
- EWPD: $|b_{L,R}| < 0.1$

tBESS model

the phenomenological vertices

- $(V^3, V^\pm) \rightarrow (\rho^0, \rho^\pm)$
- the gauge boson mixings: $\rho^0(V^3,W^3,B)$, $\rho^\pm(V^\pm,W^\pm)$
- **induced interactions** of ρ to all fermions: ~ 1/g''

the ρ decays

$$\Gamma_{\rho\to tt} = \frac{M_\rho g''^2}{128\pi}\left(b_L^2 + b_R^2\right)$$

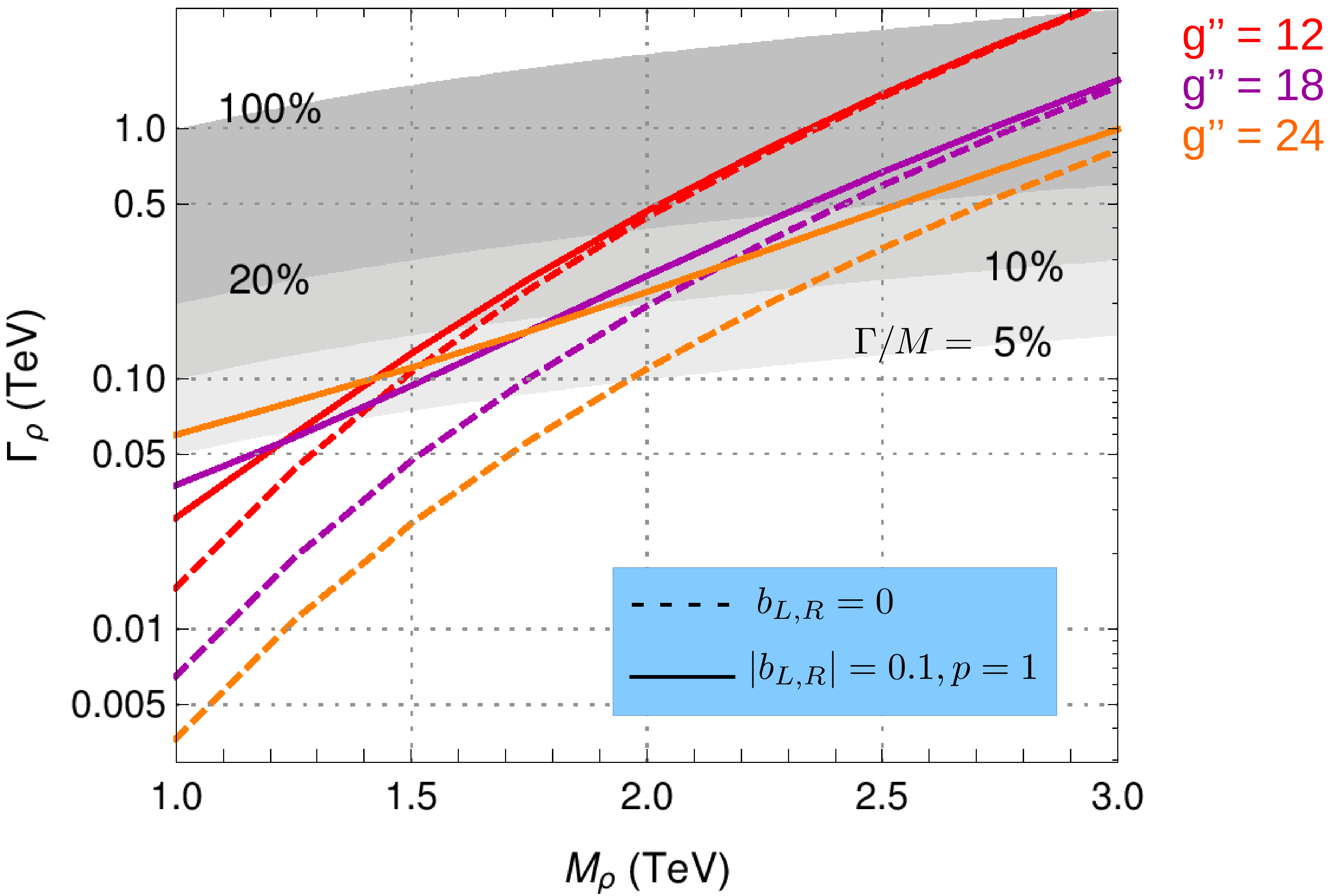
$$\Gamma_{\rho\to WW,WZ} = \frac{M_\rho}{48\pi g''^2}\left(\frac{M_\rho}{v}\right)^4$$

$$\Gamma_{\rho\to bb} = \frac{M_\rho g''^2}{128\pi}\left(b_L^2 + p^4 b_R^2\right)$$

