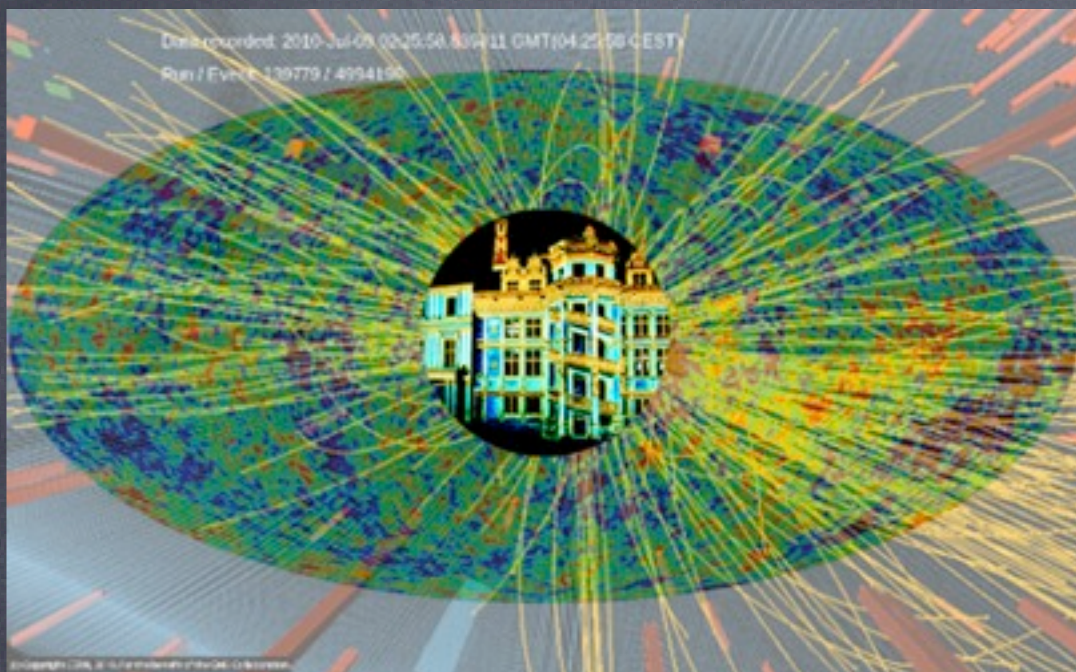
Simplified Models/Effective theory for resonances: an application to a weakly constrained W'



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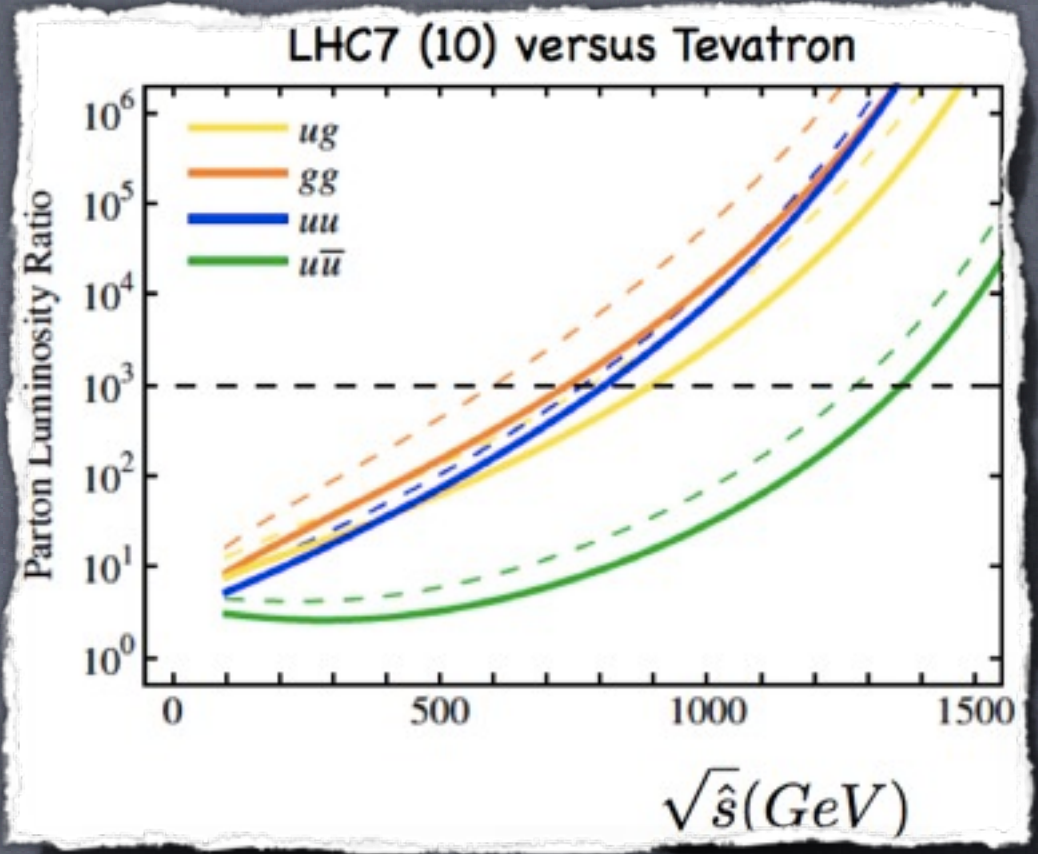
based on C. Grojean, E. Salvioni and RT, 1103.2761 [hep-ph]

Outline

- Introduction and theoretical motivations
- The simplified model
- Bounds
  - Indirect bounds
  - Tevatron direct searches
- LHC phenomenology
  - di-jet channel
  - $W\gamma$ channel
- Conclusion

Which new physics?

- At the early LHC the $q\bar{q}$ channel is less favorable with respect to the qq, qg, gg channels (Bauer et al., 0909.5213)
- Colored and colorless states in the channels qq, qg, gg are the most promising at the early LHC (Barbieri and RT, 1008.5302; Han et al., 1010.4309)
- Vector states are usually strongly constrained by flavor physics and from Tevatron direct searches
- These states are unlikely to be seen at the early LHC
- However a new iso-singlet vector charged only under the hypercharge can be very weakly constrained for some special choices of the right-handed mixing matrix (Langacker and Sankar, PRD40 1989; Grojean et al., 1103.2761)



Why a W'?

