An iso-singlet W′ at the early LHC

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based on C. Grojean, E. Salvioni and RT, 1103.2761 [hep-ph]
(updated bounds RT, 1109.xxxx [hep-ph])

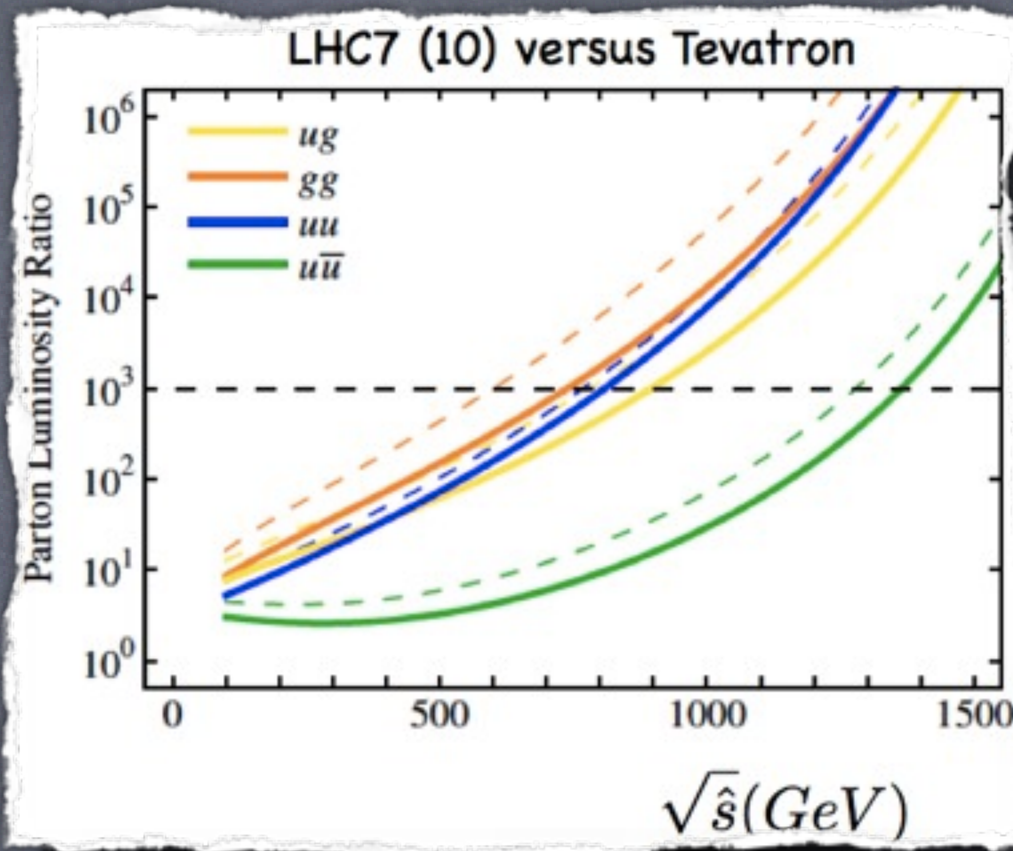
Outline

- Introduction and theoretical motivations
- A model independent approach
- Bounds
  - Indirect bounds
  - Collider 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
- 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)

- Moreover 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
- Up to dim 4, an effective Lagrangian for this state is

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_V + \mathcal{L}_{V-SM}$$

$$\mathcal{L}_V = D_\mu V_\nu^- D^\nu V^{+\mu} - D_\mu V_\nu^- D^\mu V^{+\nu} + \tilde{M}^2 V^{+\mu} V_\mu^- + \frac{g_4^2}{2}|H|^2 V^{+\mu} V_\mu^- - i c_B g' B^{\mu\nu} V_\mu^+ V_\nu^-$$

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

- There are 5 new parameters (4 couplings + 1 mass) and 1 new mixing matrix in the right-handed sector
- The coupling g_H ($\hat{\theta}$) generates a W-W' mass mixing

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

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

Indirect bounds

- Indirect bounds of different origin constrain the g_q, g_H, $\hat{\theta}$, c_B, g_4 couplings 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 the $W' \to Wh$ 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)

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

- 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.)

