Production and decay of new resonances at the LHC

Tomáš Ježo

Laboratoire de Physique Subatomique et de Cosmologie
Grenoble

Théorie – LHC France

25th of September 2009

Advisers: Dr. I. Schienbein & Prof. M. Klasen

Outline

Motivation

- **LHC** in operation in the fall of 2009
- Theorists should prepare a map of what to expect
- Particularly interesting: new **resonances**
- **Neutral** spin-1 resonances (Z'-bosons) extensively studied
- Study of **charged** spin-1 resonances (W'-bosons) not done yet
- Since $\exists\, W' \Rightarrow \exists\, Z'$, studies of W'-bosons desired

W′-boson

Charge current Lagrangian

- **Couplings** of W, W′-boson to the SM quarks and leptons:

$$\begin{aligned}\mathcal{L}_{cc} &= \frac{g_W}{\sqrt{2}}\Big\{\Big[\bar{\mathrm{u}}U\gamma^\mu P_L \mathrm{d} + \overline{\nu}\gamma^\mu P_L \mathrm{e}\Big]\mathrm{W}_\mu \\ &+ \Big[\bar{\mathrm{u}}\gamma^\mu\left(L_q P_L + R_q P_R\right)\mathrm{d} + \overline{\nu}\gamma^\mu\left(L_l P_L + R_l P_R\right)\mathrm{e}\Big]\mathrm{W}'_\mu\Big\} + \ldots\end{aligned}$$

- $P_{L,R}$ chiral projectors & flavor indices suppressed
- W′-boson $\approx$ W-boson, only with more general couplings
- Difference in **mass** from Higgs sector

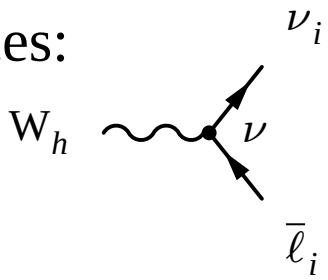
W'-boson

Feynman rules

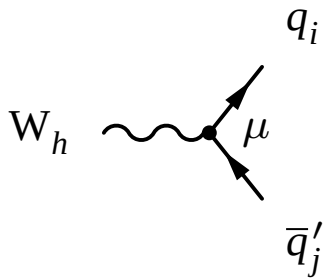
- W_ℓ, W_h: light, heavy mass eigenstate and ξ the mixing angle:

$$\begin{pmatrix} W_\ell \\ W_h \end{pmatrix} = \begin{pmatrix} \cos\xi & \sin\xi \\ -\sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} W \\ W' \end{pmatrix}$$

- Vertices:

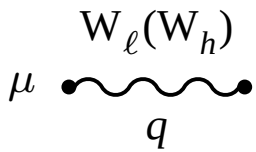


$$-i\gamma^\nu \frac{g_W}{\sqrt{2}} \left[-\sin\xi P_L + \cos\xi (L_l P_L + R_l P_R) \right]$$



$$-i\gamma^\mu \frac{g_W}{\sqrt{2}} \left[-\sin\xi P_L + \cos\xi (L_q P_L + R_q P_R) \right]$$

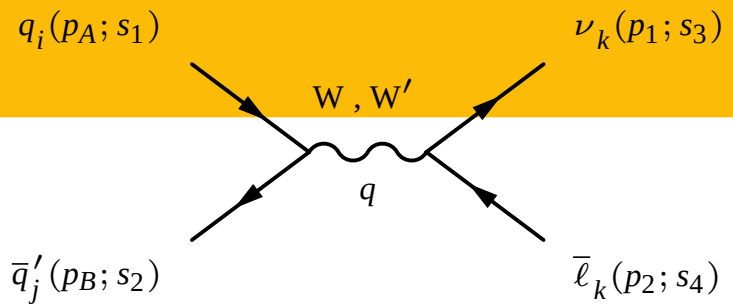
- Vertices for W_ℓ: $-\sin\xi \to \cos\xi$, $\cos\xi \to \sin\xi$
- Propagators:



$$i \left(\frac{-g_{\mu\nu} + q_\mu q_\nu / M^2_{W_\ell(W_h)}}{D_{W_\ell(W_h)}} \right), D_i = s - M_i^2 + i M_i \Gamma_i$$