- Heavy spin-1 resonances are a generic prediction of many BSM theories
- Neutral states (Z') can arise from abelian extensions of the SM gauge group (see e.g. Langacker, 0801.1345; Salvioni et al., 0909.1320-0911.1450; Accomando et al., 1010.6058 + many others)
- Charged states (W') are usually associated to non-abelian extensions of the SM gauge group (del Aguila et al., 1005.3998; Hsieh et al., 1003.3482; Schmaltz et al., 1011.5918; Gopalakrishna et al., 1008.3508; Frank et al., 1010.5809-1005.3047; Rizzo, 07040235; Nemevsek et al., 1103.1627 + many others)
- Examples are Left-Right (LR), Little-Higgs (LH), pseudo-Goldstone Higgs (pGH), Randall-Sundrum (RS) models, etc. (>100 papers)
- However there is also the interesting possibility that heavy spin-1 particles are composite states bound by a new strong dynamics responsible for EWSB (especially in Higgs-less models) (Csaki et al., 0305237; Barbieri et al., 0806.1624, 0911.1942, 1001.3149; He et al., 0708.2588; Carcamo Hernandez et al., 1005.3809; Catà et al., 0905.0490; Birkedal et al., 0412278; Martin et al., 0907.3931 + many others)

Model independent approach

- We consider a vector transforming in the $(1,1)_1$ rep of the SM gauge group
- At renormalizable level, an effective Lagrangian for this state is

$$
\begin{aligned}
\mathcal{L} &= \mathcal{L}_{SM} + \mathcal{L}_V + \mathcal{L}_{V-SM} \\
\mathcal{L}_V &= D_\mu V_\nu^- D^\nu V^{+\mu} - D_\mu V_\nu^- D^\mu V^{+\nu} + \tilde{M}^2 V^{+\mu} V_\mu^- \\
&\quad + \frac{g_4^2}{2} |H|^2 V^{+\mu} V_\mu^- - i c_B g' B^{\mu\nu} V_\mu^+ V_\nu^- \\
\mathcal{L}_{V-SM} &= V^{+\mu} \left(i g_H H^\dagger (D_\mu \tilde{H}) + \frac{g_q}{\sqrt{2}} (V_R)_{ij} \overline{u_R^i} \gamma_\mu d_R^j \right) + \text{h.c.}
\end{aligned}
$$

- There are 5 independent parameters (4 couplings + 1 mass)
- The coupling g_H ($\hat{\theta}$) generates a W-W' mass mixing

$$
\begin{pmatrix} \hat{W}_\mu^+ & V_\mu^+ \end{pmatrix} \begin{pmatrix} m_{\hat{W}}^2 & \Delta^2 \\ \Delta^2 & M \end{pmatrix} \begin{pmatrix} \hat{W}_\mu^- \\ V_\mu^- \end{pmatrix} \quad \Longrightarrow \quad \begin{pmatrix} W_\mu^+ \\ W_\mu'^+ \end{pmatrix} = \begin{pmatrix} \cos\hat{\theta} & \sin\hat{\theta} \\ -\sin\hat{\theta} & \cos\hat{\theta} \end{pmatrix} \begin{pmatrix} \hat{W}_\mu^+ \\ V_\mu^+ \end{pmatrix}
$$

$$
\tan(2\hat{\theta}) = \frac{2\Delta^2}{m_{\hat{W}}^2 - M^2}, \quad m_{\hat{W}}^2 = \frac{g^2 v^2}{4}, \quad \Delta^2 = \frac{g_H g v^2}{2\sqrt{2}}, \quad M^2 = \tilde{M}^2 + \frac{g_4^2 v^2}{4}
$$

Model independent approach

- We consider a vector transforming in the $(1,1)_1$ rep of the SM gauge group
- At renormalizable [...] this state is

$$\mathcal{L} \ldots$$

$$+\frac{\ldots}{2}\ldots$$

> Does not need to be unitary in the effective approach!

$$\mathcal{L}_{V-SM} = V^{+\mu}\left(i g_H H^\dagger (D_\mu \tilde{H}) + \frac{g_q}{\sqrt{2}} (V_R)_{ij} \overline{u^i_R} \gamma_\mu d^j_R\right) + \text{h.c.}$$

- There are 5 independent parameters (4 couplings + 1 mass)
- The coupling g_H ($\hat{\theta}$) generates a W-W' mass mixing

$$\begin{pmatrix} \hat{W}^+_\mu & V^+_\mu \end{pmatrix} \begin{pmatrix} m^2_{\hat{W}} & \Delta^2 \\ \Delta^2 & M \end{pmatrix} \begin{pmatrix} \hat{W}^-_\mu \\ V^-_\mu \end{pmatrix} \quad \Longrightarrow \quad \begin{pmatrix} W^+_\mu \\ W'^+_\mu \end{pmatrix} = \begin{pmatrix} \cos\hat{\theta} & \sin\hat{\theta} \\ -\sin\hat{\theta} & \cos\hat{\theta} \end{pmatrix} \begin{pmatrix} \hat{W}^+_\mu \\ V^+_\mu \end{pmatrix}$$

$$\tan(2\hat{\theta}) = \frac{2\Delta^2}{m^2_{\hat{W}} - M^2}, \quad m^2_{\hat{W}} = \frac{g^2 v^2}{4}, \quad \Delta^2 = \frac{g_H g v^2}{2\sqrt{2}}, \quad M^2 = \tilde{M}^2 + \frac{g_4^2 v^2}{4}$$

Indirect bounds

- Indirect bounds of different origin constrain the couplings g_q , g_H, $\hat{\theta}$ and c_B and the mass of the W′ (Langacker and Sankar, PRD40 1989)
  - g_q is mainly constrained by K and B meson mixings, i.e. $\Delta F = 2$ transitions (Frank, Hayreter and Turan, 1005.3074-1010.5809)
  - g_H (or equivalently $\hat{\theta}$) is constrained by $u \to d$ and $u \to s$ semileptonic transitions and by EWPT (del Aguila, de Blas and Perez-Victoria, 1005.3998; Buras, Gemmler and Isidori, 1007.1993)
  - c_B is only very weakly constrained by Trilinear Gauge Couplings (TGC) (Grojean, Salvioni and RT, 1103.2761)
  - g_4 is essentially unconstrained and marginal in our analysis (it is only relevant for $W' \to Wh$ channel) (Azuelos et al. (ATLAS), 0402037; Bao, Li, Si, Zhou, 1103.1688)

Summary of indirect bounds

- Choosing the least constrained $V_R^{(I)}$ (id matrix), the bound reads at 90% CL (Langacker and Sankar)

$$M_{W'} > \frac{g_q}{g}\, 300\,\text{GeV}$$

- Constraints from $B^0_{d,s} - \bar{B}^0_{d,s}$ mixing and from $b \to s\gamma$ were analyzed in the context of LR models but are negligible for our choice of V_R (Frank, Hayreter, Turan)

