A case study about the mass exclusion limits for the BSM vector resonances
with the direct couplings to the 3rd quark generation

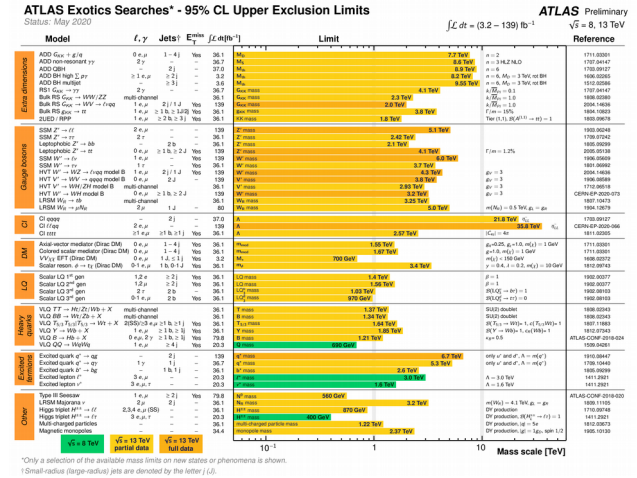Mikuláš **Gintner**[1,2] & Josef **Juráň**[1,3]

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Experimental direct searches:

- ATLAS+CMS

- $s^{1/2} \leq 13$ TeV, IL ≤ 139 fb^{-1}

- no "pp $\rightarrow$ R" signal $\Rightarrow$ upper bounds on "$\sigma_{prod} \times BR(R \rightarrow ab)$" $\Rightarrow$ **MEL**
  - the upper bounds are not universal
  - model and calculation dependency
  - plethora of BSMs – huge task to check all

ATLAS Exotics searches (May 2020) – **vector resonances**

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt$ [fb^{-1}]	Limit	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	139	Z' mass	5.1 TeV
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	36.1	Z' mass	2.42 TeV
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	36.1	Z' mass	2.1 TeV
	Leptophobic $Z' \rightarrow tt$	0 e, μ	≥ 1 b, ≥ 2 J	Yes	139	Z' mass	4.1 TeV
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	139	W' mass	6.0 TeV
	SSM $W' \rightarrow \tau\nu$	1 τ	–	Yes	36.1	W' mass	3.7 TeV
	HVT $W' \rightarrow WZ \rightarrow \ell\nu qq$ model B	1 e, μ	2 j / 1 J	Yes	139	W' mass	4.3 TeV
	HVT $V' \rightarrow WV \rightarrow qqqq$ model B	0 e, μ	2 J	–	139	V' mass	3.8 TeV
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel			36.1	V' mass	2.93 TeV
	HVT $W' \rightarrow WH$ model B	0 e, μ	≥ 1 b, ≥ 2 J		139	W' mass	3.2 TeV
	LRSM $W_R \rightarrow tb$	multi-channel			36.1	W_R mass	3.25 TeV
	LRSM $W_R \rightarrow \mu N_R$	2 μ	1 J	–	80	W_R mass	5.0 TeV

Deeper investigation of the MELs

- usually tailored for **narrow resonances**

- ATLAS+CMS upper bounds on "$\sigma_{prod} \times BR(R \to ab)$"

- the Upper Bounds depend on various characteristics of resonance and their validity is limited by the assumptions and approximations

Particular questions

- restriction by the **NWA** ($\Gamma/M < 10\%$)

- the impact of the resonance-to-fermions free parameters

- the role of the **b-quark proton contents**

the effective Lagrangian

Main features

- **SU(2)$_{L+R}$ triplet** of vector resonances (ρ^0, ρ^+, ρ^-)

- neutral & charged vector resonances are **degenerate** in mass

- its **mass** and **total width** depends on the model's couplings

- its **total width** grows quickly with the resonance mass

- **direct couplings to fermions:** 3rd quark generation only

- mixing with SM GBs

Based on

- modified BESS [R.Casalbuoni et al, PLB 155, 95 (1985), NPB 282, 235 (1987)]

- NLσM of NGBs $\quad SU(2)_L \times SU(2)_R \to SU(2)_{L+R}$

- Hidden Local Symmetry $\quad$ global $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(2)_{HLS}$

