Searching for Electroweakly Charged Bound States at the LHC
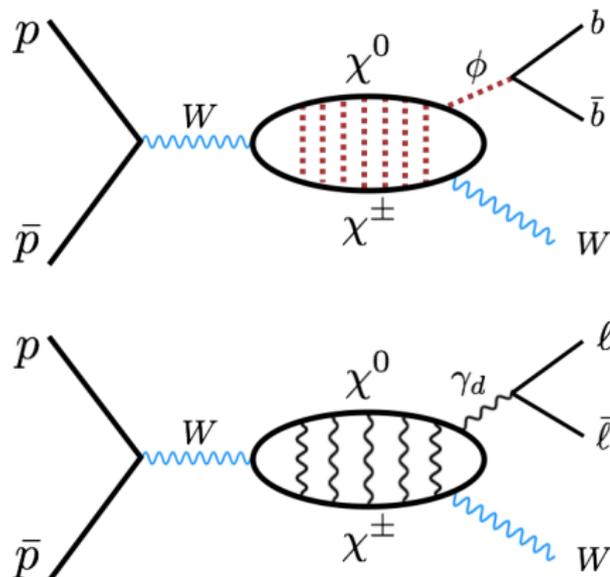
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In collaboration with Lingfeng Li, Ennio Salvioni, Yuhsin Tsai

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Production and decay of 1^- bound state at $\sqrt{s} = 13$ TeV

The hidden force carrier ϕ/γ_d couples strongly to the fermion mediators χ

[Y. Tsai, L.T. Wang and Y. Zhao, arXiv:1511.07433]

Why this channel?

- Direct production of hidden force carrier can be challenged
- Can probe dark matter at colliders without missing energy signature
- Extend the existing dibosn searches

Bound State Production

The interaction

$$\frac{g_W}{\sqrt{2}}\bar{\chi}_+ \slashed{W}^+(v_\chi^W + a_\chi^W\gamma^5)\chi_0 + h.c.$$

The cross section of production:

$$\sigma_{u\bar{d}\to V^+} = 4\pi^3 \frac{|\psi(0)|^2}{m_\chi^3}\frac{1}{s}\left(\frac{\alpha_W v_\chi^W}{1 - \frac{m_W^2}{4m_\chi^2}}\right)^2 L_{u\bar{d}}\left(\frac{4m_\chi^2}{s}\right)$$

Wavefunction assuming Coulomb potential:

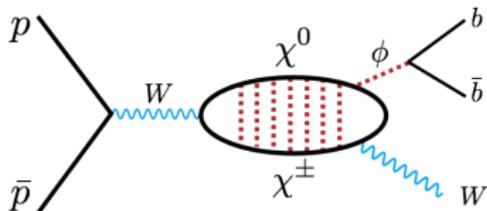$$|\psi(0)|^2 = \frac{C^3\hat{\alpha}^3 m_\chi^3}{8\pi}$$

Also,

$$m_V \approx 2m_\chi$$

refer to [arXiv:1204.1119]

Searching Strategies

- $V^{\pm} \to W^{\pm} + \phi$ with a prompt $\phi \to b\bar{b}$
- $V^{\pm} \to W^{\pm} + \gamma_d$ with a prompt $\gamma_d \to l^+l^-$
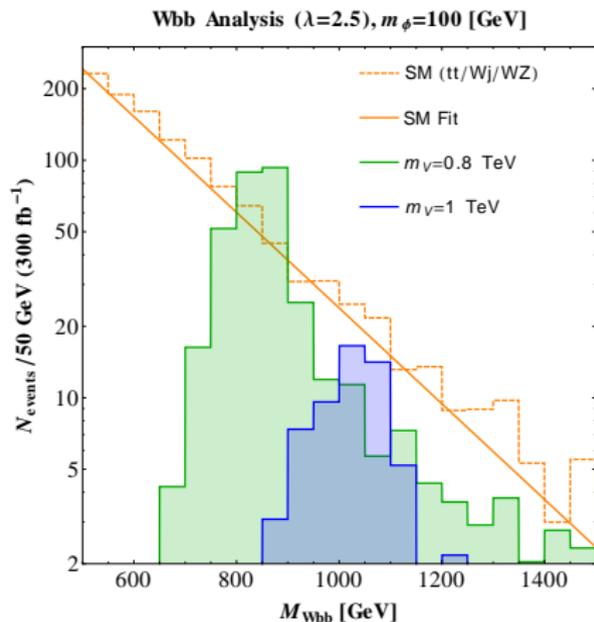- Displaced decay of ϕ/γ_d
- *Monolepton