W′-boson

Charged vector boson production at LHC



- Charged vector boson production: Drell-Yan like process

$$d\sigma_{AB} = \sum_q \int dx_1 dx_2 f_q(x_1) f_q(x_2) d\hat{\sigma}$$

- Formulas for $d\hat{\sigma}$ for $\mathrm{W_R}, \mathrm{W_L}(\mathrm{W}' = \mathrm{W_L} + \mathrm{W_R})$:

$$\begin{aligned}
\frac{d\hat{\sigma}^{\mathrm{W_L}}}{dt} &\sim t^2 \left\{ \left(\frac{1}{|D_{\mathrm{W}_\ell}|^2} + \frac{{L_q}^2 {L_l}^2}{|D_{\mathrm{W}_h}|^2} \right) \left(1 - \frac{1}{2} \sin^2 2\xi \right) + \frac{(s - M^2_{\mathrm{W}_\ell})(s - M^2_{\mathrm{W}_h}) + M_{\mathrm{W}_\ell} M_h \Gamma_{\mathrm{W}_\ell} \Gamma_{\mathrm{W}_h}}{|D_{\mathrm{W}_\ell}|^2 |D_{\mathrm{W}_h}|^2} \right. \\
&\times \left[U L_q L_l + \frac{1}{4} \sin^2 2\xi (U^2 - {L_q}^2 + {L_l}^2 + {L_q}^2 {L_l}^2 + U^2 {L_l}^2 - 2U L_q L_l) \right. \\
&+ \left. \left. \frac{1}{2} \sin 4\xi ({L_q}^2 L_l + U L_q {L_l}^2 - U L_q - U^2 L_l) \right] \right\} \\
\frac{d\hat{\sigma}^{\mathrm{W_R}}}{dt} &\sim (t^2 + t m^2_{\nu_R}) \left\{ \frac{{R_q}^2 {R_l}^2}{|D_{\mathrm{W}_h}|^2} \left(1 - \frac{1}{2} \sin^2 2\xi \right) + \frac{1}{4} \frac{(s - M^2_{\mathrm{W}_\ell})(s - M^2_{\mathrm{W}_h}) + M_{\mathrm{W}_\ell} M_h \Gamma_{\mathrm{W}_\ell} \Gamma_{\mathrm{W}_h}}{|D_{\mathrm{W}_\ell}|^2 |D_{\mathrm{W}_h}|^2} \right. \\
&\times \left. \sin^2 2\xi {R_q}^2 {R_l}^2 \right\}
\end{aligned}$$

W′-boson

Theories predicting a W′-boson – overview

- Sequential Standard model: W′-boson a heavier copy of W-boson
- SM extensions based on an enlarged gauge group ($G = SU(2)$ or larger)
  - left-right symmetric models (**LR**)
  - generation nonuniversal (**GN**), quark-lepton nonuniversal (**Q-LN**)
  - "-phobic": leptophobic (**LP**), hadrophobic (**HP**), fermiophobic (**FP**)

Table: Fermion transformation properties under $SU(2)_1$ and $SU(2)_2$ respectively.

Field/Model	LR	LP	FP	Q-LN
$q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$(2,1)$	$(2,1)$	$(2,1)$	$(2,1)$
$q_R \equiv \begin{pmatrix} u_R \\ d_R \end{pmatrix}$	$(1,2)$	$(1,2)$	$(1,1)$ $(1,1)$	$(1,1)$ $(1,1)$
$l_L \equiv \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$(2,1)$	$(2,1)$	$(2,1)$	$(1,2)$
$l_R \equiv \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$	$(1,2)$	$-$ $(1,1)$	$-$ $(1,1)$	$-$ $(1,1)$