- A recent electroweak fit (including LEP2 data) gives at 95% CL (del Aguila et al.)

$$\left|\frac{g_H}{M}\right| < 0.11\,\text{TeV}^{-1}$$

$$|\hat{\theta}| \lesssim 4\times 10^{-3} \quad \text{for} \quad M_{W'} = 300\,\text{GeV}$$
$$|\hat{\theta}| \lesssim 5\times 10^{-4} \quad \text{for} \quad M_{W'} = 2\,\text{TeV}$$

- From u→d and u→s semileptonic transitions (i.e. from CKM measurements) we have in the limit of maximal CP phases

$$\left|\frac{g_q\hat{\theta}}{g}\right| < 10^{-(2\div 1)}$$

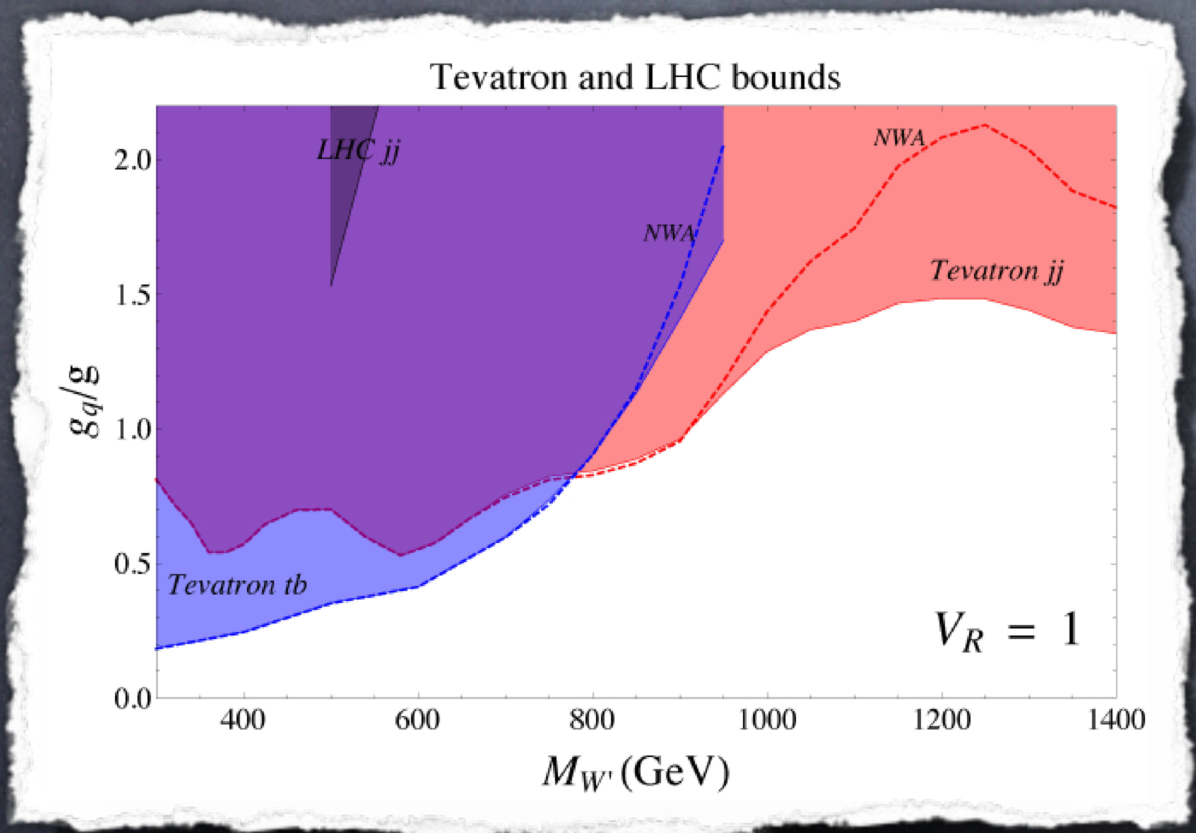
- The constraint on c_B from TGC turns out to be very weak: e.g. at 95% CL we obtain for $\hat{\theta}\approx 10^{-1}$

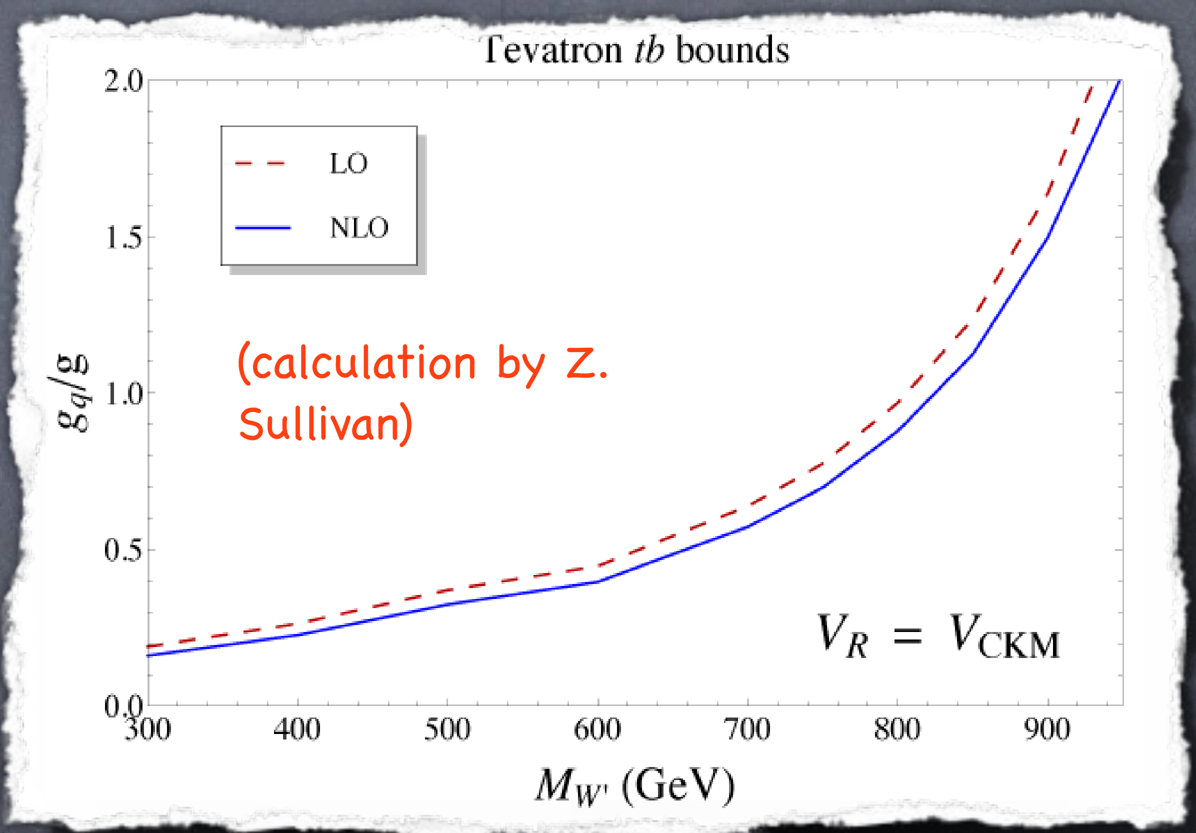
$$-11 < c_B < 20 \;\; (-3.9 < g_B < 7.1)$$