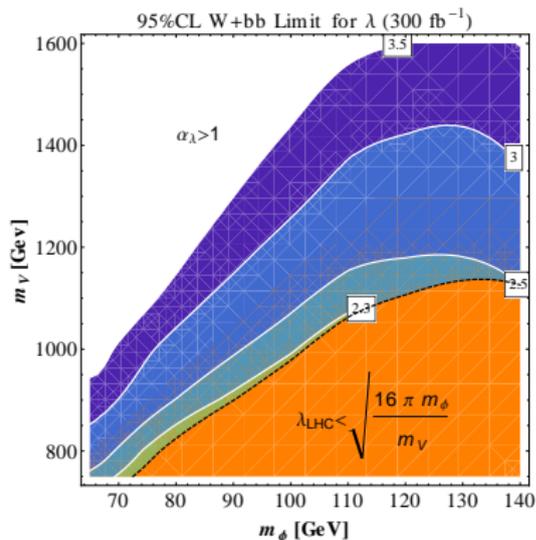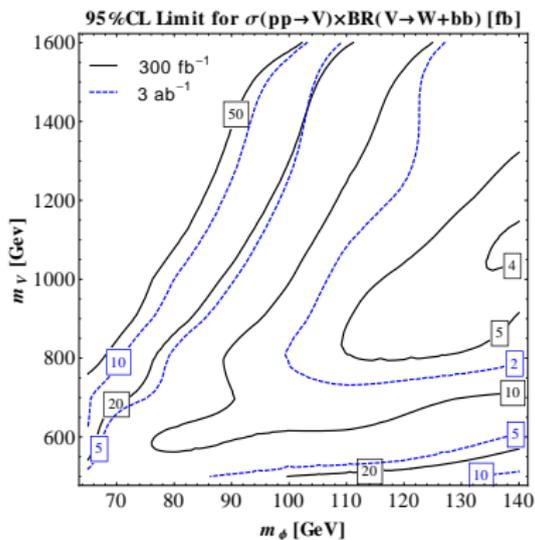# $V^{\pm} \to W^{\pm} + \phi$ with a prompt $\phi \to b\bar{b}$

Looking for:

- Two b-tagged jets with $p_T^{b_1} > 100$, $p_T^{b_2} > 30$
- One lepton ($e^{\pm}/\mu^{\pm}$) with $p_{Tl} > 30$ GeV
- MET > 30 GeV

Reconstruct two invariant masses

Wbb Analysis (λ=2.5), m_{ϕ}=100 [GeV]

SM (tt/Wj/WZ)
SM Fit
m_V=0.8 TeV
m_V=1 TeV

N_{events}/50 GeV (300 fb^{-1})

M_{Wbb} [GeV]

$V^\pm \to W^\pm + \phi$ with a prompt $\phi \to b\bar{b}$

Upper bound $\lambda \sim 2.3$

$V^{\pm} \to W^{\pm} + \gamma_d$ with a prompt $\gamma_d \to ll$

Based on [ATLAS-CONF-2013-015]: resonant $W' \to WZ \to l\nu ll$
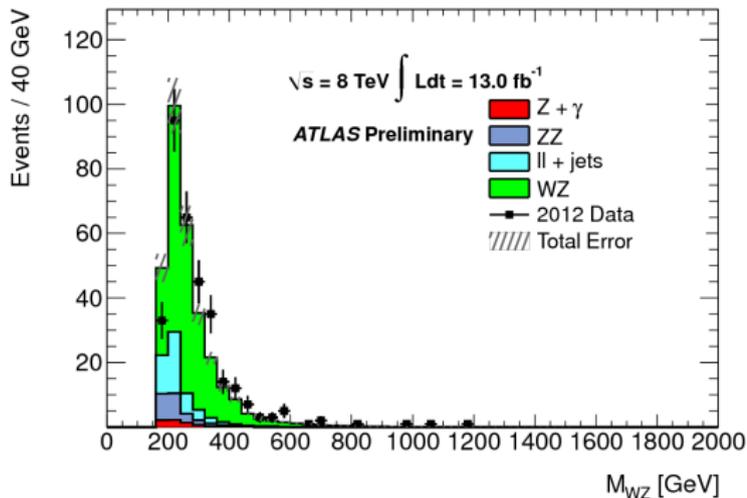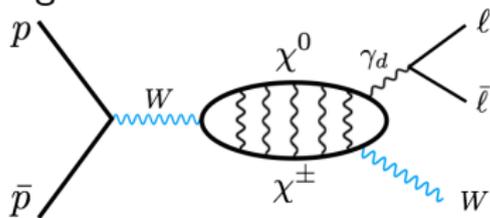
(Fig. 4 from the ref.)

