W' Decays to Heavy Higgs Particles

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Based on work with Bogdan Dobrescu

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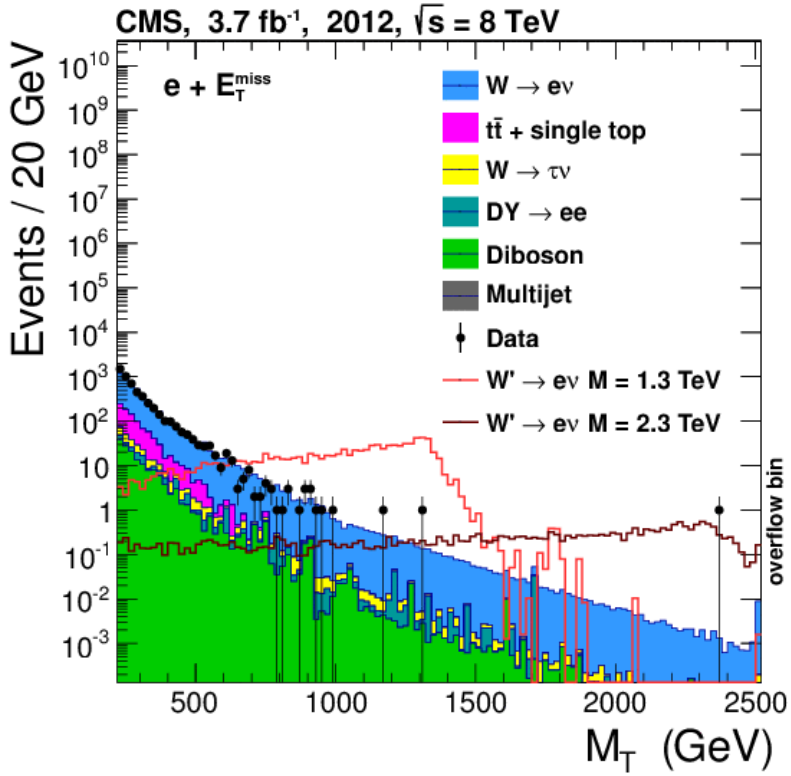
- PHENO: Can easily construct simplified and effective theories with only a few parameters; often useful in explaining anomalies in data
- EXP: Clean signatures possible $\leftarrow$ Is this still an advantage?

Classic benchmark search: $W' \to l\nu$

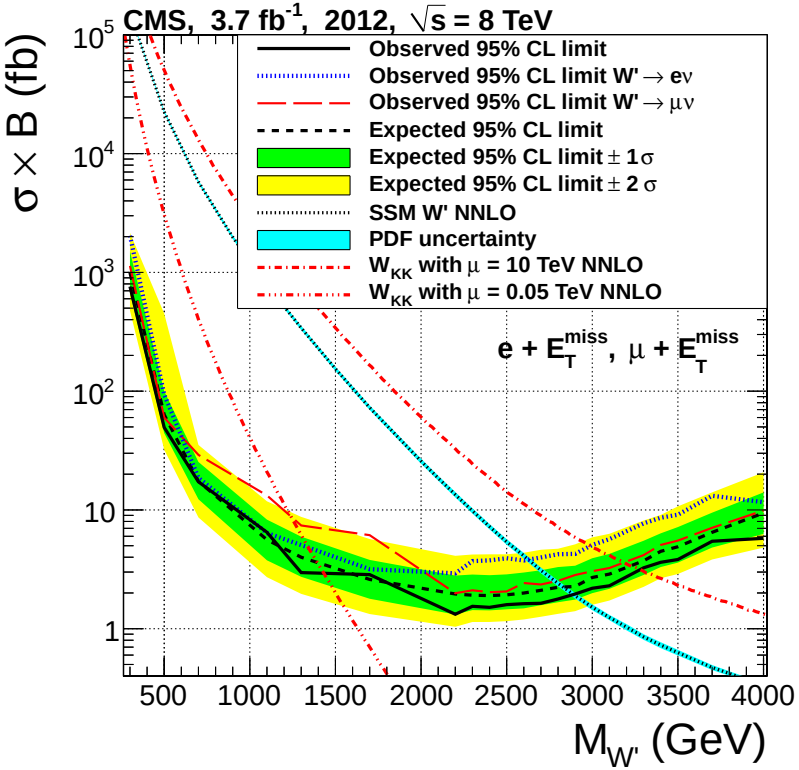
- Large MET, Jacobian peak in transverse mass ending at $M_{W'}$