Bounds from Tevatron direct searches

- Using the upper bounds on the cross sections for the di-jet (red) and tb (blue) final states set by D0 and CDF we can construct an allowed region in the plane $(g_q/g, M_{W'})$

- Note that the NWA differs from the exact 2→2 in the high mass region!



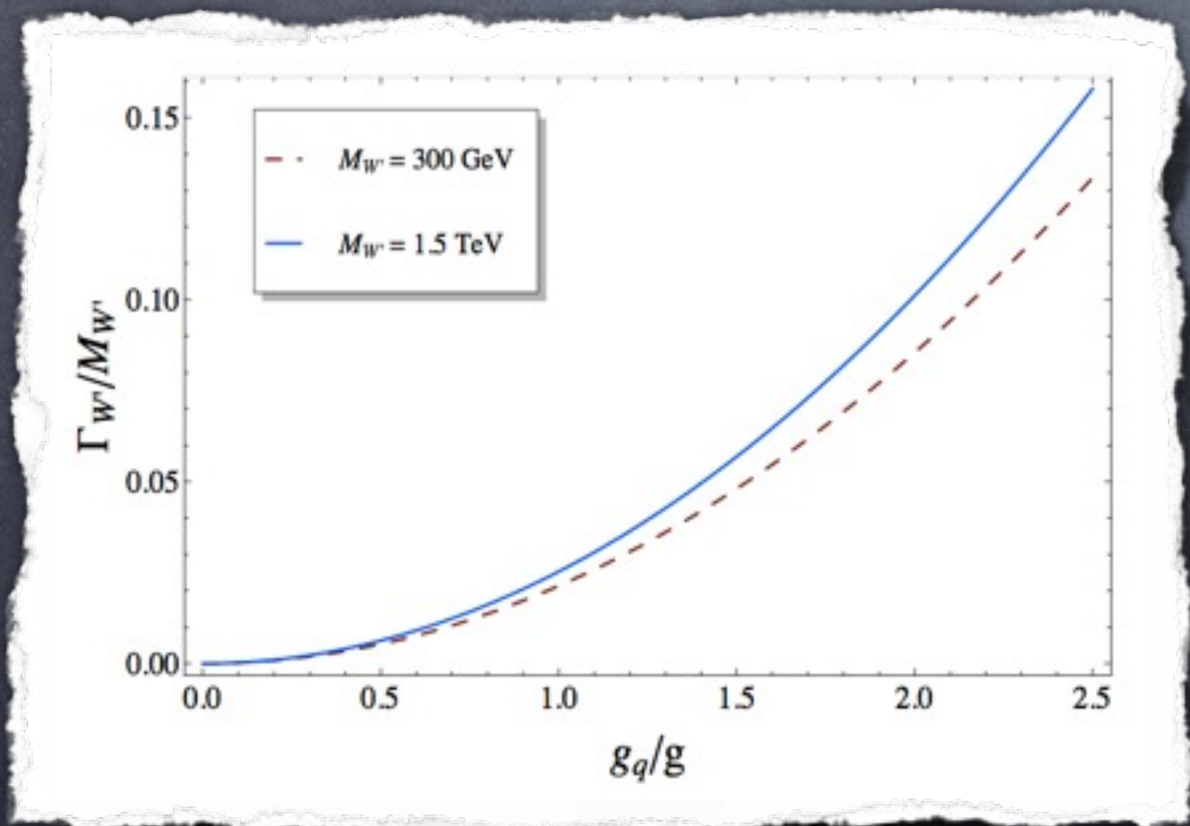


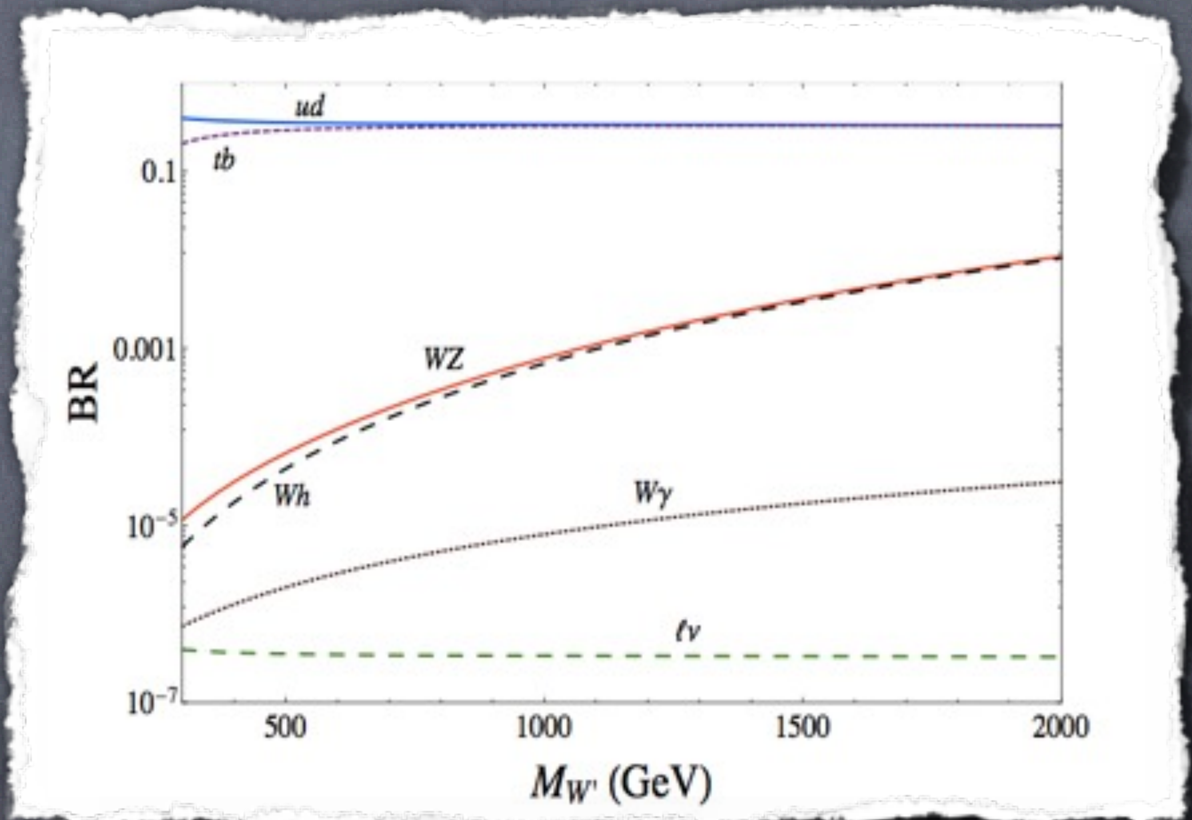
- The bound is pretty stable to radiative corrections (Z. Sullivan, 2002)