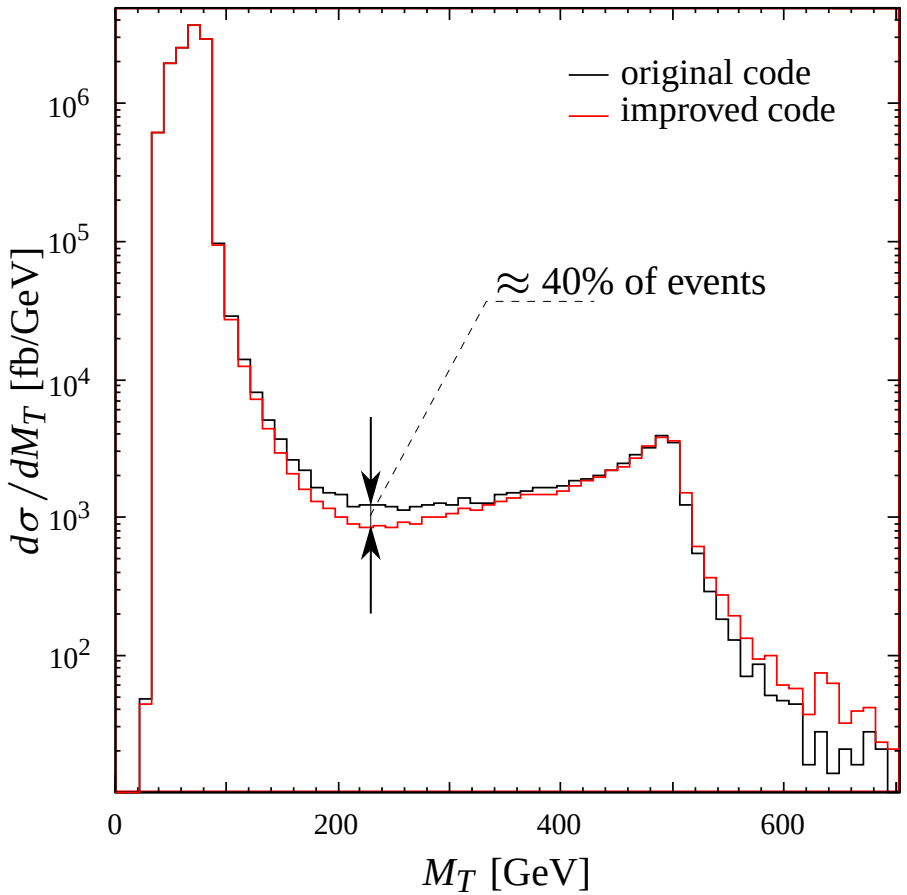
- Many more like Kaluza Klein excitations, Technicolor …

PYTHIA

Critical review & extension

- Tool used for the numerical analysis: PYTHIA (ver 6.4.20)
- Original code:
  - **Interference** of W' with W not accounted for
  - W' no right-handed component
  - W_R not general enough
- Improved code:
  - Formulas for cross section now account for the **interference**
  - Implemented 6 new processes
  - Generalized W_R