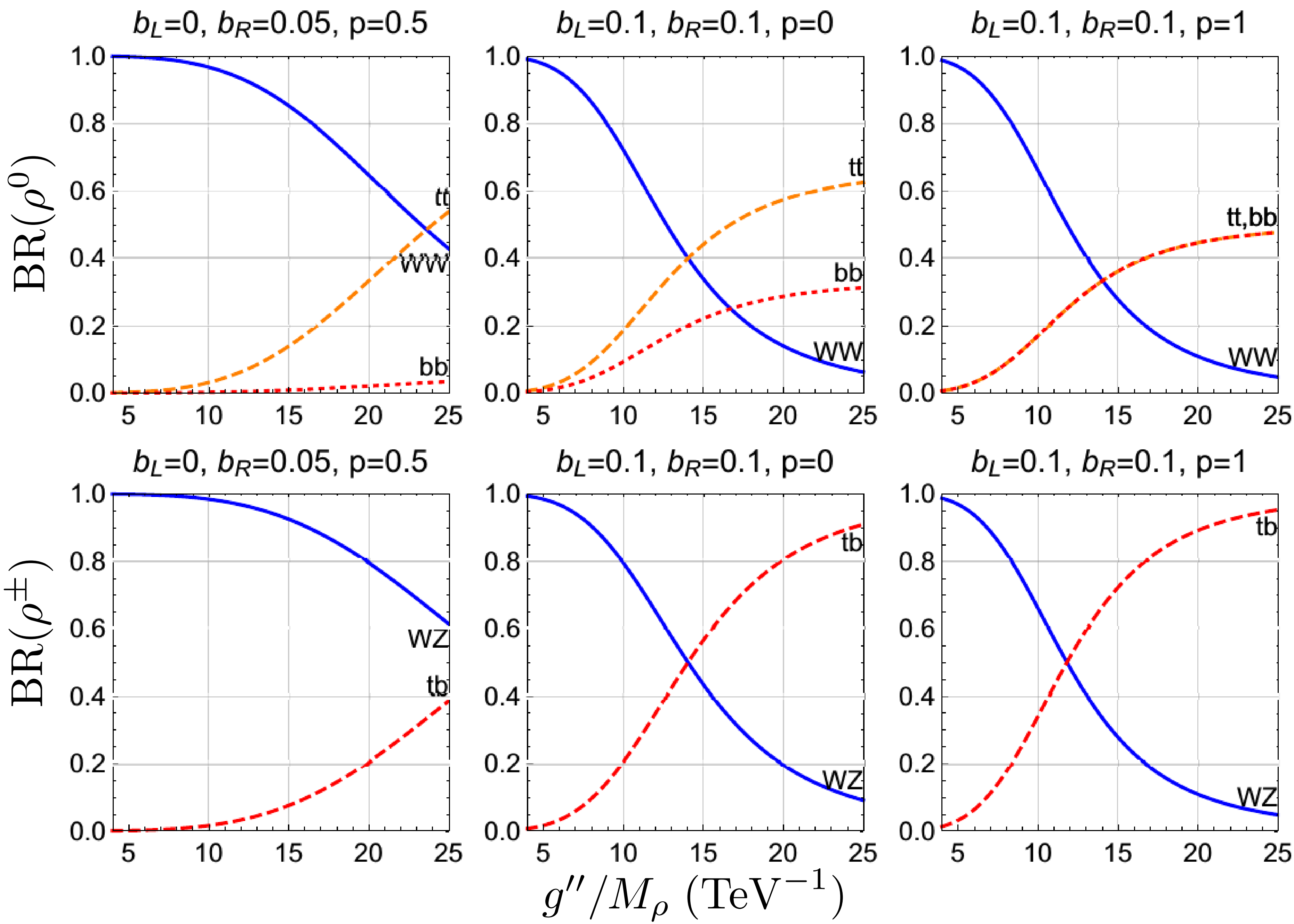
$$\Gamma_{\rho\to tb} = \frac{M_\rho g''^2}{64\pi}\left(b_L^2 + p^2 b_R^2\right)$$