LHC Phenomenology

- We have studied the LHC Phenomenology of the W′ focusing on the case of a narrow resonance ($\Gamma_{W'} < 0.1 M_{W'}$) produced in the s-channel

- Assuming a small mixing (as imposed by present bounds) the width of the W′ and its BRs are given by

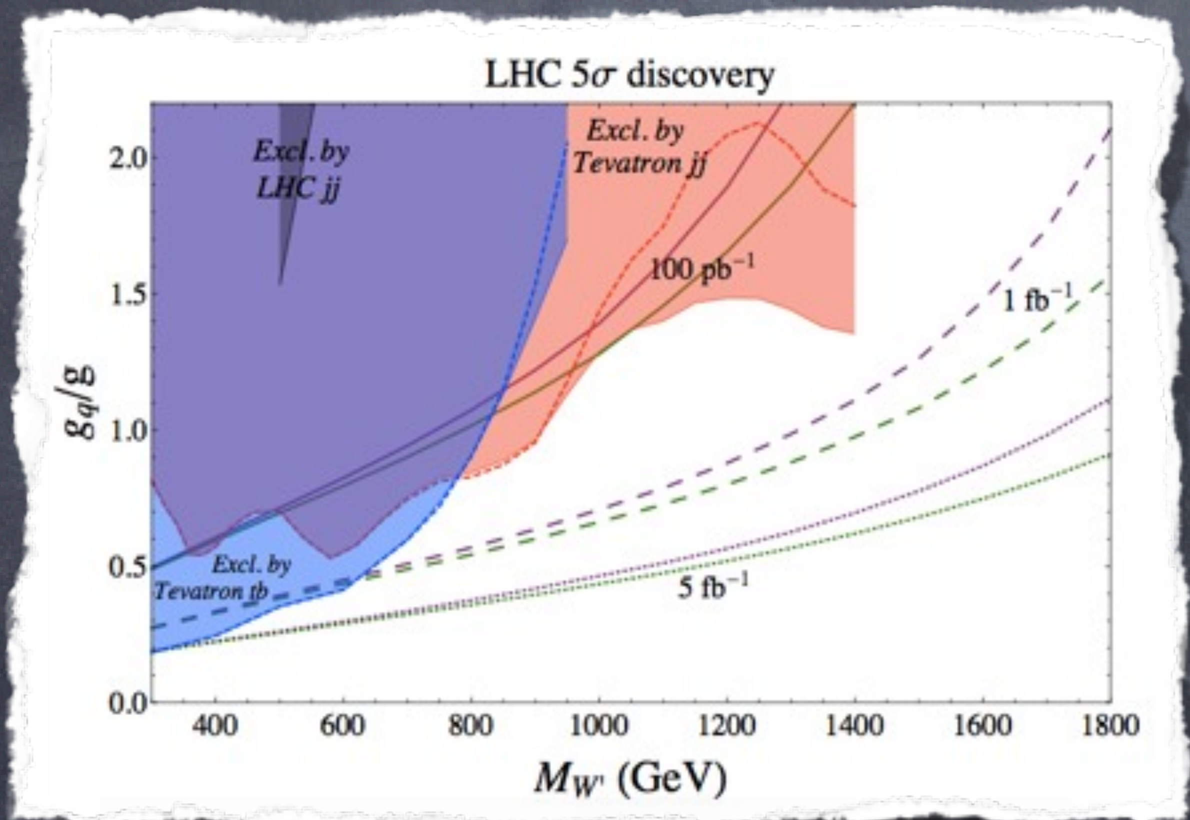


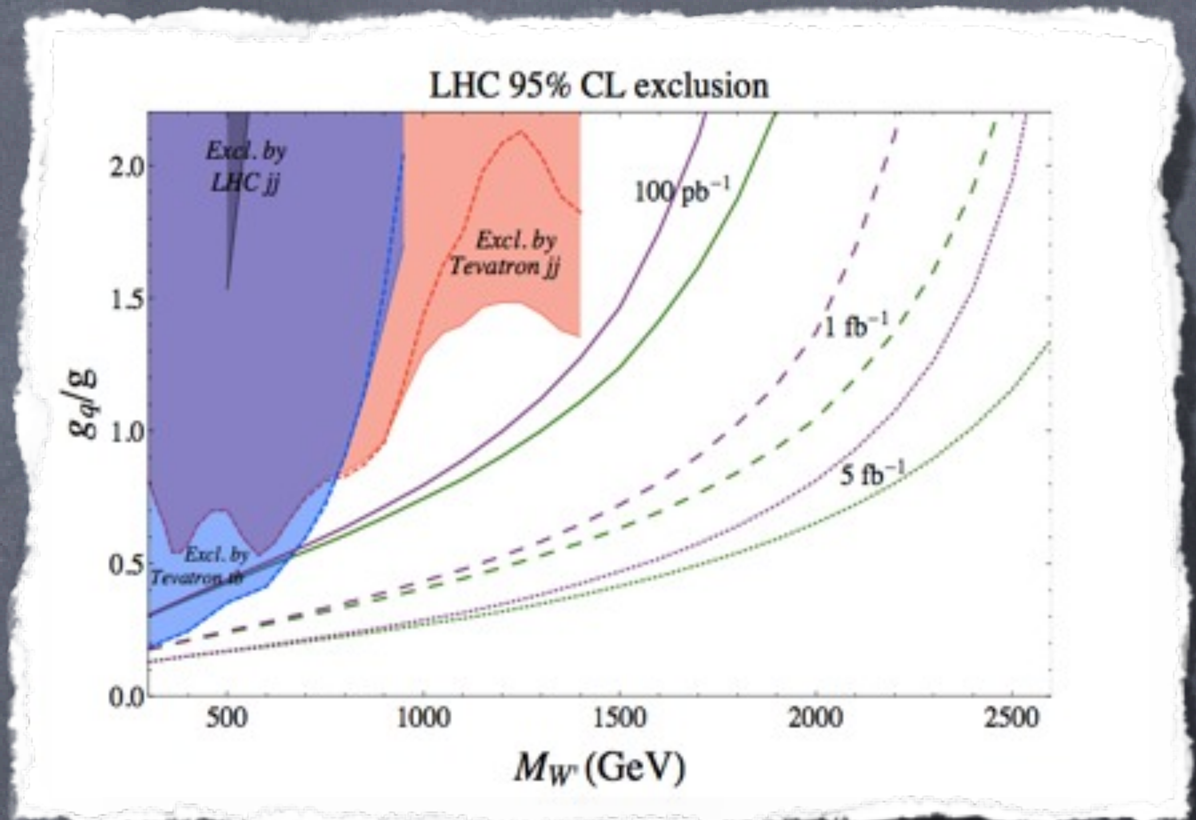


$$g_q = g,\ \hat{\theta} = 10^{-3},\ c_B = -3$$

LHC Phenomenology: di-jet

- A discovery is possible at the LHC@7TeV with >100 inverse pb
- The LHC will do better than the Tevatron very soon in the high mass region
- >1 inverse fb is required to do better than the Tevatron in all the mass range





- The cut on the invariant mass makes the results less sensitive to smearing effects generated by hadronization and jet reconstruction

$$|\eta_j| < 2.5 \qquad |\Delta\eta_{jj}| < 1.3$$

$$M_{jj} > M_{W'}(1-\tfrac{\epsilon}{2}) \quad \epsilon = 0.08 - \frac{0.03}{2000}(M_{W'} - 500)$$

LHC Phenomenology: Wγ

- $W' \to W\gamma$ is interesting to test the gauge/composite structure of the W'
- The width into $W\gamma$ is proportional to $(c_B+1)^2$