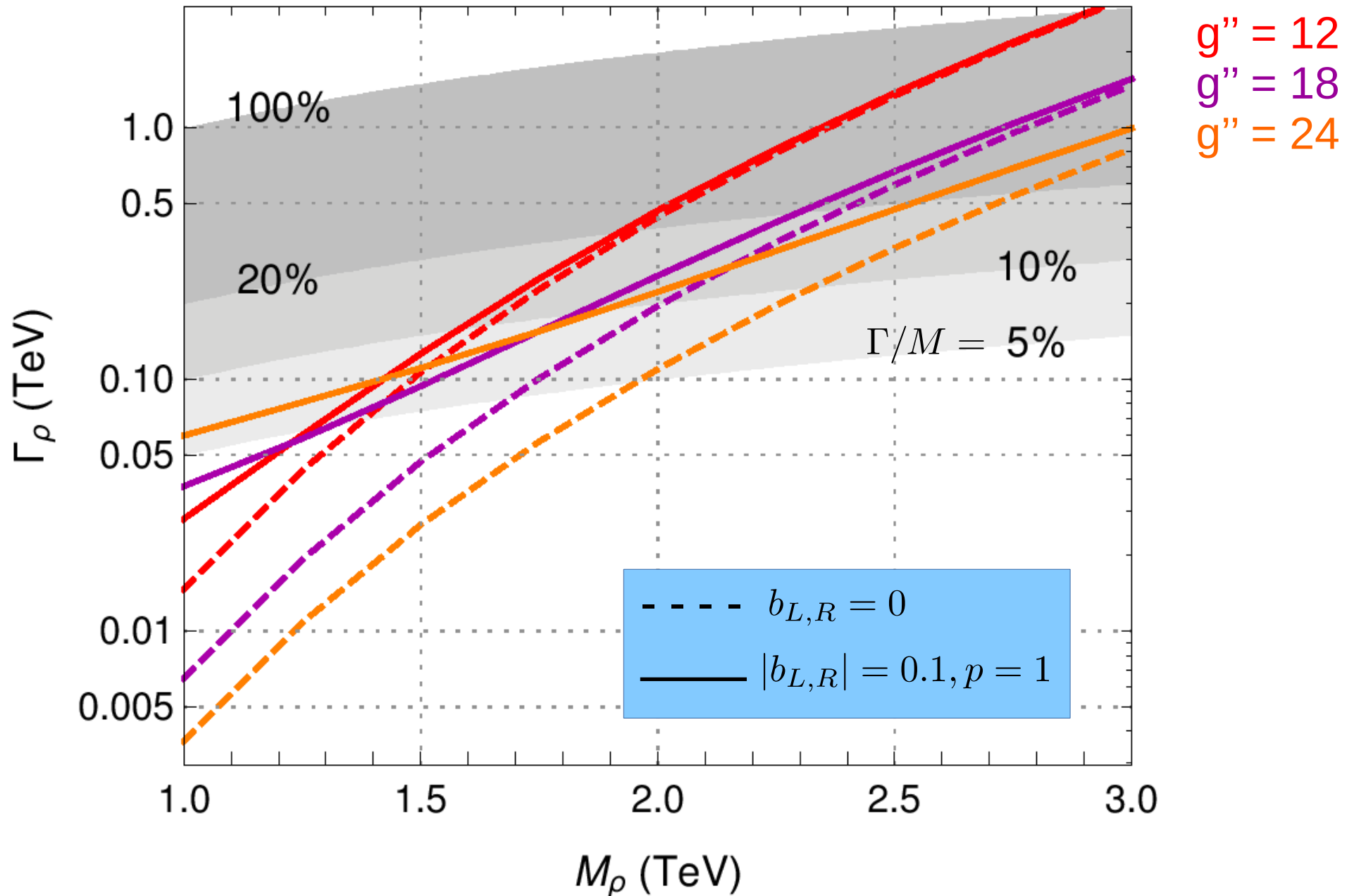- symmetries $\quad$ local $\quad SU(2)_L \times U(1)_Y \times SU(2)_{HLS}$

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:

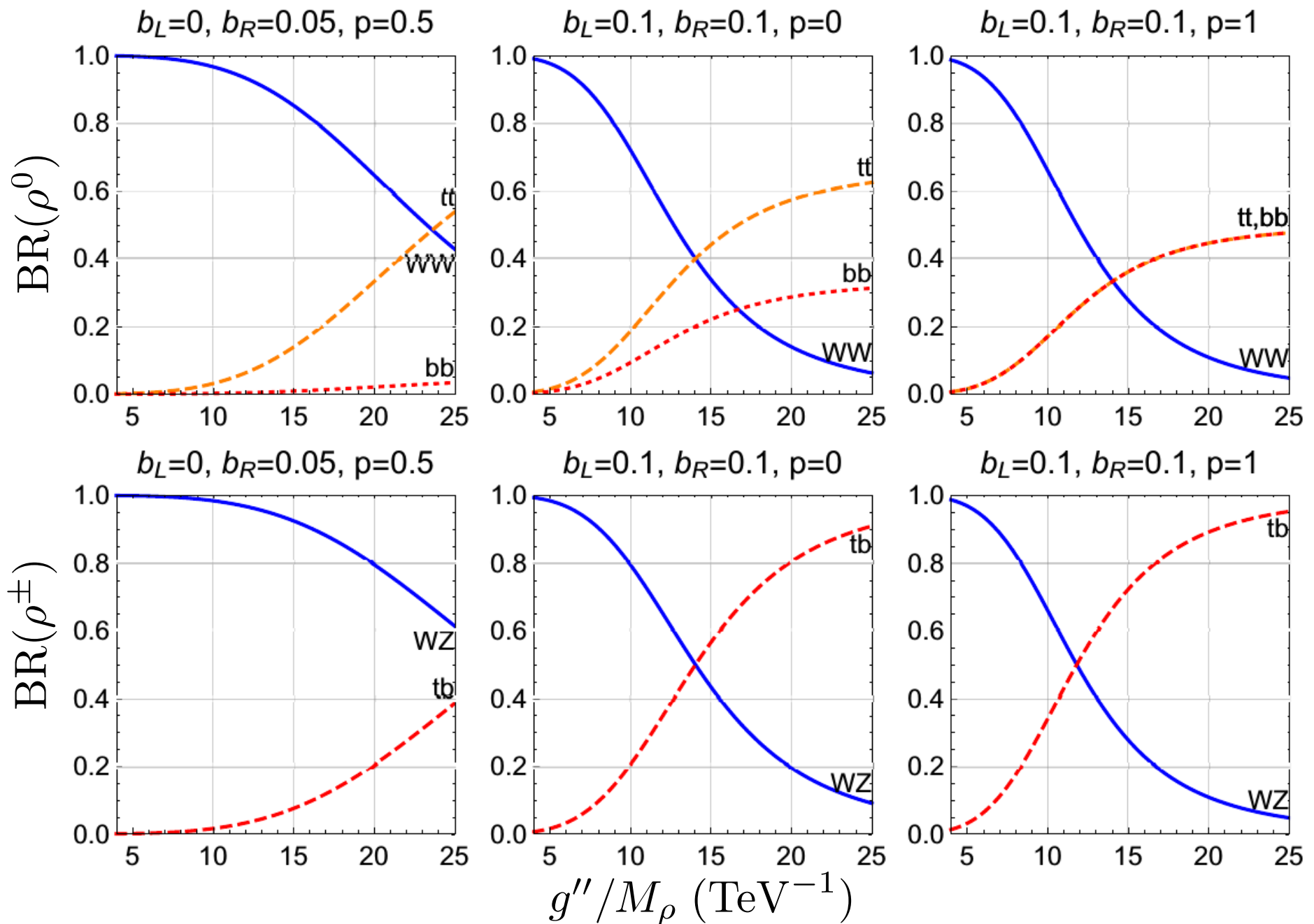| vertex	$V^3 t_L t_L$, $V^3 b_L b_L$	$V^\pm t_L b_L$	$V^3 t_R t_R$	$V^3 b_R b_R$	$V^\pm t_R b_R$
cplng	$b_L\, g''/2$	$b_L\, g''/2$	$b_R\, g''/2$	$p^2\, b_R\, g''/2$	$p\, b_R\, g''/2$

- mixing induced interactions of ρ to all fermions: ~ 1/g''