- Comparison of the M_T distribution with and without the **interference**



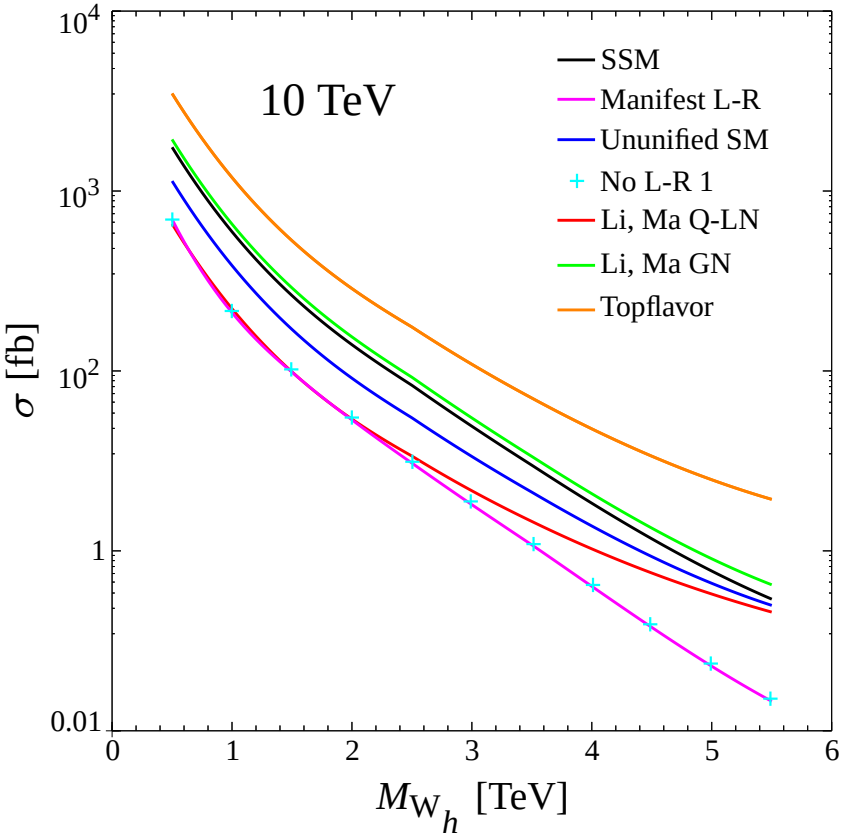
$$M_T = \sqrt{p_{T_W}^2 + M_W^2}$$

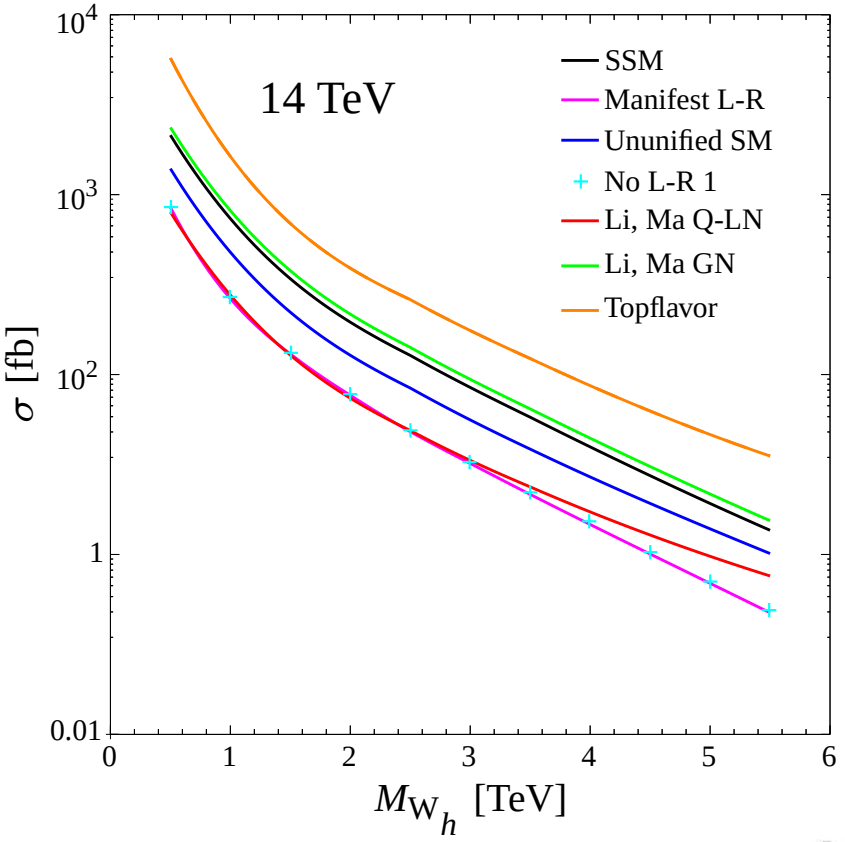
$$\frac{1}{\sigma}\frac{d\sigma}{dM_T} \sim \left(1 - \frac{M_T^2}{M_W^2}\right)^{-\frac{1}{2}}$$

Preliminary numerical analysis

Total cross section

- Estimate of the **total cross section** of the process $q + \bar{q}' \xrightarrow{W'} \nu + \ell$ as a function of the mass of W_h