$$\Gamma(W' \to W\gamma) = \frac{e^2 M_{W'}}{96\pi}(c_B+1)^2 \sin^2\hat{\theta}\cos^2\hat{\theta}\left(1-\frac{M_W^2}{M_{W'}^2}\right)^3\left(1+\frac{M_{W'}^2}{M_W^2}\right)$$

- It was shown that for an elementary particle (of any spin!) coupled to the photon the gyromagnetic ratio has to be $g=2$ in order for perturbative unitarity to be preserved up to $E \gg M/e$ (Ferrara, Porrati, Telegdi, PRD46 1992)
- In our case this implies $c_B=-1$ and no $W'W\gamma$ coupling
- In fact we have verified that the contribution growing with s of the amplitude $BB \to VV$ is proportional to c_B+1

$$A_{++\to LL} \approx \frac{(1-c_B^2)g'^2 s}{2M^2} \qquad A_{+-\to LL} \approx \frac{(1+c_B)^2 g'^2 s}{4M^2}$$

- These amplitudes fix an NDA cut-off as a function of c_B, e.g. requiring $A=16\pi^2$

$$\Lambda > 5M_{W'}$$

LHC Phenomenology: $W\gamma$

- To make predictions in the $W\gamma$ channel we have chosen to saturate the bound on g_q in order to maximize the production cross section
- We have studied the signal (800GeV and 1.2TeV) vs background in the channel $\gamma e \not{E}_T$ with the following cuts

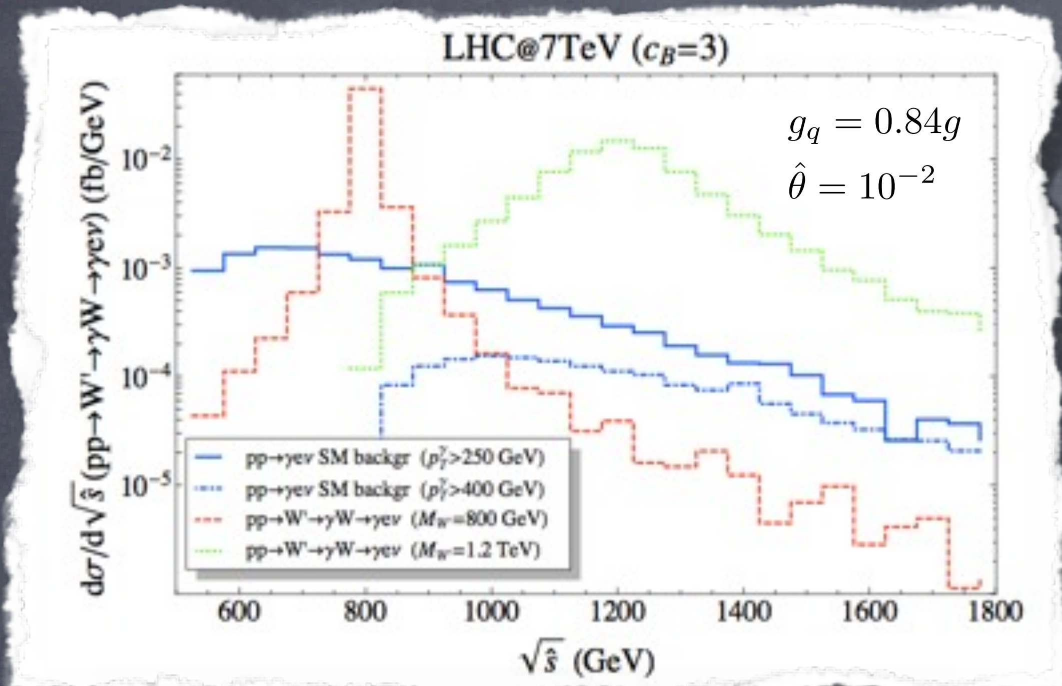
$$p_T^\gamma > 250\,(400)\,\mathrm{GeV} \qquad p_T^{e,\nu} > 50\,\mathrm{GeV}$$