- perturbativity limit: $g''/2 \le 4\pi$

- EWPD, Higgs sector measurements, unitarity limits: $g'' > 12$

- EWPD: $|b_{L,R}| < 0.1$

Total Decay Width of ρ$_{\text{tBESS}}$

Studied processes

- LHC *s*-channel production + 2-body decay

- 2 prod. mechanisms: DY + VBF

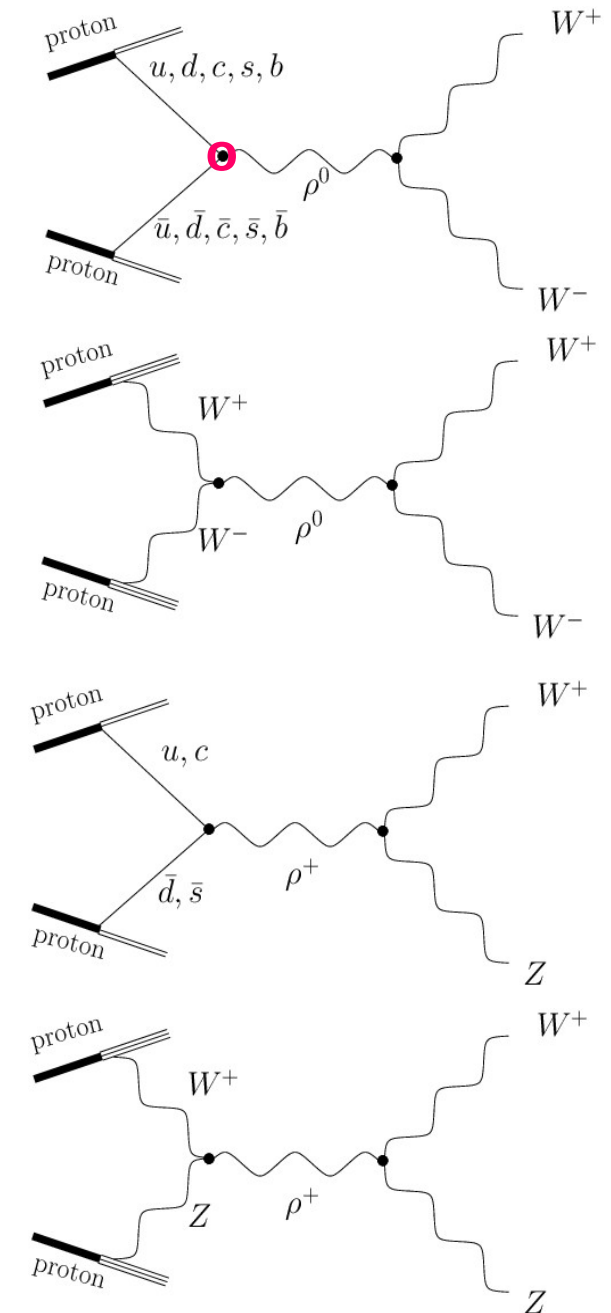- used approximations: NWA (both) & EWA (VBF)

Experimental input

- ATLAS+CMS, $\leq$ 13 TeV, $\leq$ 36 fb^{-1}

- 95% CL **upper bounds** on "$\sigma_{prod} \times BR(R \rightarrow ab)$"