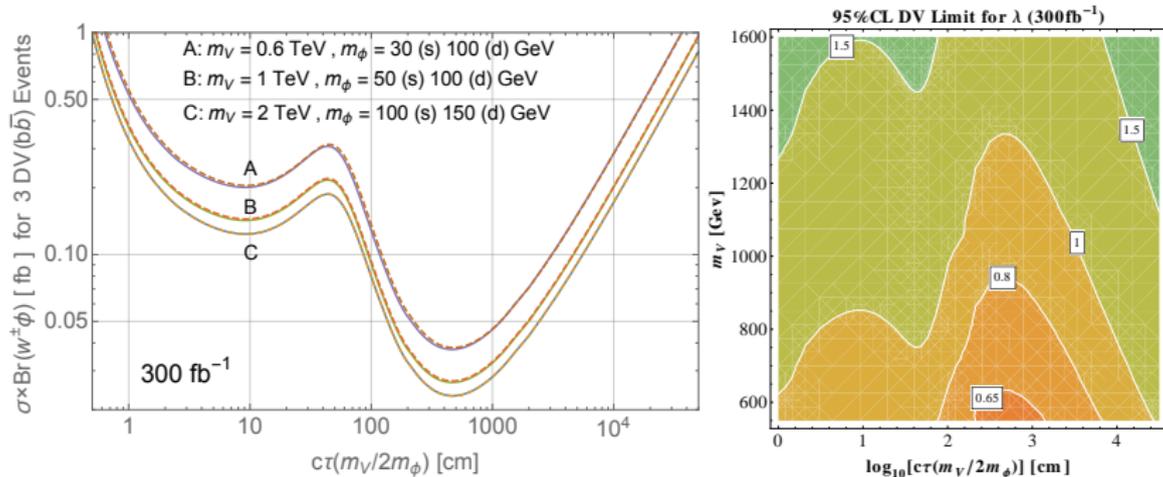# $V^{\pm} \to W^{\pm} + \gamma_d$ with a prompt $\gamma_d \to ll$
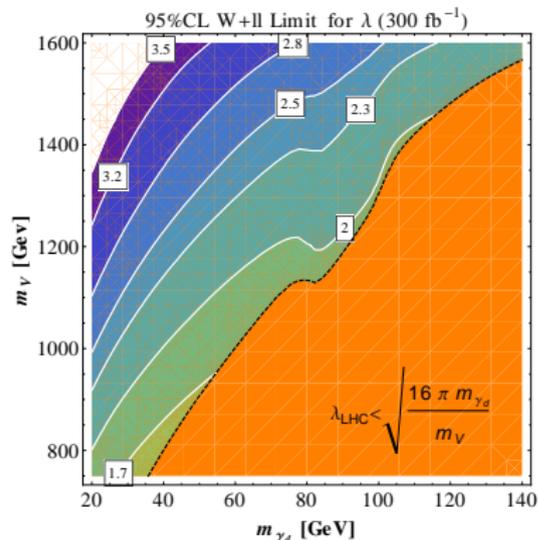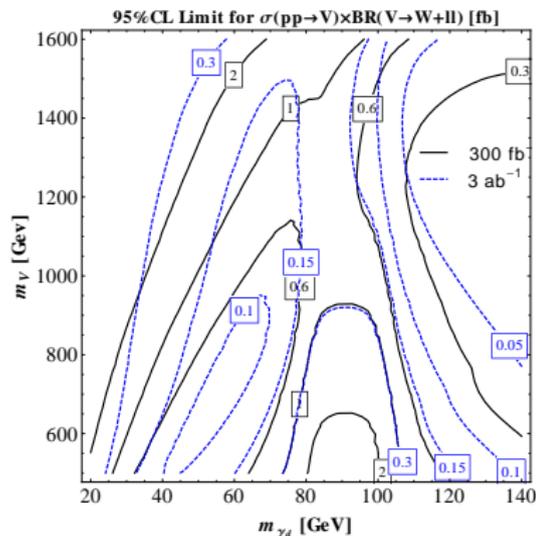
Upper bound $\lambda \sim 1.7$