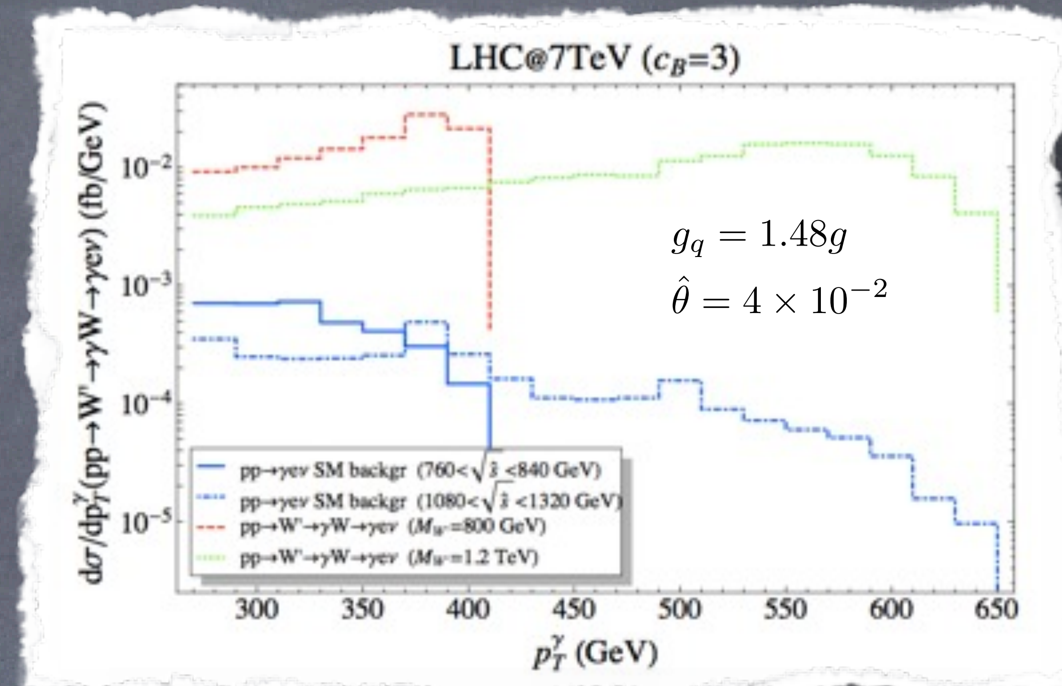
$$|\eta_{e,\gamma}| < 2.5 \qquad |M_{W\gamma} - M_{W'}| < 0.05\,(0.1)\,M_{W'}$$

- We have only considered the $\gamma e \not{E}_T$ irreducible background leaving out the $W+j$, $ee\not{E}_T$
- $W+j$ with a jet misidentified as a photon can be important but the Rejection Factor for high-p_T jets can be 5×10^3 if photon id and isolation cuts are applied (ATLAS TDR) and we have checked that with this RF the background $W+j$ is one order of magnitude below the irreducible $\gamma e \not{E}_T$
- E.G.: in the D0 $\gamma e \not{E}_T$ search the total background is roughly twice the irreducible background: this means a factor of $\sqrt{2}$ in the $S/\sqrt{B}$ ratio and a factor of $2^{1/4} \approx 1.2$ in the limit on the coupling