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

$$\begin{array}{lll} |\hat{\theta}| \lesssim 4\times 10^{-3} & \text{for} & M_{W'} = 300\,\mathrm{GeV} \\ |\hat{\theta}| \lesssim 5\times 10^{-4} & \text{for} & M_{W'} = 2\,\mathrm{TeV} \end{array}$$

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

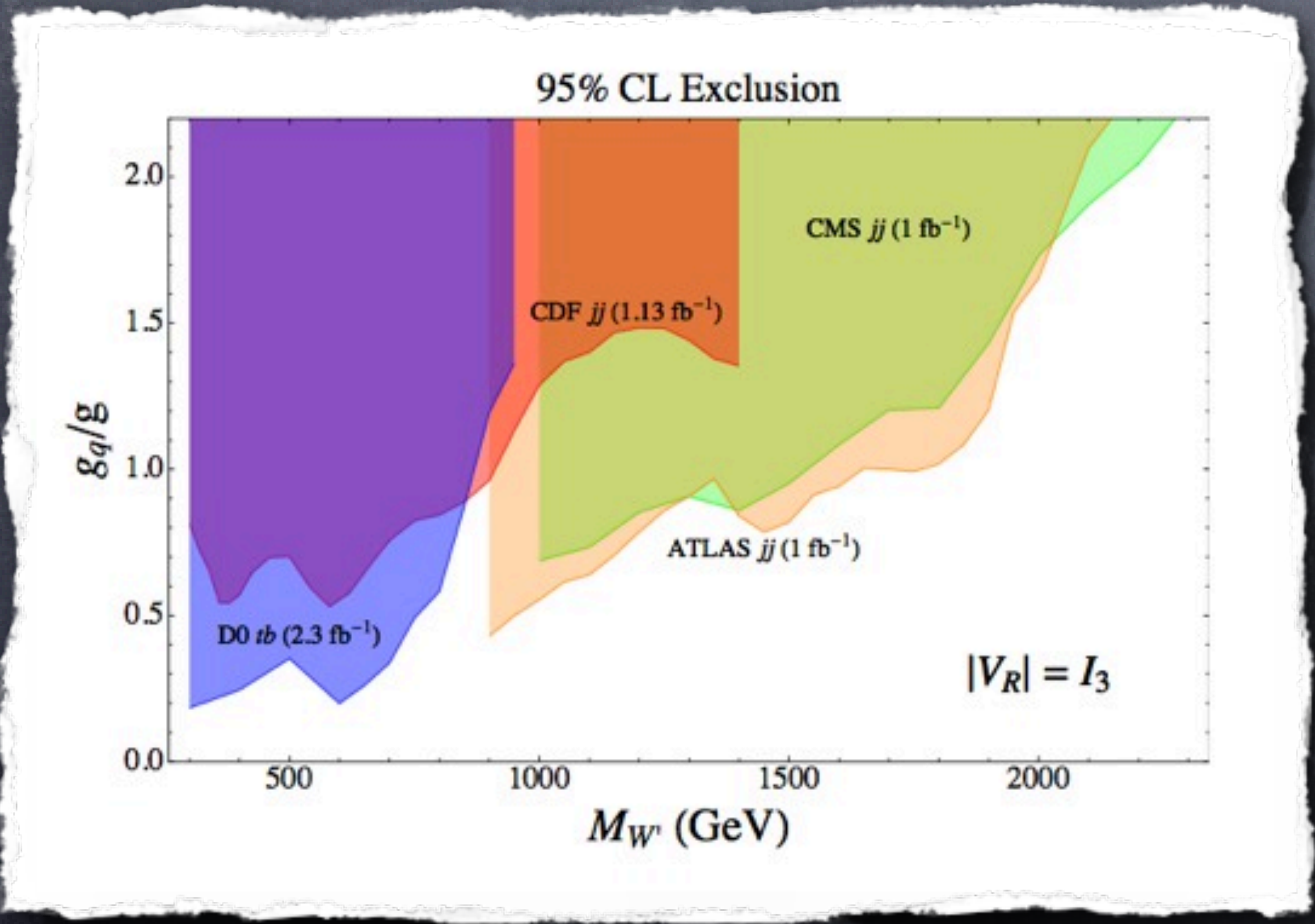
$$\left|\frac{g_q\hat{\theta}}{g}\right| < 10^{-(2\div 1)}$$

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

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

Collider searches

- Both the Tevatron (CDF and D0) and the LHC (ATLAS and CMS) have published searches for new particles decaying to two quarks (light jets or tb)
- The Tevatron is dominating the low mass region (<0.9-1 TeV) while the LHC is already doing better in the high mass region (from ~1 TeV to ~4TeV)
- These searches allow to exclude a region in the (coupling, mass) plane



CDF Collaboration, 0812.4036 [hep-ex]

D0 Collaboration, 1101.0806 [hep-ex]