CMS, arXiv:1302.2812v2

Constraints

However, collider constraints are pretty strong...



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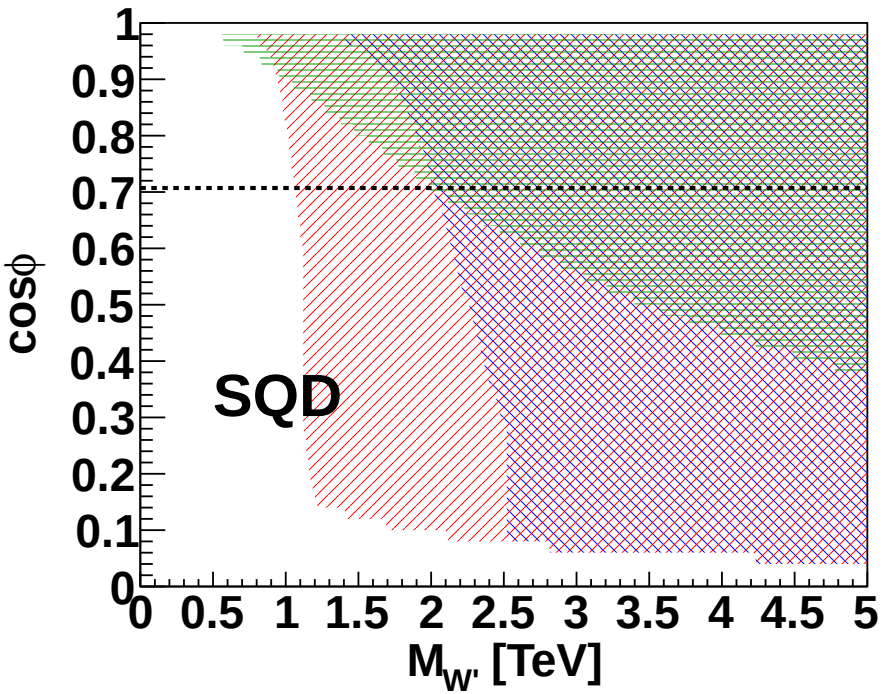
Constraints

...as are EWPT constraints



from Cao *et al.*, arXiv:1205.3769

Green = EWPT, Blue = LHC7,
Red = Tevatron

Our motivating question

Can we build viable models that haven't been detected?

