Measuring the mass, width, and couplings of semi-invisible resonances with the matrix element method

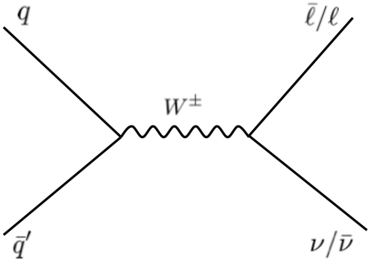
Prasanth Shyamsundar
University of Florida

based on work done with (arXiv:1708.07641)

Amalia Betancur
Dr. Dipsikha Debnath
Dr. James Gainer
Dr. Konstantin Matchev

7 May, 2018

The problem



W could be a charged Higgs scalar or a new W' heavy guage boson.
To find: M_W, M_ν, Γ_W, and the chirality of the couplings.

$$g^q = g^q_L P_L + g^q_R P_R \qquad\qquad g^l = g^l_L P_L + g^l_R P_R$$

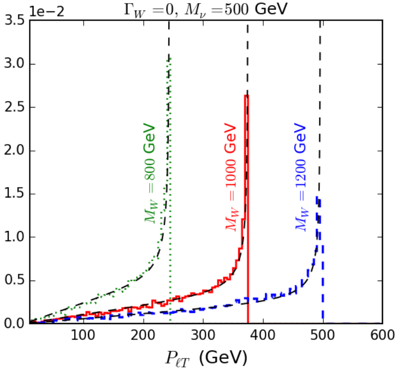
where $P_{L,R} = (1 \mp \gamma_5)/2$

$$\tan(\varphi_q) \equiv \frac{g^q_R}{g^q_L} \qquad\qquad \tan(\varphi_l) \equiv \frac{g^l_R}{g^l_L}$$

End point methods for mass measurements

The end point of the P_{lT} distribution is given by

$$\mu = \frac{M_W^2 - M_\nu^2}{2M_W}$$



Matrix Element Method

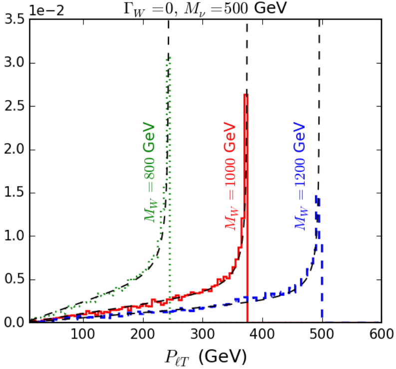
Likelihood of an event $\{P_j^{\mathrm{vis}}\}$ under a set of parameter values α

$$\mathcal{P}(\{P_j^{\mathrm{vis}}\}|\alpha) = \frac{1}{\sigma_\alpha}\left(\prod_{j=1}^{N_f}\int \frac{d^3 p_j}{(2\pi^3 2E_j)}\right) W(\{P_j^{\mathrm{vis}}\},\{p_j^{\mathrm{vis}}\})$$
$$\times \sum_{a,b} \frac{f_a(x_1) f_b(x_2)}{2 s x_1 x_2} |\mathcal{M}_\alpha(\{p_i\},\{p_j\})|^2$$
$$\times (2\pi)^4 \delta^4 \left(\sum_{i=1}^{2} p_i - \sum_{i=1}^{N_f+2} p_j\right)$$

Likelihood of set of N events

$$\mathcal{L}_\alpha = \prod_{n=1}^{N} \mathcal{P}(\{P_j^{\mathrm{vis}}\}_n|\alpha)$$

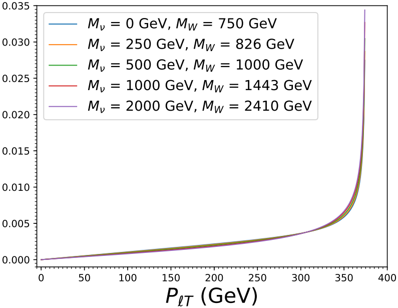
"Mass difference" μ



Endpoint

$$\mu = \frac{M_W^2 - M_\nu^2}{2M_W}$$

Mass scale M_ν

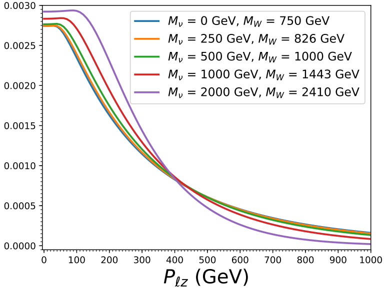


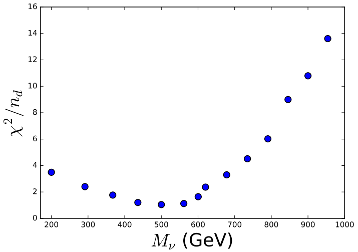
$$\frac{1}{\sigma}\frac{d\sigma}{dP_{lT}} = \frac{3}{4+3\rho}\frac{P_{lT}}{\mu\sqrt{\mu^2 - P_{lT}^2}}\left(2 - \frac{P_{lT}^2}{\mu^2} + \rho\right)$$

where $\rho = 2M_\nu^2/(M_W^2 - M_\nu^2)$

Mass scale M_ν

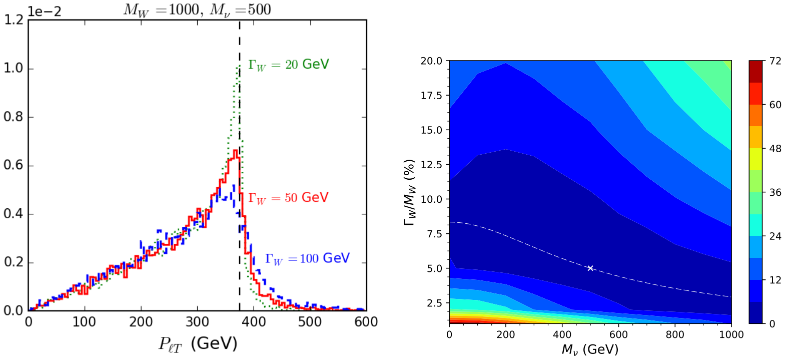
χ^2 per d.o.f. fit from P_{lz} templates