- decay channels:
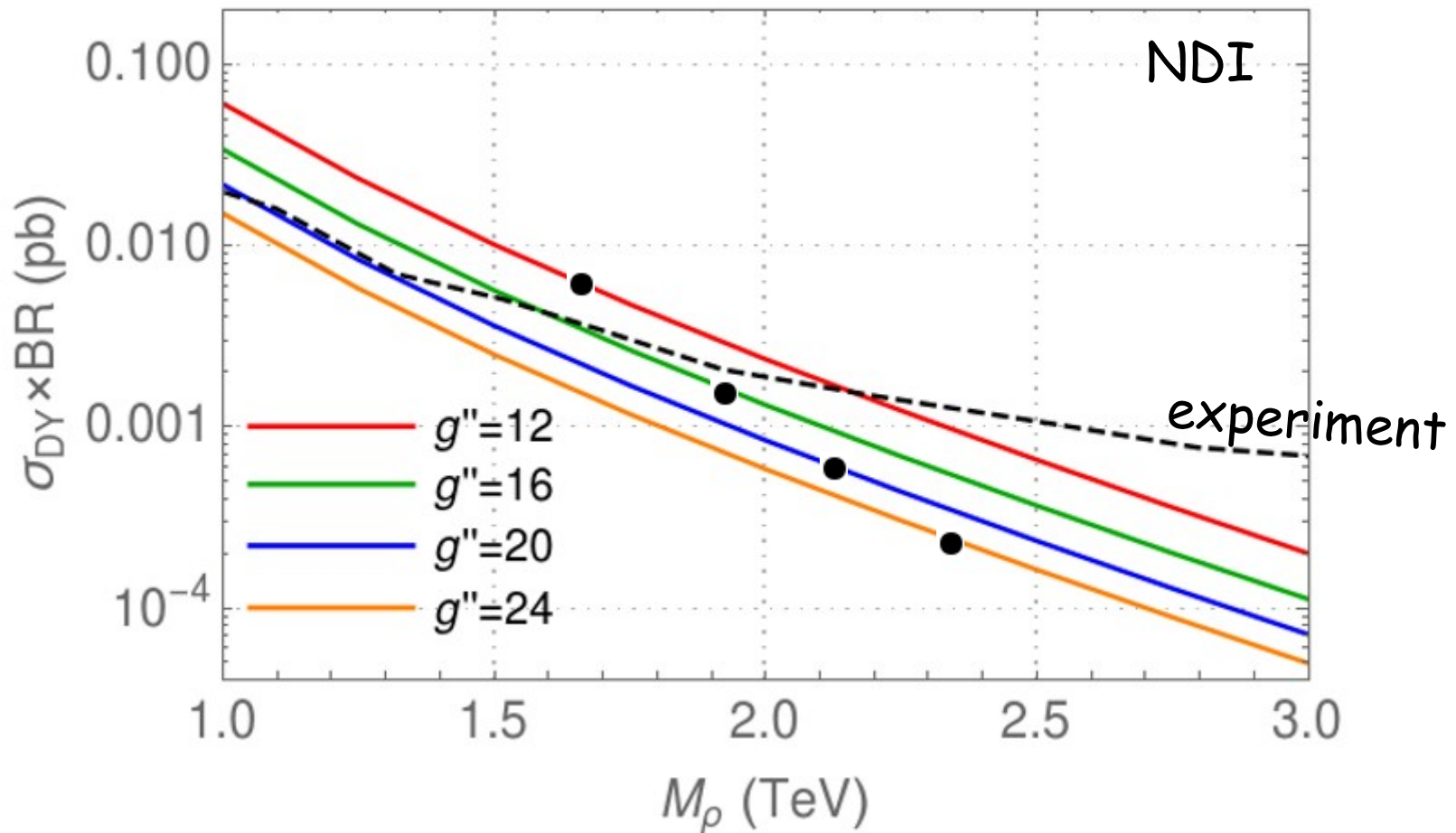 $$WW, WZ, WH, ZH, jj, \ell\ell, \ell\nu, \tau\tau, \tau\nu, bb, tt, tb$$
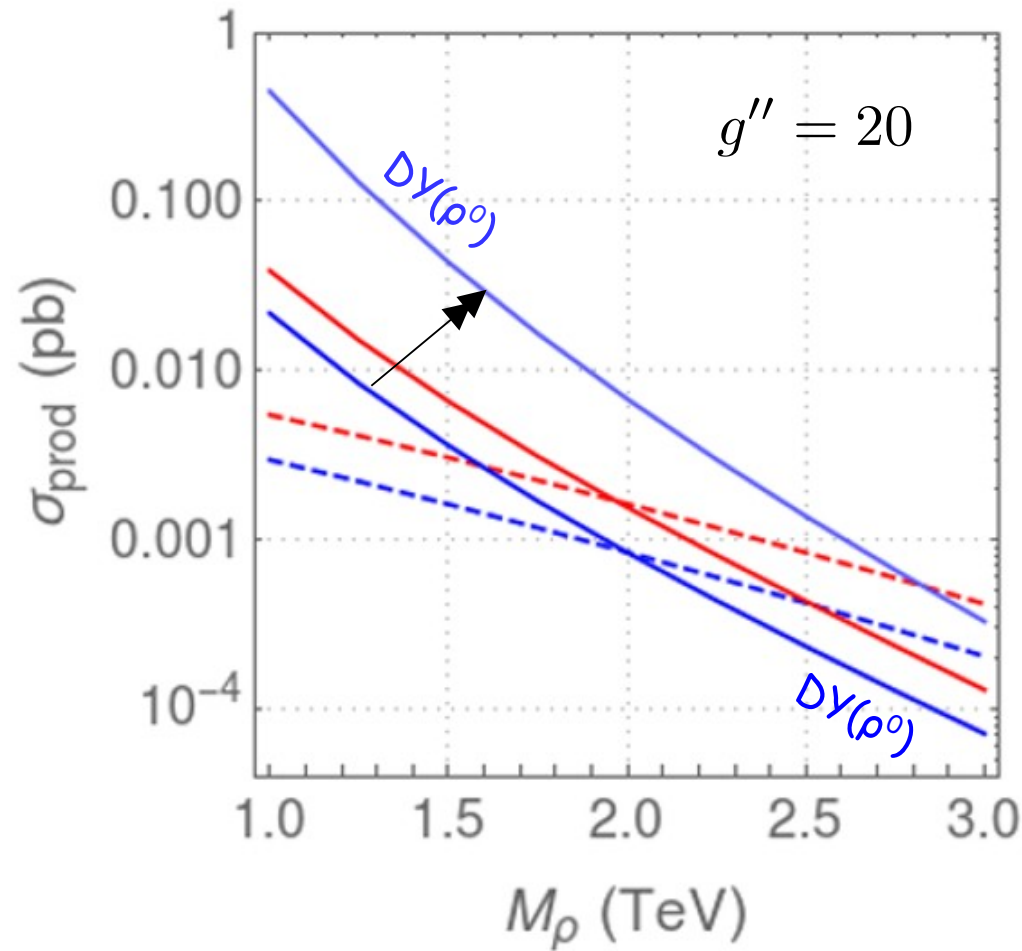
- ➢ **restrictions from:**