- $\rho \rightarrow$ light ferms, HZ, HW: **negligible** $\Gamma \sim 1/(g'')^2$

Total Decay Width of ρ_{tBESS}



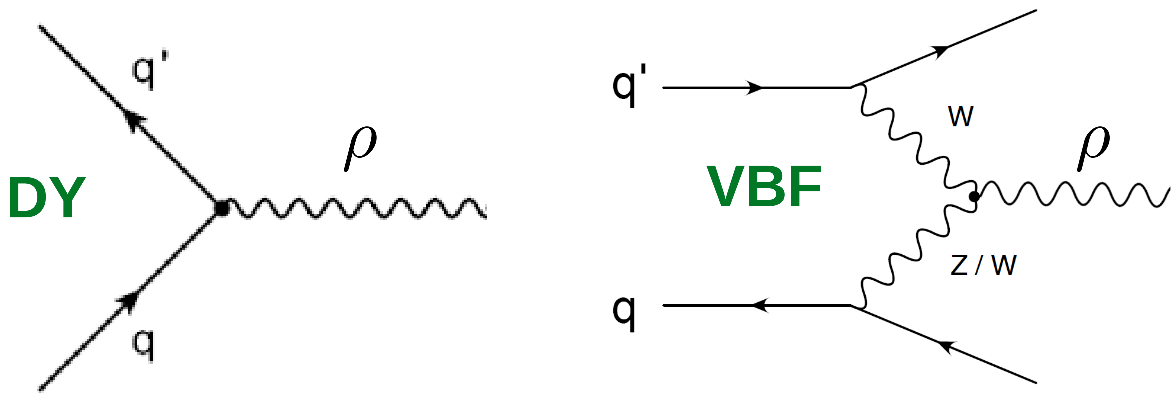
Dominant decay channels $\rho_{tBESS} \to AB$



Calculations

studied processes

- LHC ***s*-channel production** + **two-body decay**
- 2 production mechanisms: **DY** + **VBF**



- used approximations: **NWA**(both) & **EWA**(VBF)

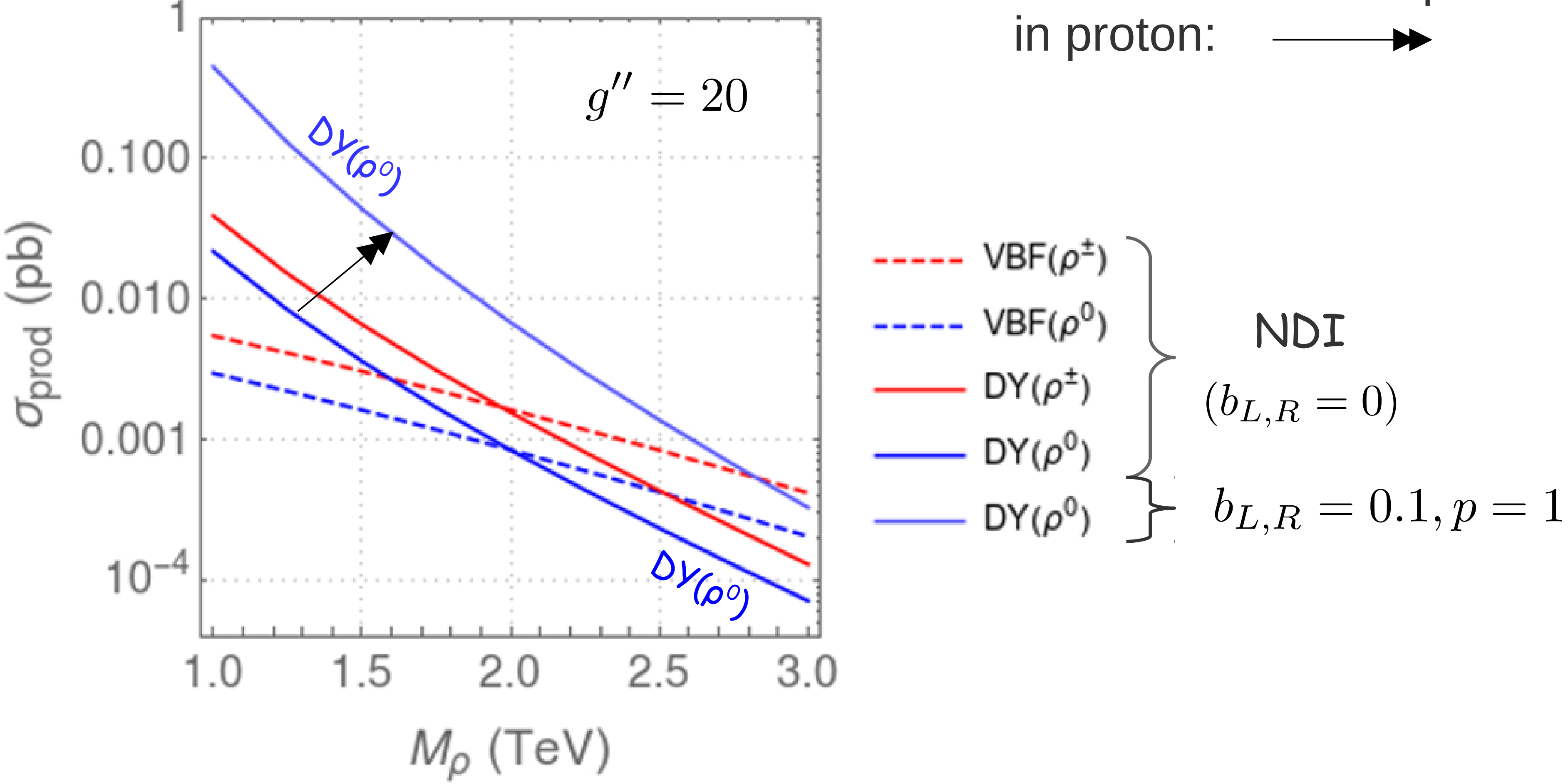
$$\sigma(pp \to abX) = \sigma_{\text{prod}}(pp \to \rho X) \times \text{BR}(\rho \to ab)$$