Width Γ_W

χ^2 per d.o.f. fit from P_{lT} templates (10000 events)

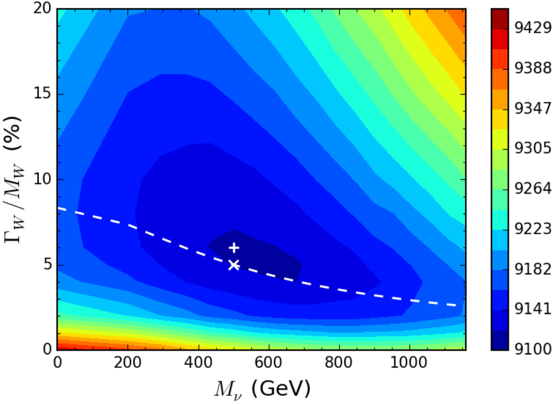


Flat direction

$$\frac{\Gamma_W}{\Gamma_W^{\rm true}} = \frac{1+(M_\nu^{\rm true}/M_W^{\rm true})^2}{1+(M_\nu/M_W)^2}$$

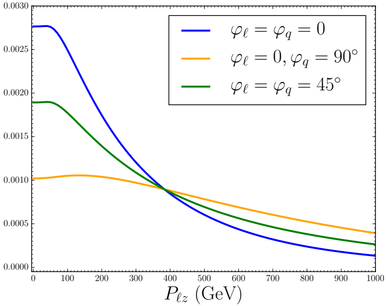
Masses and width using MEM

Negative log likelihood fit for masses and width (1000 events)



Including both P_{lT} and P_{lz} eliminates the flat direction

Chirality (φ_l, φ_q)



$$u\bar{d} \to W^+ \to \bar{l}\nu$$

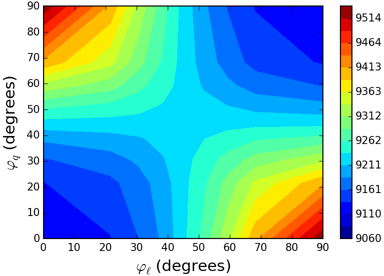
$$\langle|\mathcal{M}|^2\rangle \propto \{(g_L^q g_L^l)^2 + (g_R^q g_R^l)^2\}(p_u.p_{\bar{l}})(p_{\bar{d}}.p_\nu) + \{(g_R^q g_L^l)^2 + (g_L^q g_R^l)^2\}(p_{\bar{d}}.p_{\bar{l}})(p_u.p_\nu)$$

The dependence on (φ_l, φ_q) is through $\cos(2\varphi_l)\cos(2\varphi_q)$

Chirality (φ_l, φ_q)

Dependence of matrix element on chirality has a degeneracy.
Matrix element depends on

$$\cos(2\varphi_l)\cos(2\varphi_q) = \cos^2(\varphi_l - \varphi_q) - sin^2(\varphi_l + \varphi_q)$$



Negative log likelihood fit for 1000 events assuming values of other parameters. True value: $\varphi_q = \varphi_l = 0$

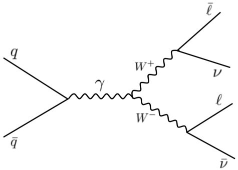
Simultaneous measurement

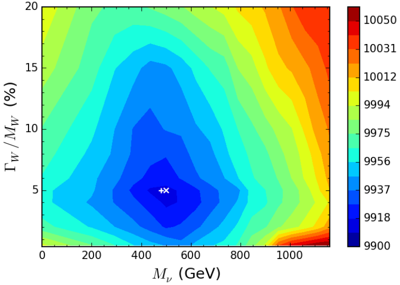
Extent to which different components of the visible momenta are affected by the parameters

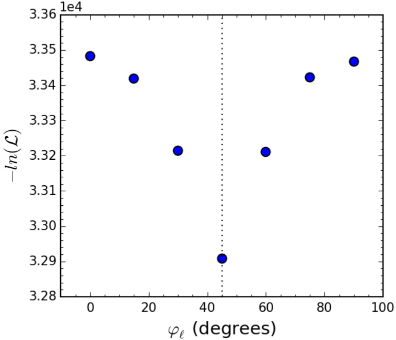
	$P_{\ell T}$	$P_{\ell z}$
mass difference	$\checkmark$	$\sim$
mass scale	$\sim$	$\checkmark$
width	$\sim$	$\sim$
chirality	$\times$	$\checkmark$

For 100 events produced at
$M_W = 1000$ GeV, $M_\nu = 500$ GeV, $\Gamma_W = 50$ GeV, $\varphi_q = \varphi_q = 45°$,
multivariate minimization of the log likelihood function yielded
$M_W = 998$ GeV, $M_\nu = 502$ GeV, $\Gamma_W = 43$ GeV, $\varphi_q = \varphi_q = 46.5°$

Pair production of W like resonances







Log likelihood minimization with 500 events

Thank You!