  $$WZ_{DY}, WW_{DY}, WZ_{DY+VBF}, WW_{DY+VBF}$$

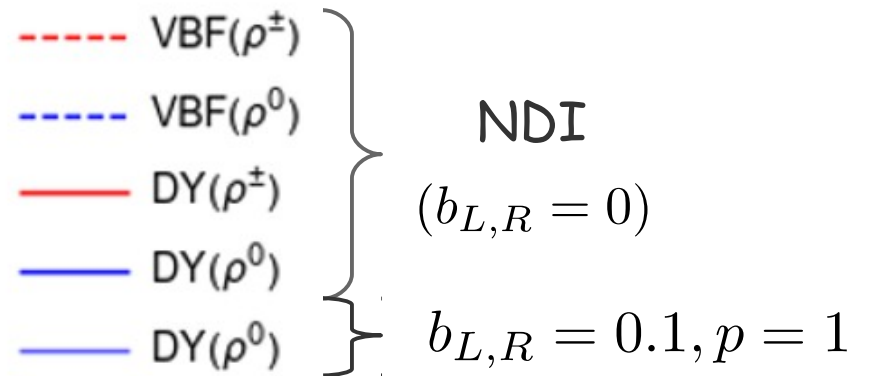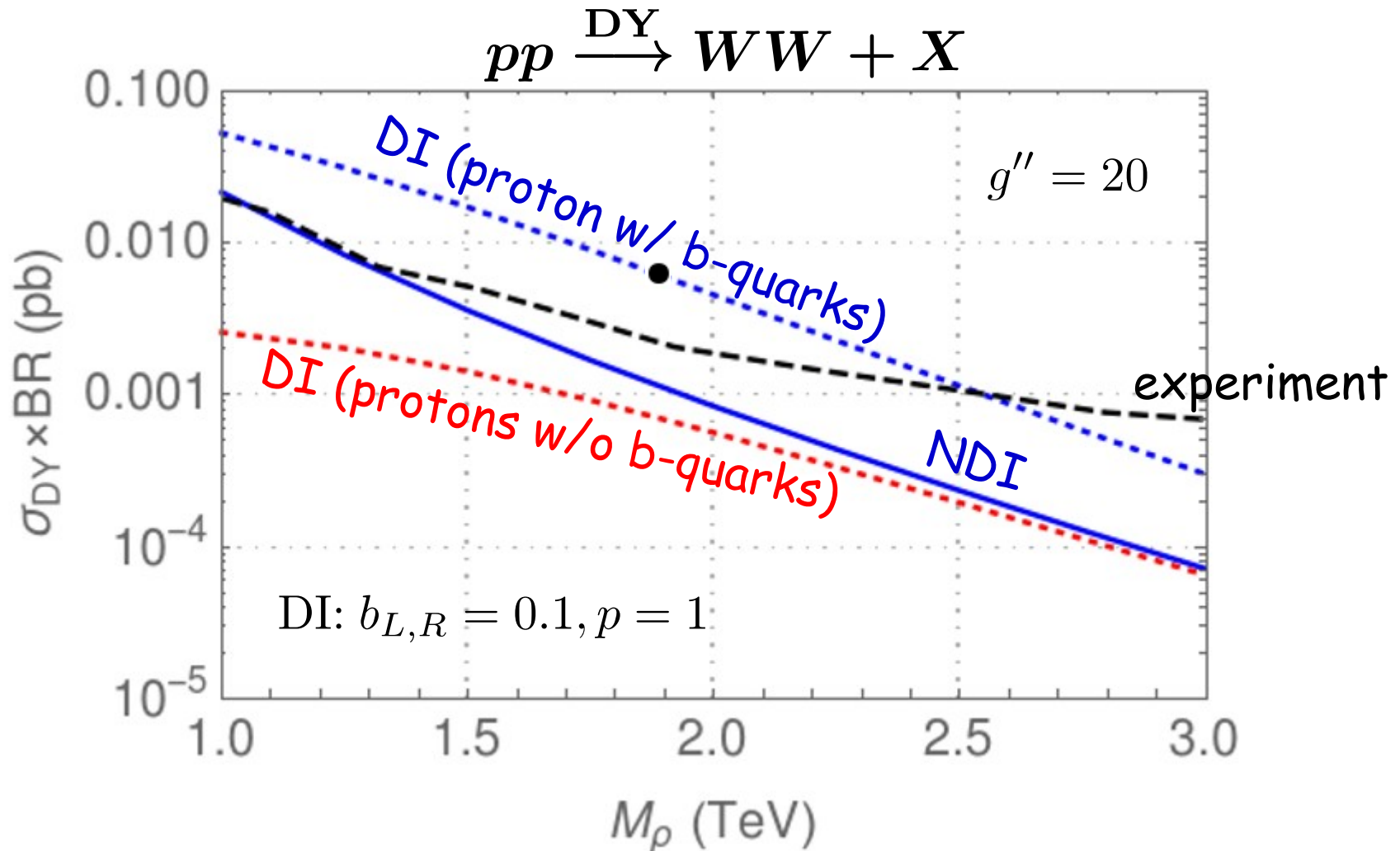no direct interactions ($b_{L,R} = 0$)