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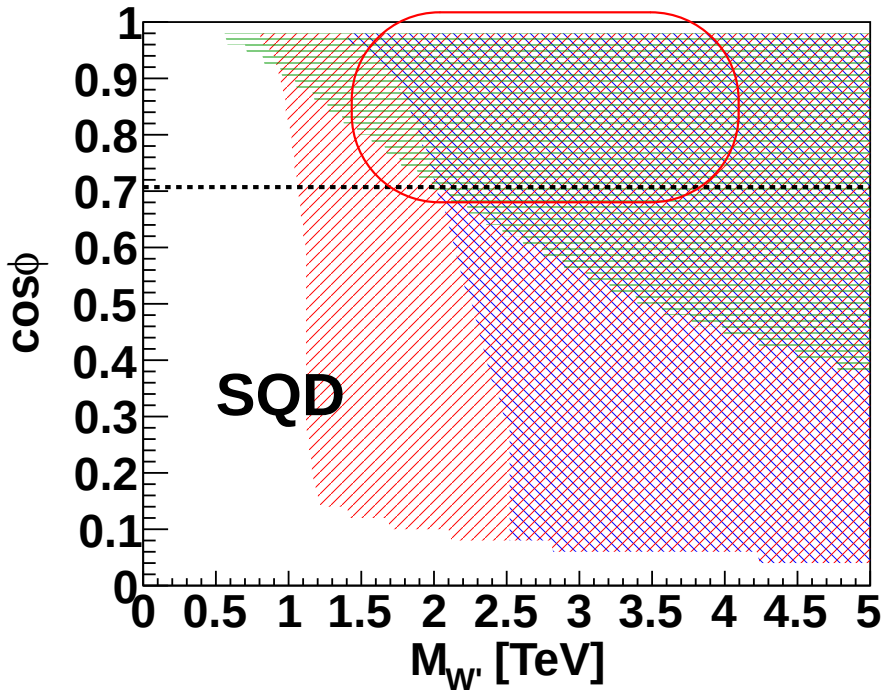
Of course! Just push the scale up, or reduce the couplings to SM particles.



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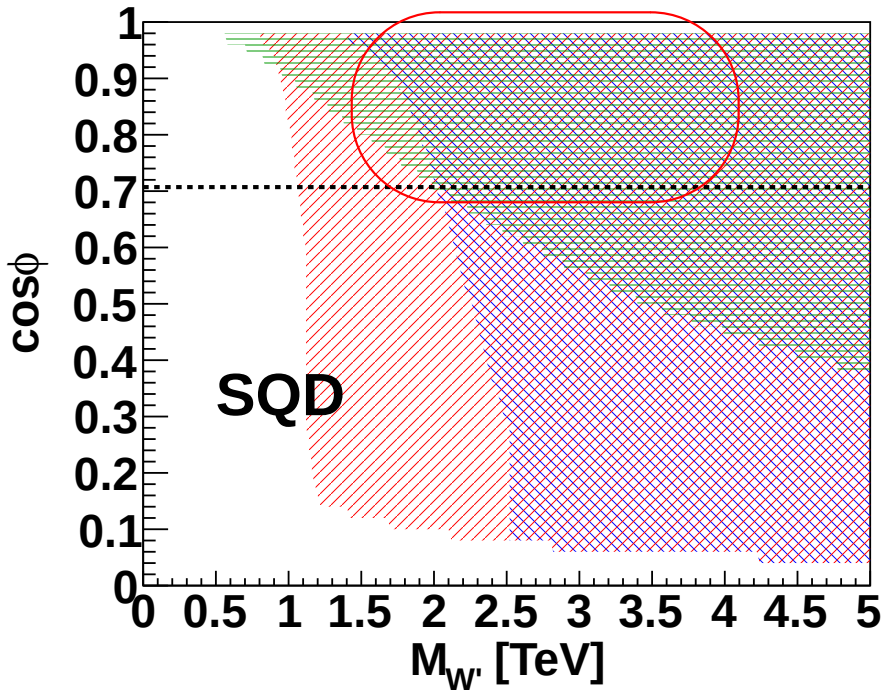

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But can we detect them at the LHC? How?

A broken symmetry must come with a symmetry breaking mechanism

$\rightarrow$ Can the Higgs sector provide any insight?

Symmetry structure

$$SU(2)_1 \times SU(2)_2 \times U(1)_Y$$

- $SU(2)_1 \times SU(2)_2$ broken at the TeV scale by a bidoublet Higgs

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- Diagonal subgroup $SU(2)_W \times U(1)_Y$ broken by a $SU(2)_1$ doublet – same as SM
- Left handed SM fermions charged under $SU(2)_1$
- All SM particles are singlets under $SU(2)_2$

Particle content

After symmetry breaking, we end up with the following states:

- 6 gauge bosons: TeV-scale W' and Z' and SM W and Z
  - Heavy bosons are degenerate
  - Neglect tiny $W - W'$ mixing of $\mathcal{O}(\frac{v_\phi^2}{v_\Delta^2})$
- Charged and neutral heavy Higgs particles

Gauge boson sector

- Require
$$\frac{1}{e^2} = \frac{1}{g_Y^2} + \frac{1}{g_1^2} + \frac{1}{g_2^2}$$
- W' has sequential couplings to SM fermions, but with coupling strength
$$g \tan\theta$$
where
$$\tan\theta = \frac{g_1}{g_2}$$
- Perturbativity $\Rightarrow 0.2 < \tan\theta < 5$, roughly - look at low end of range

Higgs sector

Higgs fields:

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \phi^+ \\ \frac{\phi^{0r} + i\phi^{0i} + v_\phi}{\sqrt{2}} \end{pmatrix} \quad SU(2)_1$$

$$\Delta = \begin{pmatrix} \eta^0 & \chi^+ \\ \eta^- & \chi^0 \end{pmatrix} = \begin{pmatrix} \frac{\eta^{0r} + i\eta^{0i} + v_\Delta/\sqrt{2}}{\sqrt{2}} & \chi^+ \\ \eta^- & \frac{\chi^{0r} + i\chi^{0i} + v_\Delta/\sqrt{2}}{\sqrt{2}} \end{pmatrix} \downarrow SU(2)_1$$

$$\leftarrow SU(2)_2$$

- 12 total degrees of freedom $\Rightarrow$ 6 physical Higgs particles

Higgs sector

Higgs potential:

$$
\begin{aligned}
V = & \, m^2 \,\mathrm{Tr}\, \Delta^\dagger \Delta + \mu^2 \Phi^\dagger \Phi \\
& + \frac{1}{2}\lambda_1 |\Phi\Phi|^2 \\
& + \lambda_2 |\mathrm{Tr}\, \Delta^\dagger \Delta|^2 - \lambda_3 |\mathrm{Tr}\, \Delta^\dagger \tilde{\Delta}|^2 - \lambda_4 \,\mathrm{Re}(\mathrm{Tr}\, \Delta^\dagger \tilde{\Delta})^2 \\
& + \lambda_5 \Phi^\dagger \Delta^\dagger \Delta \Phi + \lambda_5' \Phi^\dagger \tilde{\Delta}^\dagger \tilde{\Delta} \Phi
\end{aligned}
$$

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& + \lambda_5 (\Phi^\dagger \Delta^\dagger \Delta \Phi + \Phi^\dagger \tilde{\Delta}^\dagger \tilde{\Delta} \Phi)
\end{aligned}
$$

$\rightarrow$ Impose symmetry $\Delta \leftrightarrow \tilde{\Delta}$

Higgs sector

- Change to mass eigenstates:

$$\Delta = \begin{pmatrix} \frac{1}{2}(h_\Delta + v_\Delta + H^0 + iA^0) & \frac{1}{\sqrt{2}}H^+ \\ \frac{1}{\sqrt{2}}H^- & \frac{1}{2}(h_\Delta + v_\Delta - H^0 + iA^0) \end{pmatrix}$$

$$\Phi = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(h + v_\phi) \end{pmatrix}$$

- h is the SM Higgs boson – breaks $SU(2)_W$ symmetry and has SM Yukawa couplings.

Higgs sector

- Masses are controlled by λ_i and VEVs:

$$M_\Delta = \sqrt{2(\lambda_2 - \lambda_3 - \lambda_4)}\, v_\Delta$$
$$M_H = \sqrt{2(\lambda_3 + \lambda_4)}\, v_\Delta$$
$$M_A = 2\sqrt{\lambda_4}\, v_\Delta$$
$$M_\phi = \sqrt{\lambda_1}\, v_\phi.$$

- Choose $M_\Delta \gg M_{W'} > M_H, M_A > M_\phi = 125 - 126$ GeV.
- λ_5 induces $\mathcal{O}(\frac{v_\phi}{v_\Delta})$ mixing between h_Δ and h.