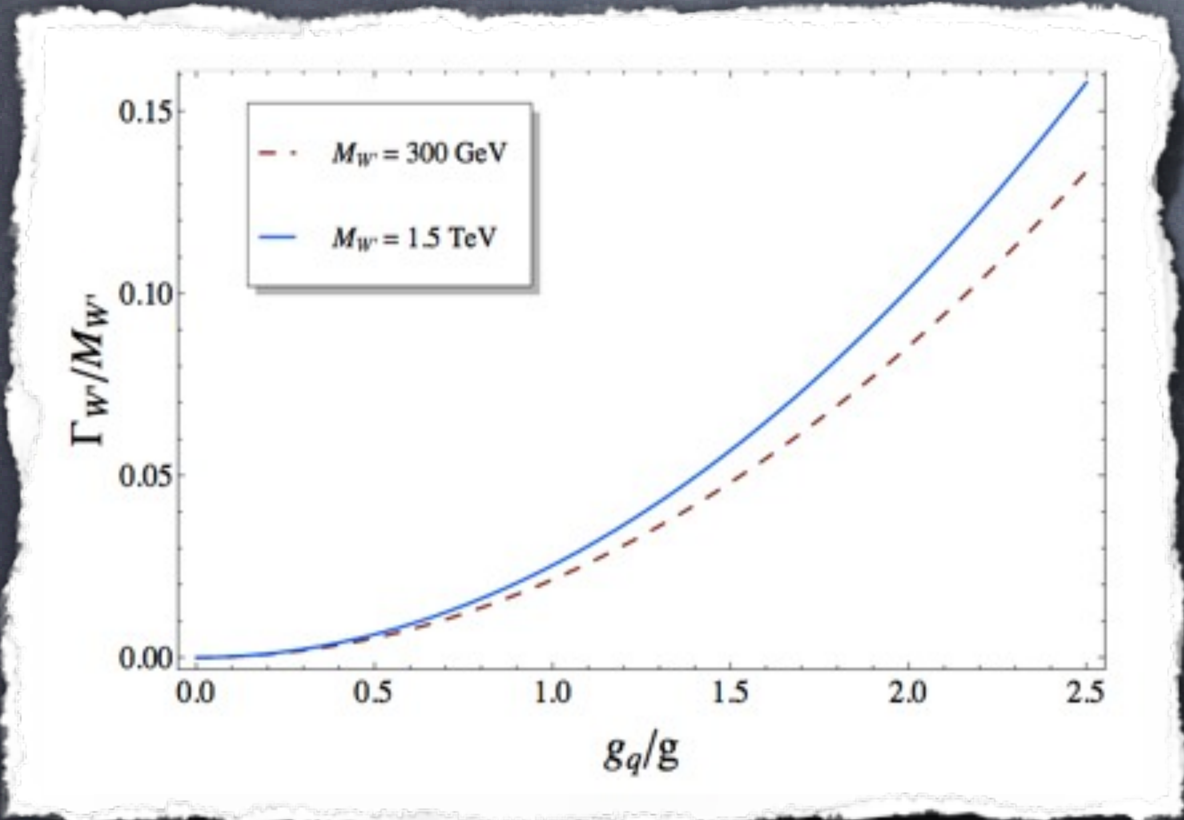
ATLAS Collaboration, 1108.6311 [hep-ex]