$$\sigma_{\text{prod}}(pp \to \rho + X) = \sum_{i \leq j \in p} 16\pi^2 K_{ij} \frac{\Gamma_{\rho \to ij}}{M_\rho} \frac{dL_{ij}}{d\hat{s}} |_{\hat{s}=M_\rho^2}$$

Calculations

production XS

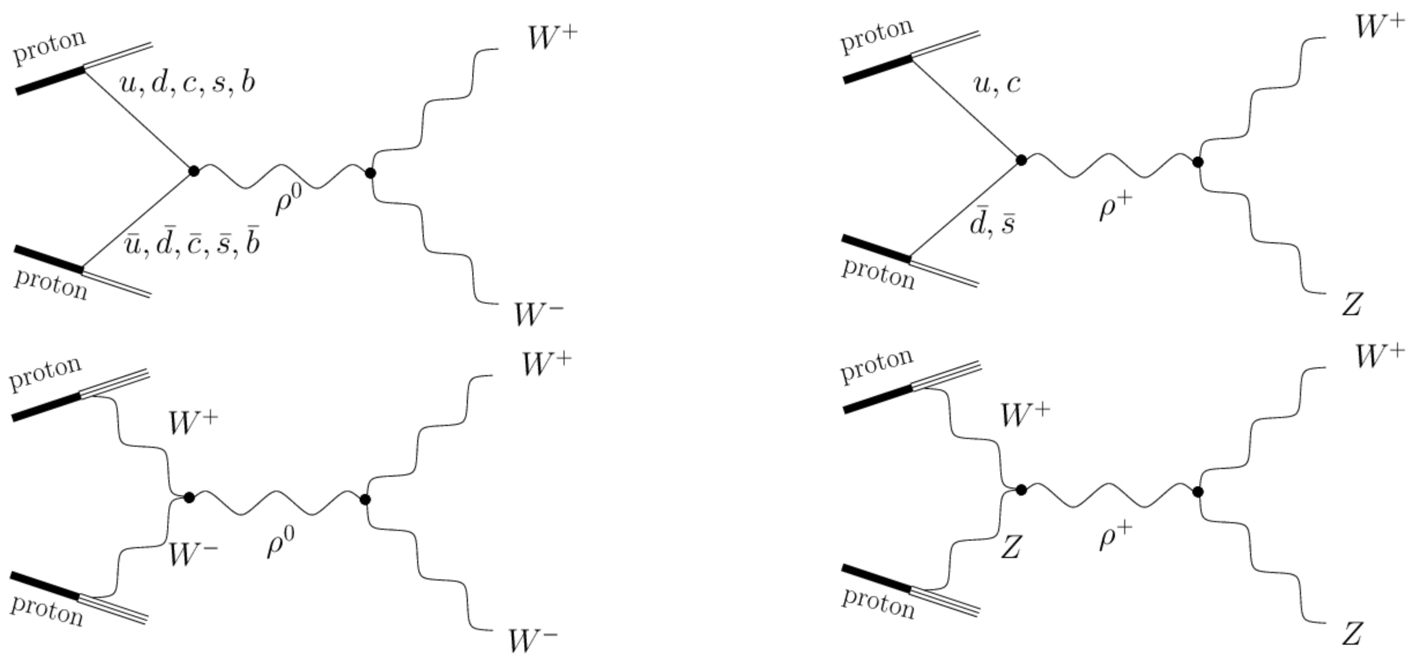
- the effect of the b-quark in proton: →