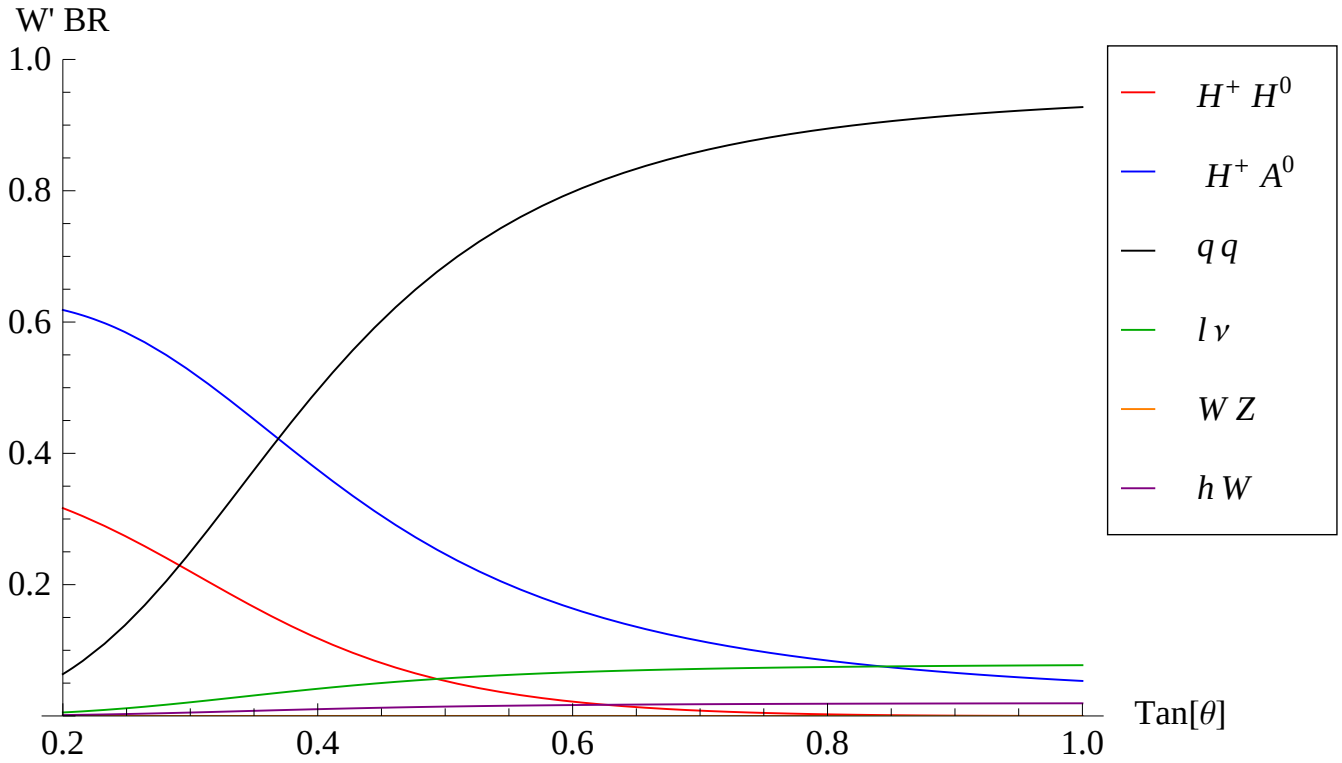
Higgs sector

$$\tilde{\Delta} = \tau_2 \Delta^* \tau_2$$

$$\Rightarrow \tilde{\Delta} = \begin{pmatrix} \frac{1}{2}(h_\Delta + v_\Delta - H^0 - iA^0) & -\frac{1}{\sqrt{2}} H^+ \\ -\frac{1}{\sqrt{2}} H^- & \frac{1}{2}(h_\Delta + v_\Delta - H^0 - iA^0) \end{pmatrix}$$