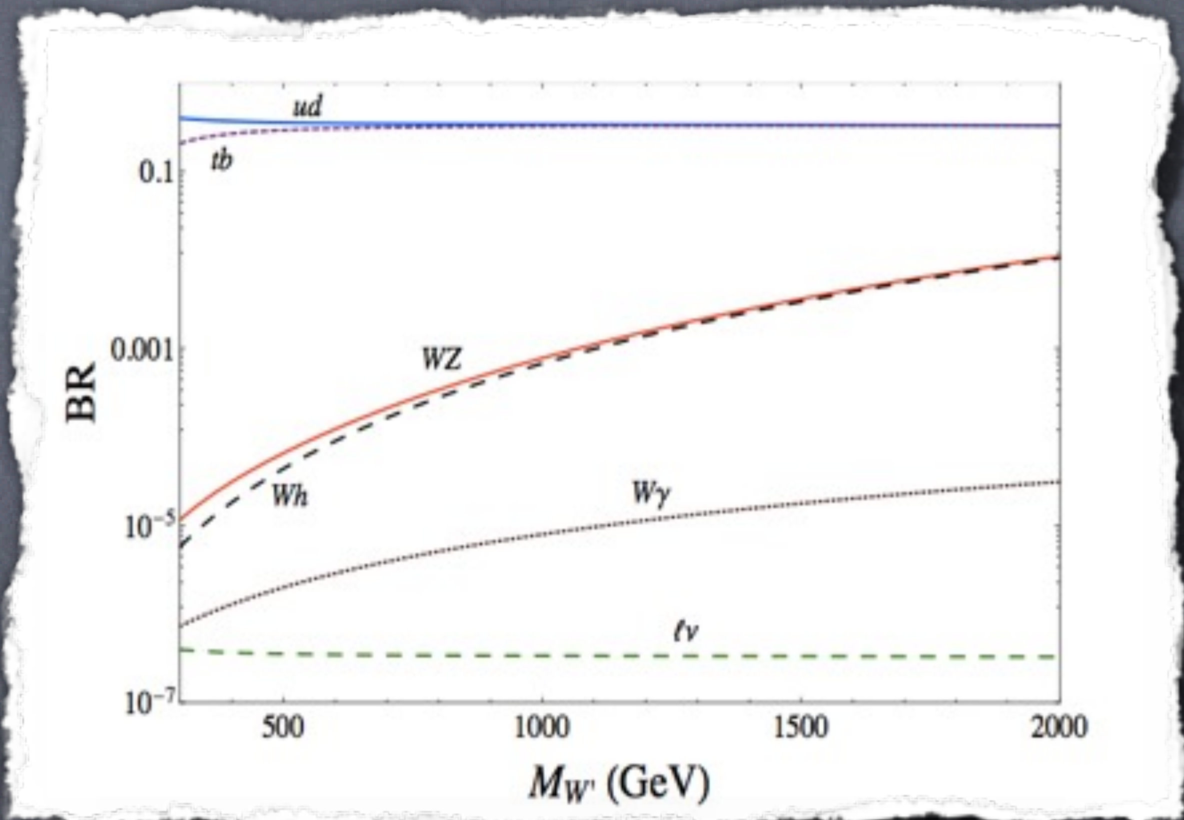
CMS Collaboration, 1107.4771 [hep-ex]

(slides of A. De Roeck)