Results

experimental input

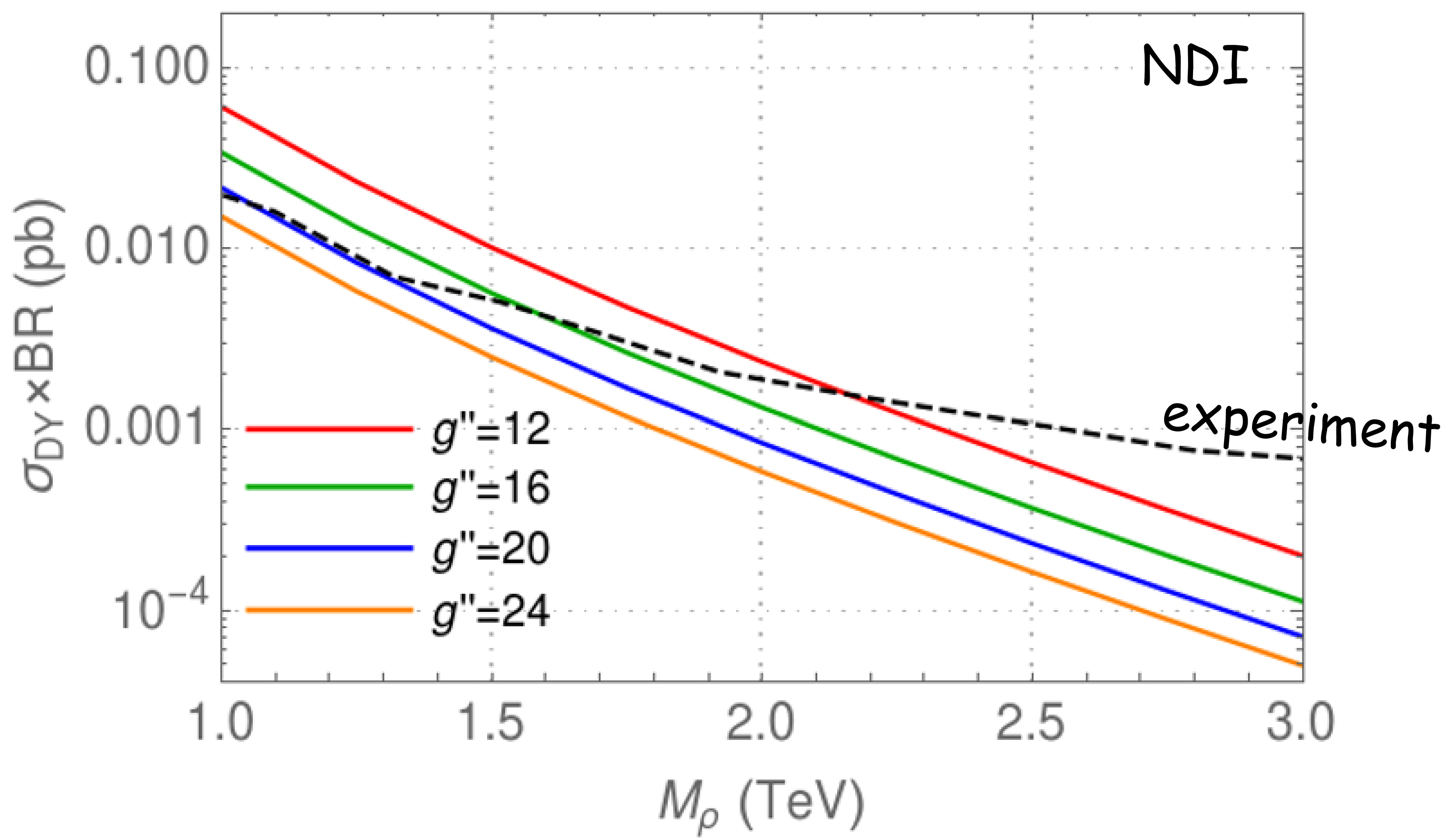
- ATLAS+CMS, ≤ 13 TeV, ≤ 36 fb^{-1}
- upper limits on "$\sigma_{prod} \times \mathrm{BR}(R \to ab)$":
  - available: $WW, WZ, WH, ZH, jj, \ell\ell, \ell\nu, \tau\tau, \tau\nu, bb, tt, tb$
  - **restrictions from:** $\boldsymbol{WZ_{\mathbf{DY}}, WW_{\mathbf{DY}}, WZ_{\mathbf{DY+VBF}}, WW_{\mathbf{DY+VBF}}}$