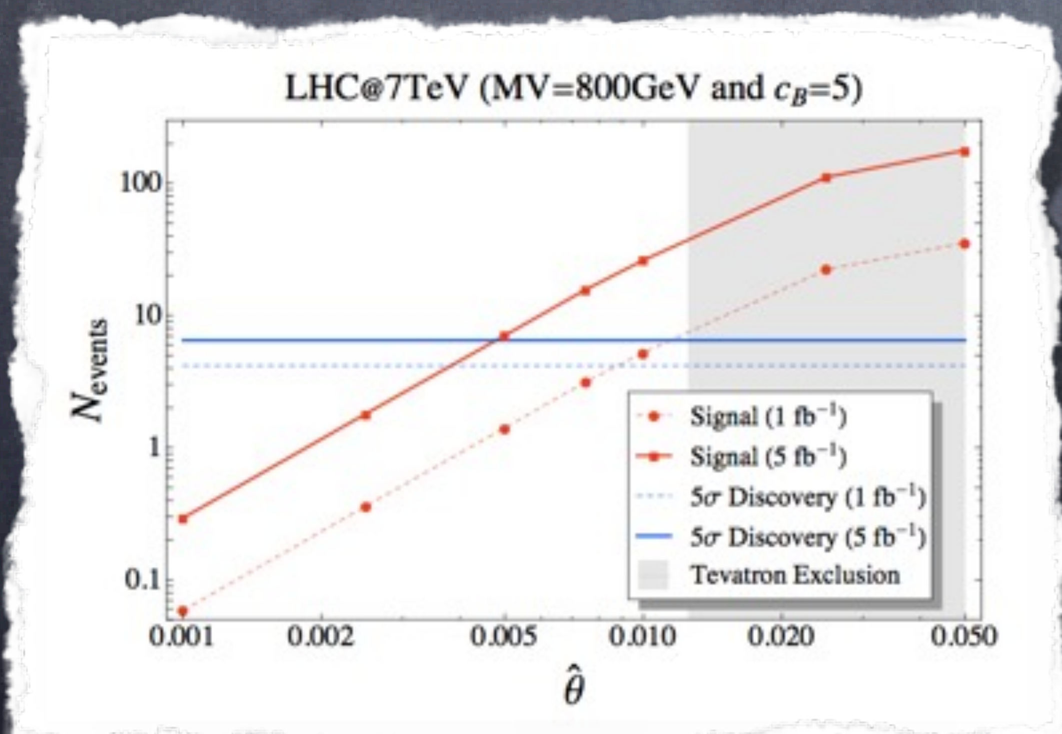
LHC Phenomenology: Wγ

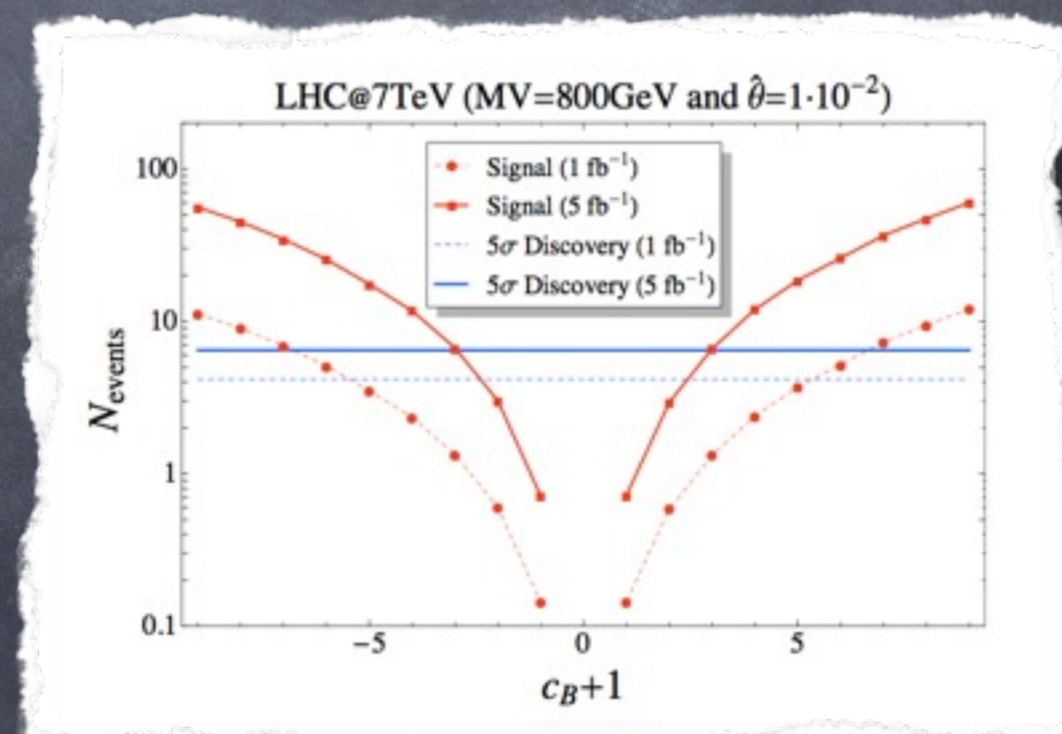
- Invariant mass and transverse momentum distributions





- Since this channel is sensitive both to $\hat{\theta}$ and c_B we have fixed one parameter and plotted the number of events as a function of the other





Conclusion

- The resonant production of a vector state in the $q\bar{q}$ channel is challenging for the early LHC unless..
- ..the new vector is very weakly constrained (light + large couplings)
- We have applied an effective approach to study the case of a weakly constrained W' (iso-singlet) which can be light $M_{W'} < 1\,\mathrm{TeV}$ and can be produced with a large rate $g_q \sim 1$
- The discovery is possible in the di-jet channel with some hundreds inverse picobarns of integrated luminosity
- In a general framework in which the vector is composite it can couple to the final state $W\gamma$ with a sizable coupling
- $W\gamma$ (and also WZ) final states can be studied to gain insight on the possibly composite nature of the resonance by measuring the mixing angle and the gyromagnetic ratio

Thank you

And thanks to

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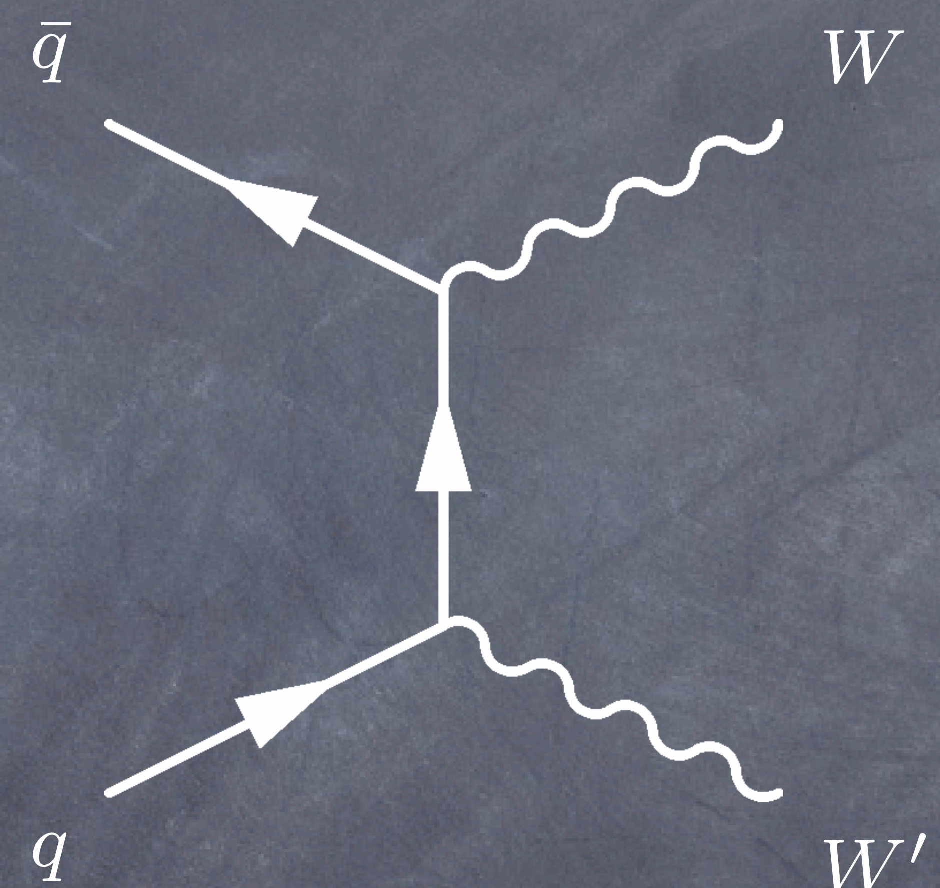
UNILHC, LHCPhenoNet, MassTEV and EU in general for support

Backup: Wjj

- The W′ can contribute to the Wjj total cross section through a t-channel exchange



- Since the W′ is right-handed a mass insertion is needed to change the chirality of the quark
- Due to the mass insertion the rate is very small and cannot reproduce the 'anomaly'

Backup: Top asymmetry

- The most recent measurement of the top pair FB asymmetry $A_{\rm FB}^{t\bar{t}}$ (CDF, 1101.0034) has a discrepancy with the SM prediction of about 2σ
- The asymmetry was observed to be larger in the region of large invariant mass of the top pair and in the region of large rapidity difference $|y_t - y_{\bar{t}}|$
- The t-channel exchange of a W' that couples only to the t and d quarks was suggested as a possible explanation of the anomaly (Jung, Murayama, Pierce and Wells, 0907.4112; Cheung, Keung, Yuan, 0908.2589; Shelton and Zurek, 1101.5392)
- In particular for $M_{W'} \approx 200 \div 600\,\mathrm{GeV}$ and $g_{W'td} \approx 0.85 \div 2.1$ the observed asymmetry can be reproduced
- Such W' is described by our framework, where the right-handed mixing matrix does not need to be unitary
- In such a way we can account for a large $W'td$ coupling tuning the remaining entries to evade the strong bounds from meson mixing