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

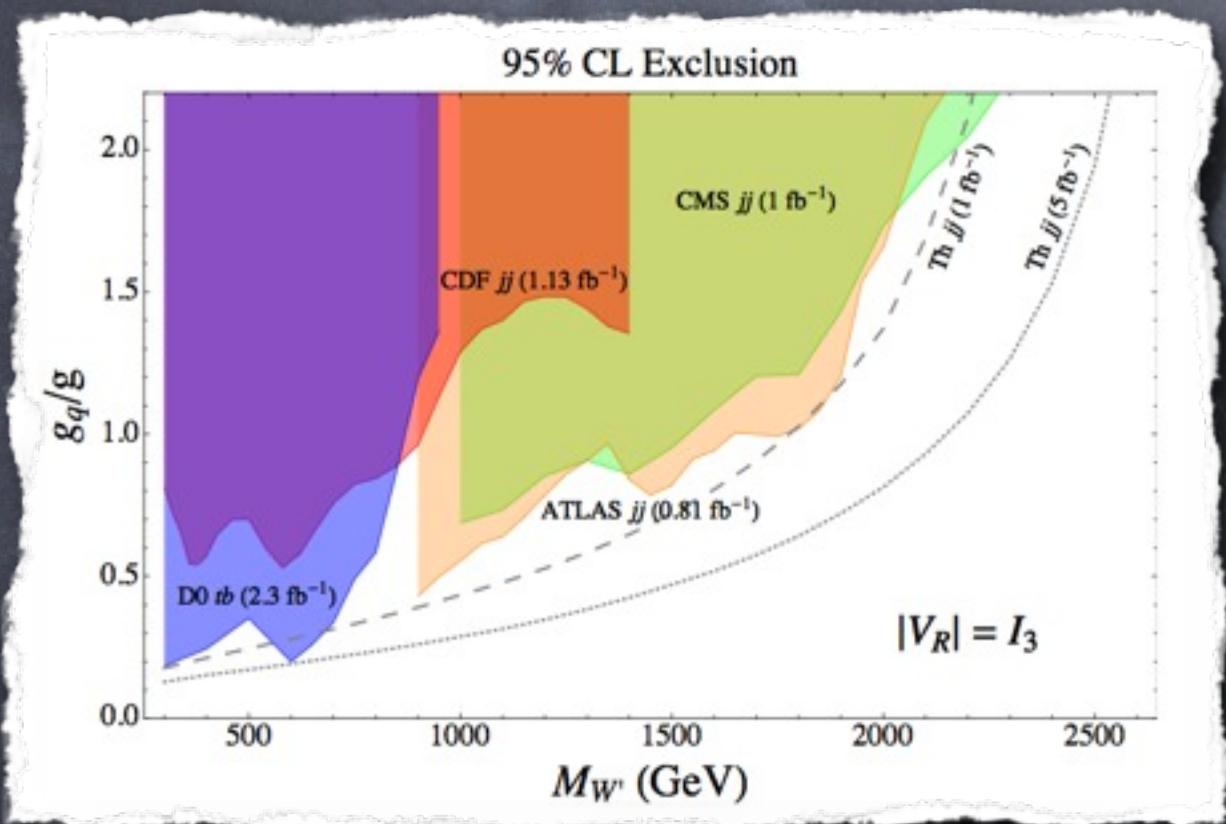


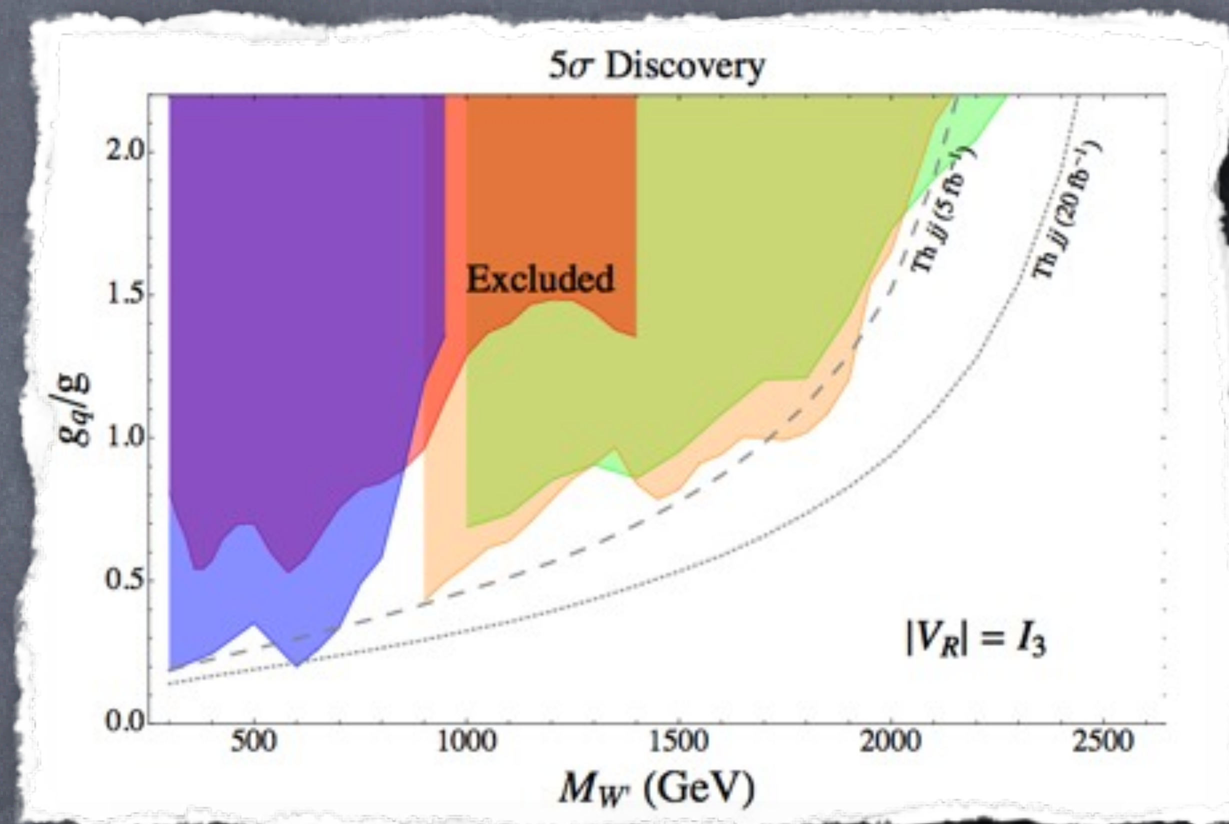


$$g_q = g,\ \hat{\theta} = 10^{-3},\ c_B = -3$$

LHC Phenomenology: di-jet

- A discovery is possible at the LHC@7TeV with few inverse fb
- The LHC started doing better than the Tevatron in the high mass region
- More statistics is necessary to do better than the Tevatron in the low mass region where the di-jet SM background makes more difficult the LHC analyses