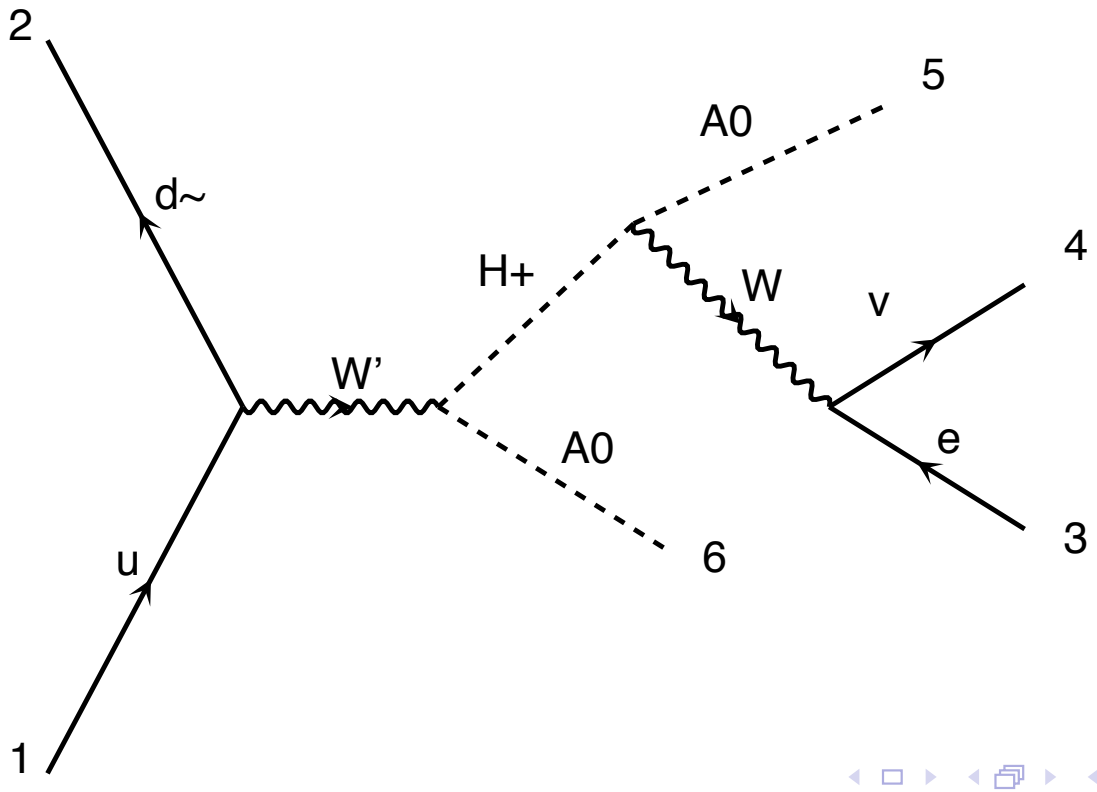
Under $\Delta \leftrightarrow \tilde{\Delta}$ the triplet H and singlet A pickup minus signs. $\mathbb{Z}_2$ symmetry $\Rightarrow$ stable lightest Higgs particle. A possible DM candidate?

If the W' is heavier than the Higgs particles and $\tan\theta \lesssim 0.5$, $W' \to H^{\pm} H^0$ and $W' \to H^{\pm} A^0$ are important decay channels!