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

NDI

experiment

- red: $g''=12$
- green: $g''=16$
- blue: $g''=20$
- orange: $g''=24$

• $\Gamma/M = 10\%$

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

$g'' = 20$

$DY(\rho^0)$

$DY(\rho^0)$

Legend:
- - - - VBF($\rho^\pm$)
- - - - VBF(ρ^0)
——— DY($\rho^\pm$)
——— DY(ρ^0)
——— DY(ρ^0)

NDI $(b_{L,R} = 0)$

$b_{L,R} = 0.1, p = 1$

the effect of the b-quark proton contents

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

DI (proton w/ b-quarks)

$g'' = 20$

DI (protons w/o b-quarks)

NDI

experiment

DI: $b_{L,R} = 0.1, p = 1$

the direct interactions turned on

$$pp \xrightarrow{\text{DY}} WW + X$$
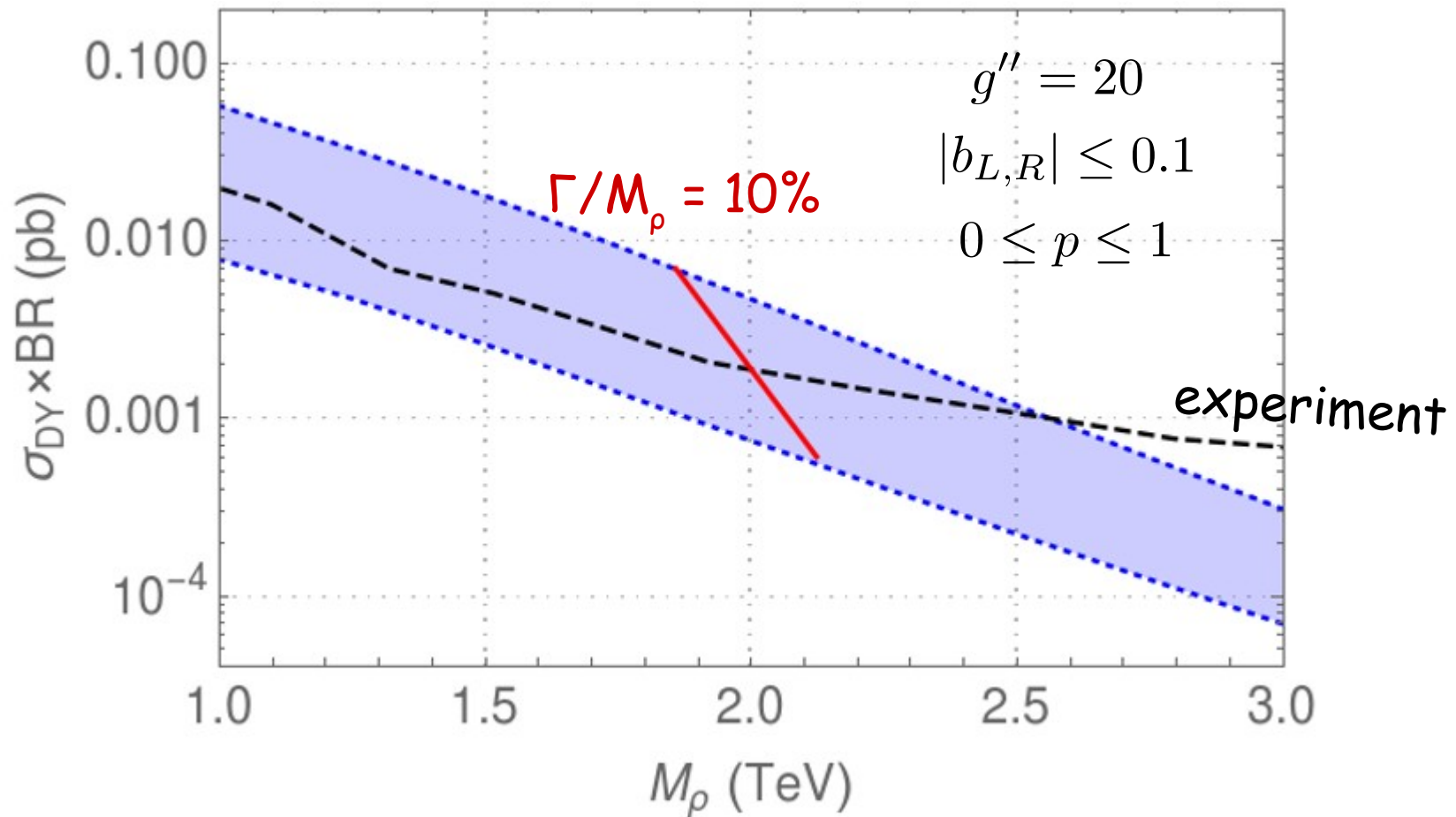
allowed values of $b_{L,R}$