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

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

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

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 $g=2$ to preserve perturbative unitarity 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 can be used to 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

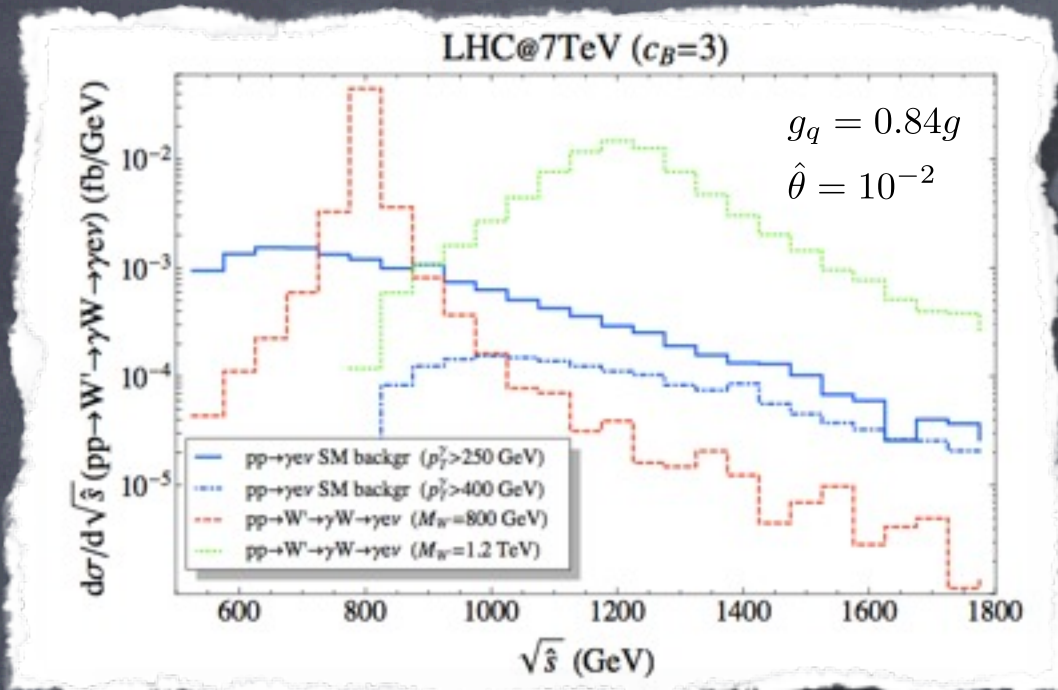
$$p_T^\gamma > 250\,(400)\,\text{GeV} \quad p_T^{e,\nu} > 50\,\text{GeV}$$

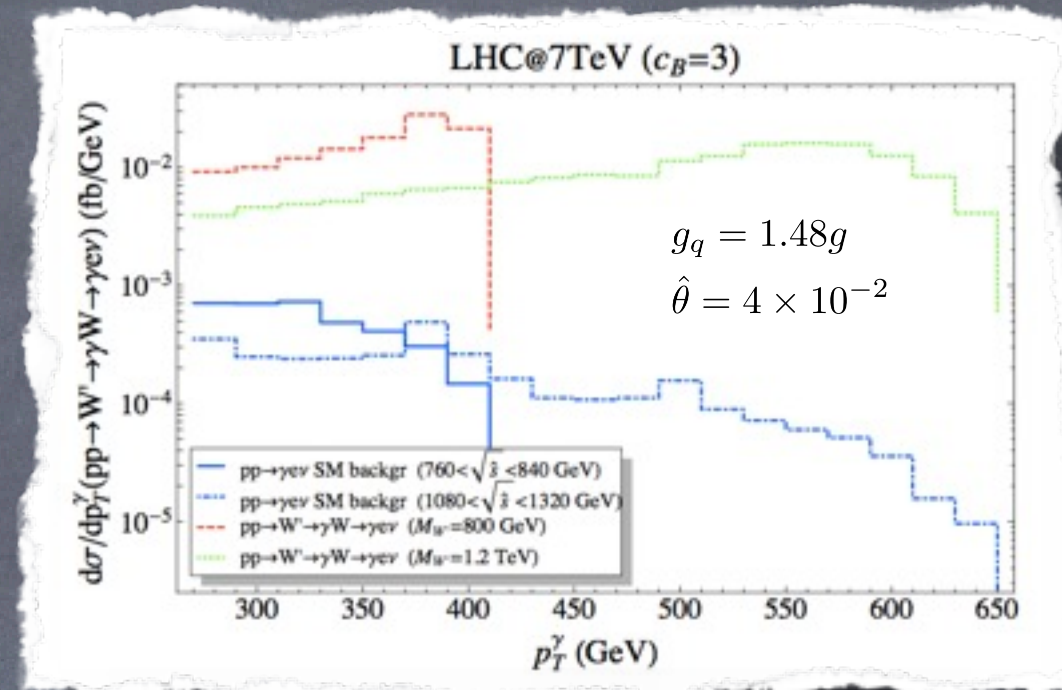
$$|\eta_{e,\gamma}| < 2.5 \qquad |M_{W\gamma} - M_{W'}| < 0.05\,(0.1)\,M_{W'}$$