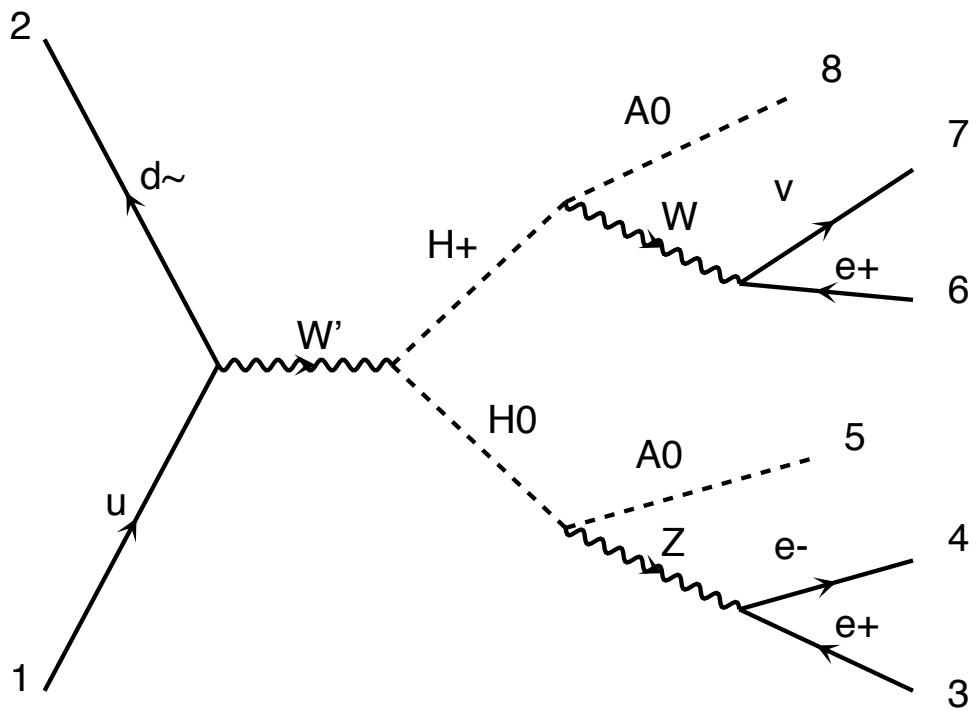
Decay diagrams

Final state: electron + MET



Decay diagrams

Final state: 3 leptons (2 same-flavor, opposite-charge) + MET



Cross section

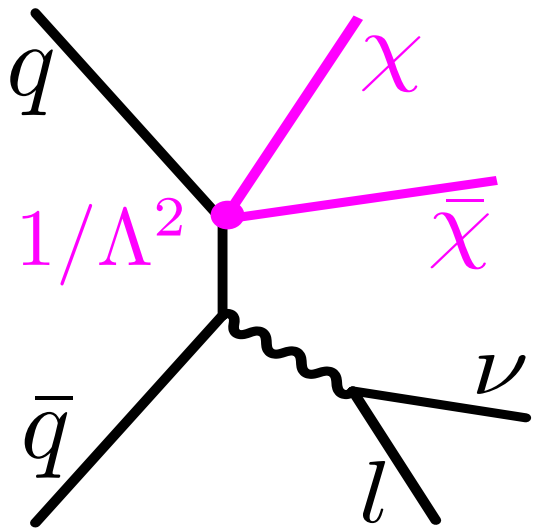
- Choose $M_A = 200$ GeV, $M_H = 1$ Tev, $M_{W'} = 3$ TeV
- $\tan\theta = 0.25$
- $\sigma B(W' \to H^+ A^0) = 1$ fb
- $\sigma B(W' \to l^+ \nu_l) = 0.2$ pb

Missing energy distribution

- A_0 escapes detector
- However, missing transverse energy is not necessarily large since the two A_0's "cancel"
- Easier to see if mass splitting between H and A_0 is large.

Experimental searches

Same final state in DM search at CMS, but a different topology:



- How does signal differ? Can data be used to place limits on model?
- SUSY searches (chargino, neutralino) also relevant

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- Classic searches assume sizeable couplings to leptons or heavy quarks, but this need not be true!
- Massive gauge bosons are a sign of a broken symmetry: require extended Higgs sector
- W's can be easy to hide, but decays through Higgs bosons can provide information

Conclusions

Thank you!