Results

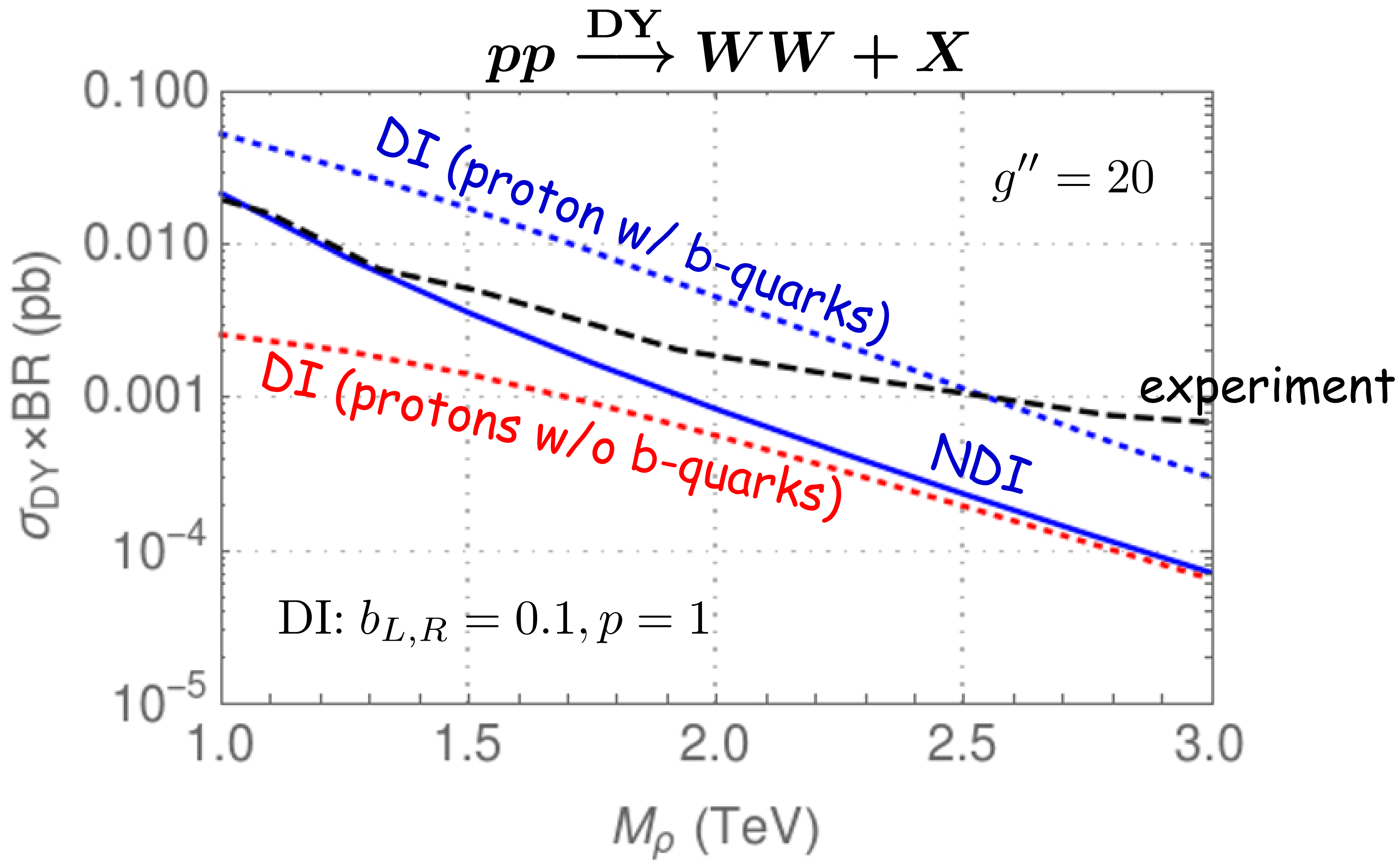
no direct interactions ($b_{L,R} = 0$)