- 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

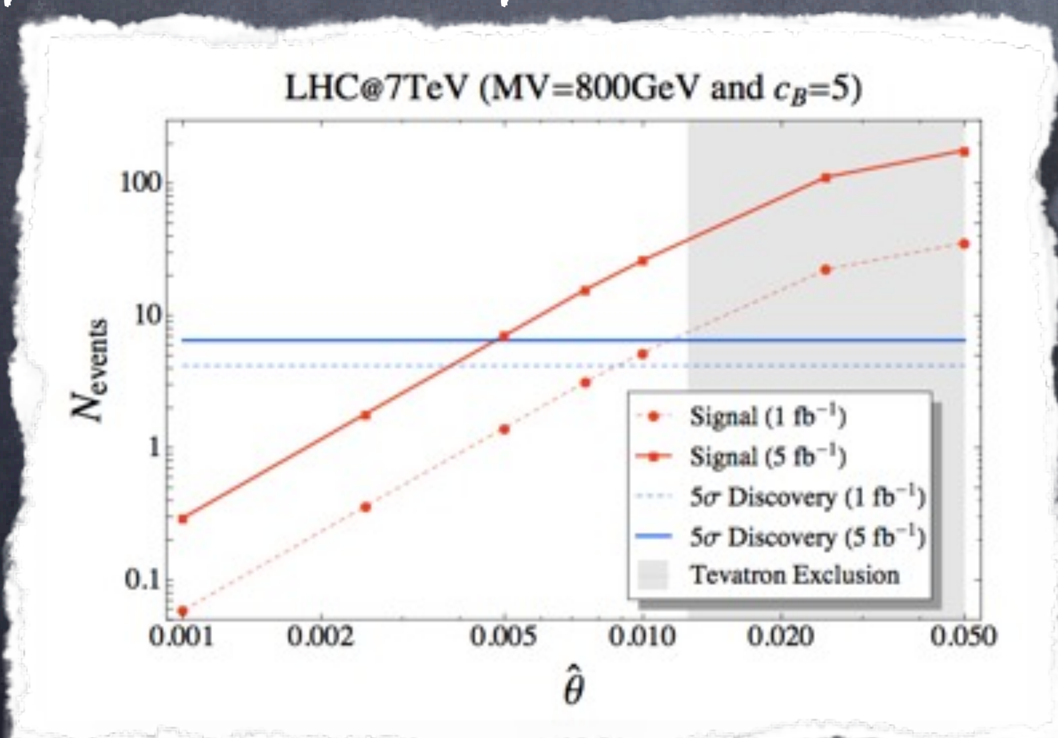
LHC Phenomenology: Wγ

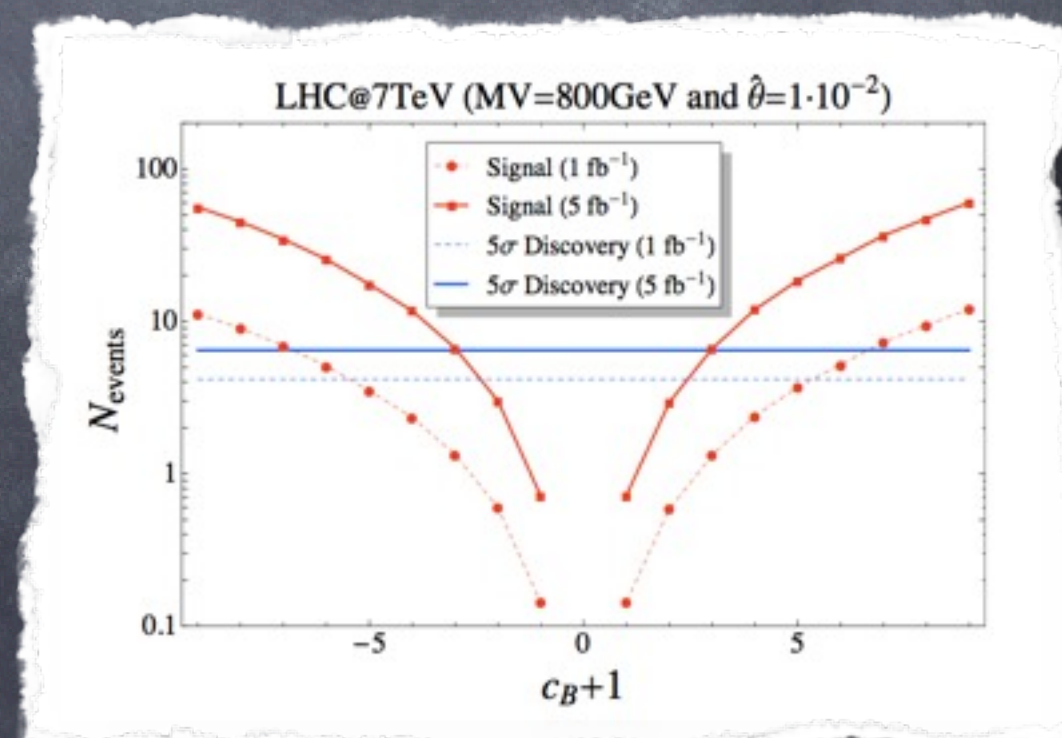
- Invariant mass and transverse momentum distributions





- 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 few inverse picobarns of integrated luminosity (i.e starting from now!)