$g'' = 18$

$M_\rho = 1.80$ TeV

$M_\rho = 1.85$ TeV

$p = 0.4$

$p = 1.0$

allowed

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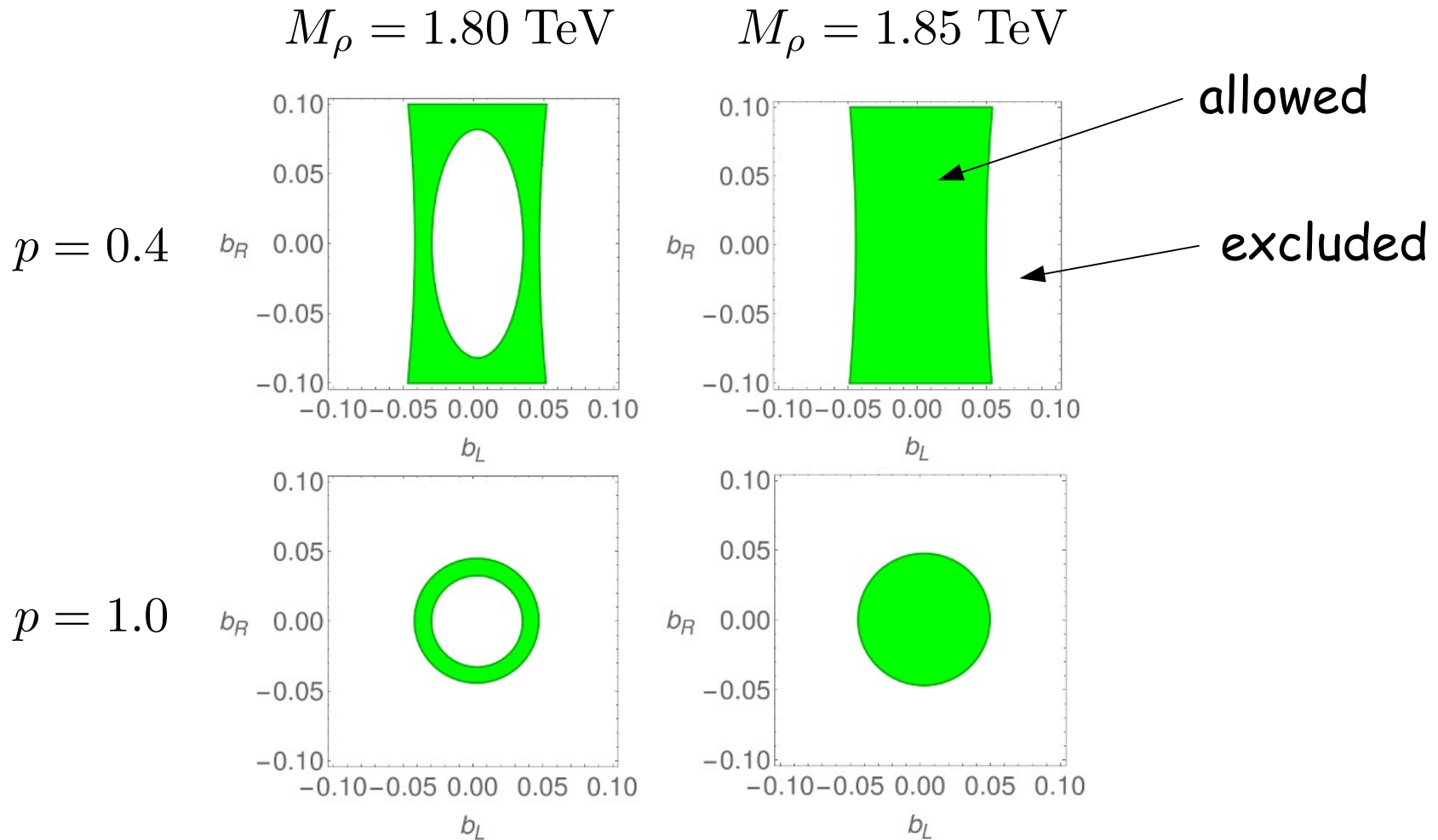
- unification of the $WZ_{\mathrm{DY}}, WW_{\mathrm{DY}}, WZ_{\mathrm{DY+VBF}}, WW_{\mathrm{DY+VBF}}$ limits

Summary

- MEL's of the tBESS vector resonance triplet were investigated

- NWA limitation: $\Gamma/M_\rho \leq 0.1$ (0.2) $\Rightarrow M_\rho \leq 2.3$ (2.8) TeV

- for MEL ≥ 3 TeV **analysis beyond NWA required**

- **Even when NWA applies:**

  - the **b-quark contents** of the proton **cannot be ignored**

  - **there are param. space regions for which MEL $\leq$ 2 TeV**

- widely accepted generalization that the current vector resonance MEL's dwell at 5 TeV or higher is of limited validity