$$pp \xrightarrow{\mathbf{DY}} WW + X$$



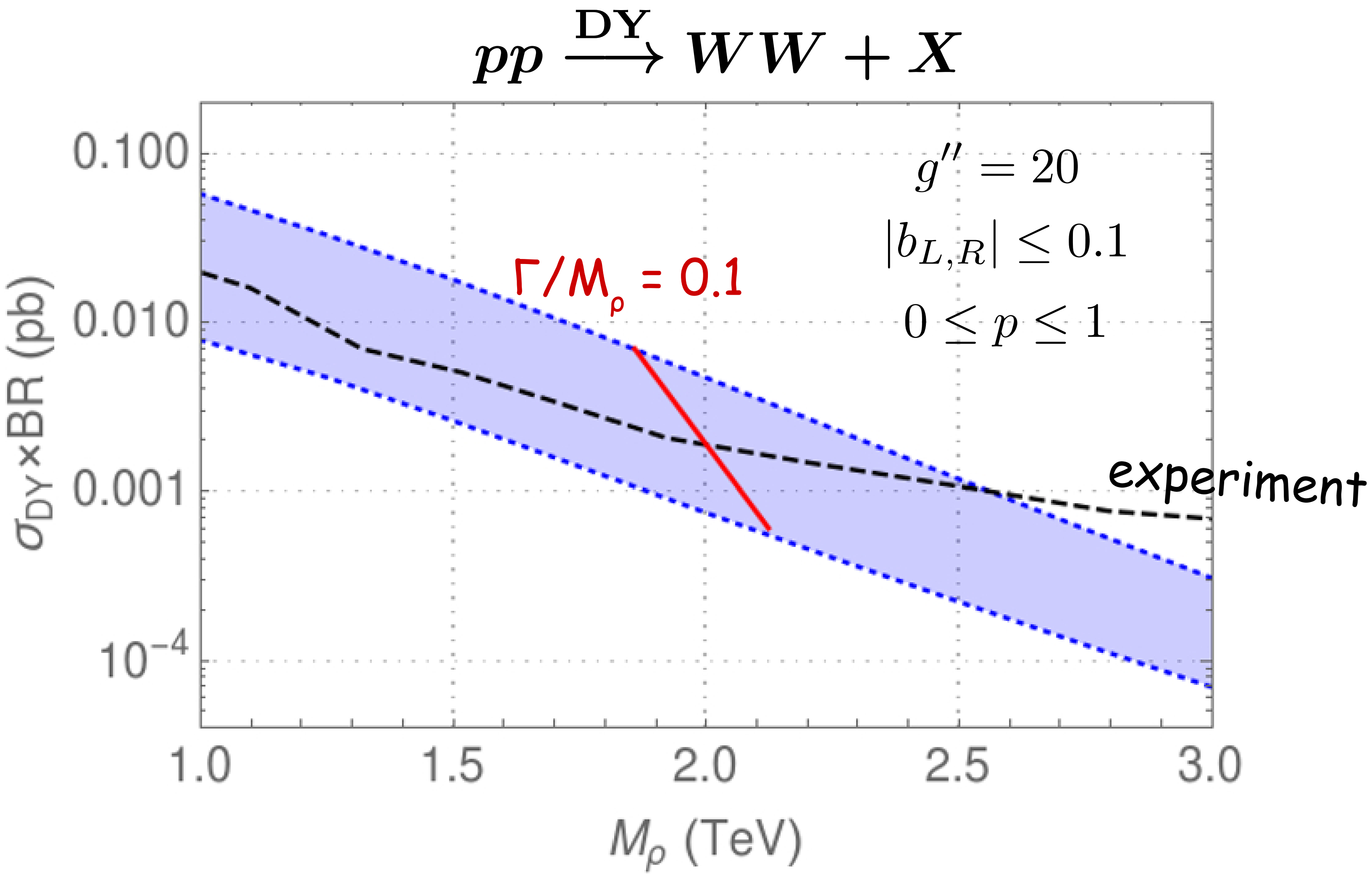
Results

the effect of the b-quark proton contents



Results

the direct interactions turned on



Results

MEL's for different scenarios

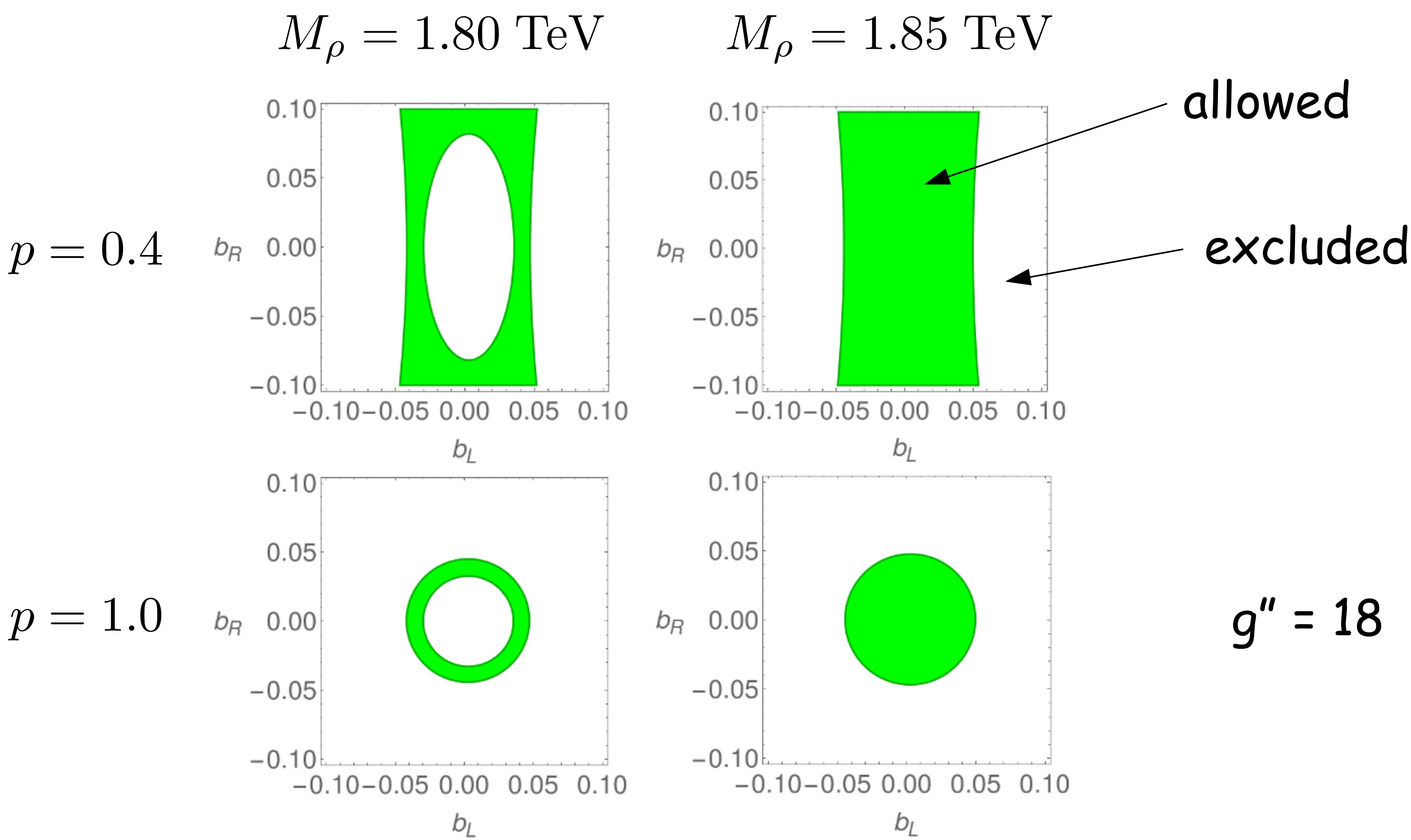
- the strongest of the $WZ_{\mathrm{DY}}, WW_{\mathrm{DY}}, WZ_{\mathrm{DY+VBF}}, WW_{\mathrm{DY+VBF}}$ limits

g''	MEL/TeV (Γ/M_ρ)		
	NDI $b_L = b_R = 0$ p irrelevant	DI free $b_L = b_R = b$ $p = 1$	DI $b_L = 0, b_R = 0.1$ free p
		for most relaxing b	for most relaxing p
16	2.07 (0.14)	2.04 (0.14), $b = 0.044$	2.02 (0.14), $p = 0.772$
17	1.95 (0.10)	1.92 (0.10), $b = 0.036$	1.87 (0.09), $p = 0.707$
18	1.83 (0.07)	1.77 (0.06), $b = 0.032$	1.68 (0.06), $p = 0.672$
19	1.70 (0.05)	1.64 (0.04), $b = 0.028$	1.49 (0.04), $p = 0.630$
20	1.60 (0.03)	1.53 (0.03), $b = 0.025$	1.33 (0.03), $p = 0.589$
21	1.51 (0.02)	1.44 (0.02), $b = 0.020$	no MEL for some p
22	1.43 (0.02)	1.38 (0.02), $b = 0.017$	no MEL for some p
23	1.37 (0.01)	1.30 (0.01), $b = 0.017$	no MEL for some p
24	1.31 (0.01)	1.11 (0.01), $b = 0.017$	no MEL for some p
25	1.24 (0.01)	1.03 (0.01), $b = 0.016$	no MEL for some p

Results

allowed values of $b_{L,R}$

- unification of the $WZ_{\mathrm{DY}}, WW_{\mathrm{DY}}, WZ_{\mathrm{DY+VBF}}, WW_{\mathrm{DY+VBF}}$ limits



Summary

- MEL's of the tBESS vector resonance triplet were investigated
- the **b-quark contents** of the proton **cannot be ignored**
- $\Gamma/M_\rho \leq 0.1(0.2) \Rightarrow M_\rho \leq 2.3(2.8)$TeV
- **there are param. space regions for which MEL ≤ 2TeV**
- **analysis beyond NWA required** for MEL ≥ 3TeV
- avoid the false generalization that the current vector resonance MEL's dwell at 5TeV or higher