- 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

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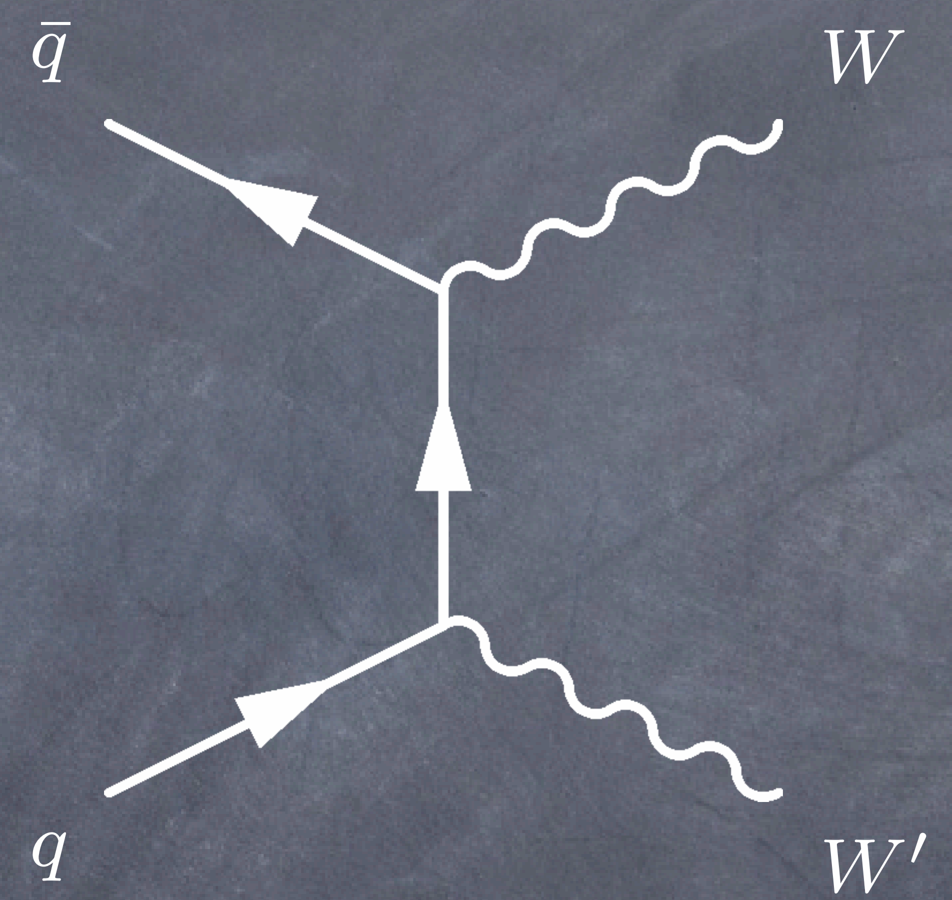
Thanks to Corfu for the fantastic environment

"Barcarola", Corfu, 7 August 2011

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 exchanged 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