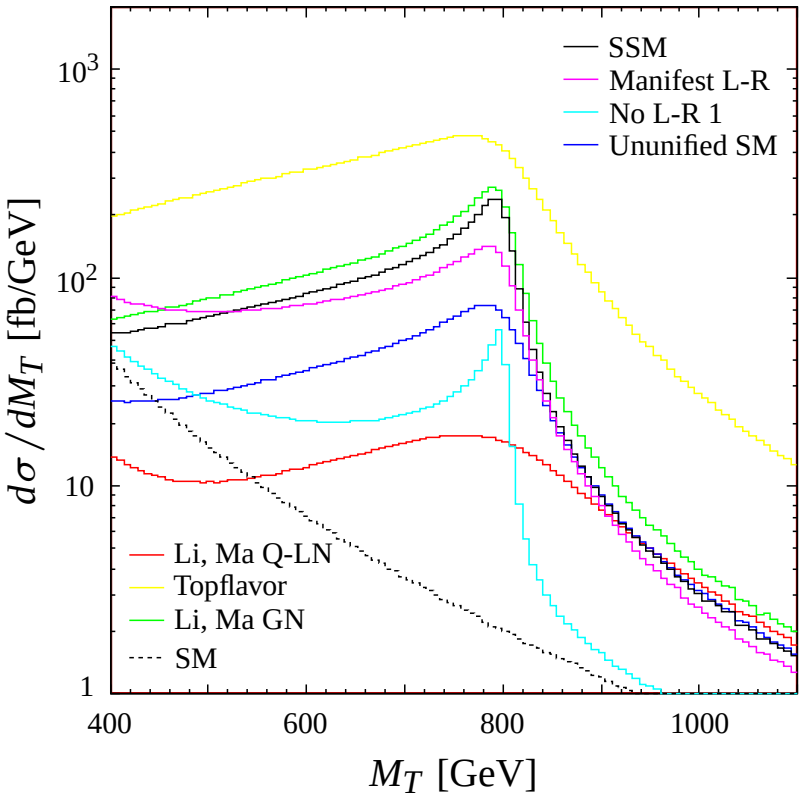


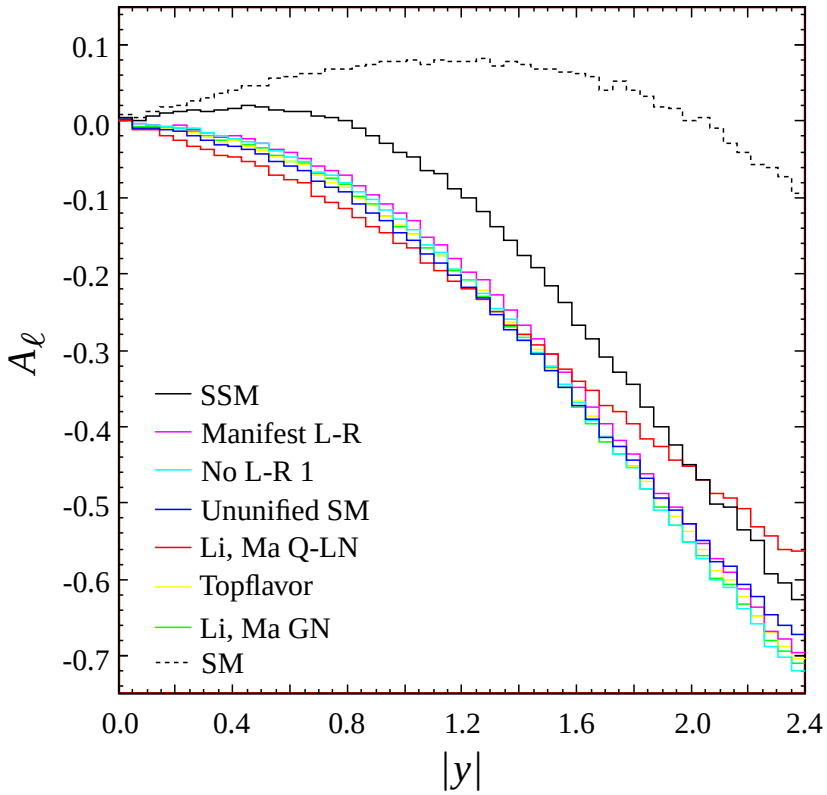


Preliminary numerical analysis

Transverse mass and charge asymmetry

- M_T distribution and A_ℓ for models under study





- Where $A_\ell \equiv \frac{d\sigma(\bar{\ell})/dy - d\sigma(\ell)/dy}{d\sigma(\bar{\ell})/dy + d\sigma(\ell)/dy}$

Outlook

- Classification & constraints (including KK excitations, Technicolor . . .)
- W′- and Z′-boson production in SO(10) SUSY GUT models
- Correlations between signals for W′, Z′ and Higgs boson
- For that purpose:
  - Additional study of M_T, A_l within different models
  - Another distributions & asymmetries: $\cos\theta_\ell$, A_{FB} – **LR** models
  - Third family leptonic final state ($\tau\nu_\tau$) – **GN** models
  - Heavy quark (tb) final state for – **LP** models
  - VBF (WZ) – **FP** models
- Cross section at next-to-leading order – POWHEG (MC@NLO)

Backup slides

Lagrangian, mass matrix, mass eigenvalues, mixing

$$\begin{aligned}\mathcal{L}_{cc}^{\mathrm{W}'} &= \frac{g_W}{\sqrt{2}}\Big[\bar{\mathrm{u}}_i\gamma^\mu\left((U^L_{\mathrm{CKM}})_{ij}C^L_{q_{jk}}P_L + (U^R_{\mathrm{CKM}})_{ij}C^R_{q_{jk}}P_R\right)\mathrm{d}_k \\ &+ \bar{\nu}_j\gamma^\mu\left(C^L_{l_{jk}}P_L + C^R_{l_{jk}}P_R\right)\mathrm{e}_k\Big]\mathrm{W}'_\mu + \mathrm{h.c.}\,.\end{aligned}$$

$$\mathfrak{M}^2_{\mathrm{W}} = \begin{pmatrix} M^2_{11} & M^2_{12} \\ M^2_{12} & M^2_{22}\end{pmatrix}\,,$$

$$M^2_\ell, M^2_h = \frac{1}{2}\left[M^2_{11} + M^2_{22} \mp \sqrt{\left(M^2_{11} - M^2_{22}\right)^2 + 4\left(M^2_{12}\right)^2}\right]\,.$$

▸ *

Numerical analysis

Widths

- The total decay rate $\Gamma_{W'} = f(L_q, R_q, L_l, R_l)$