Displaced Vertex for ϕ/γ_d

- Hidden force carrier couples weakly to SM sector
- Assume background free
- Reconstruct DV in ID or HCAL+MS. Follow [1512.02647]

A: $m_V = 0.6$ TeV , $m_\phi = 30$ (s) 100 (d) GeV
B: $m_V = 1$ TeV , $m_\phi = 50$ (s) 100 (d) GeV
C: $m_V = 2$ TeV , $m_\phi = 100$ (s) 150 (d) GeV

300 fb^{-1}

$\sigma \times$Br$(w^\pm \phi)$ [fb] for 3 DV$(b\bar{b})$ Events

$c\tau(m_V/2m_\phi)$ [cm]

95%CL DV Limit for λ (300fb^{-1})

m_V [Gev]

$\log_{10}[c\tau(m_V/2m_\phi)]$ [cm]

Results in λ-SUSY
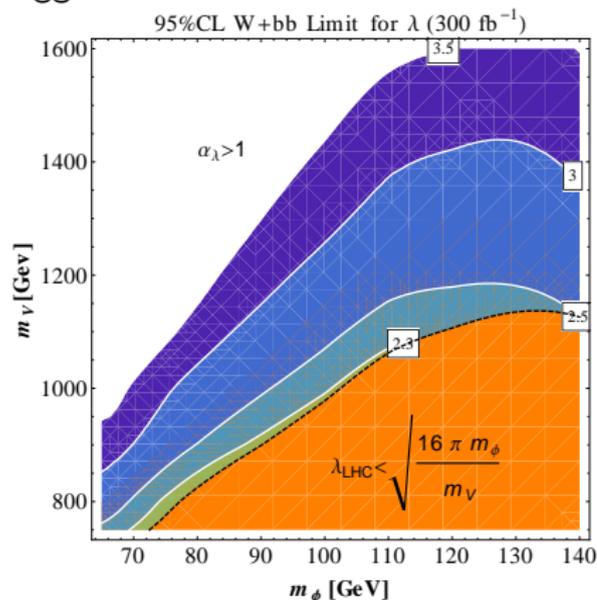
Superpotential

$$W \supset \lambda S H_u H_d$$

λ is big in λ-SUSY, s mediates a strong attractive force between higgsinos.
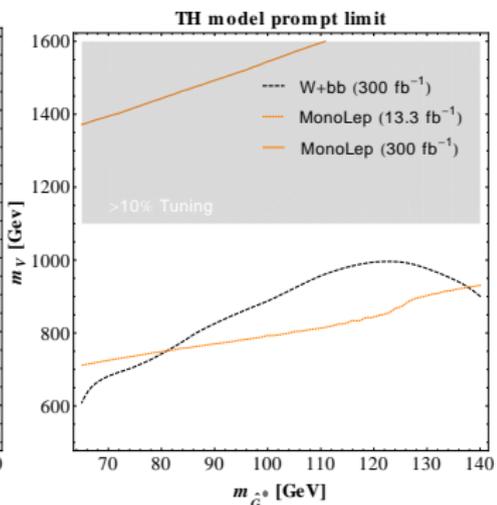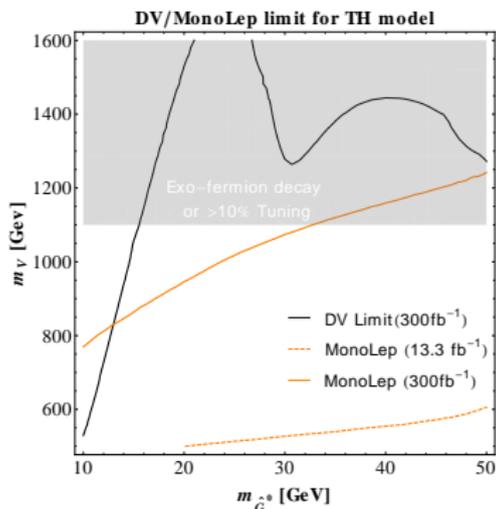

95%CL W+bb Limit for λ (300 fb^{-1})

- χ=higgsinos $\tilde{h}^{0,\pm}$, ϕ=singlet scalar s
- The mass reach for pure higgsino dark matter is $\sim$ 200 GeV in monojet search at 14 TeV [1511.06495]

Motivated by [Y. Tsai, L.T. Wang and Y. Zhao, arXiv:1511.07433]

Results in Twin-Higgs Model

- χ=exotic fermions ($\mathcal{K}^{0,\pm}$) charged under $SU(3)_{Twin} \times SU(2)_{SM}$
  ϕ=twin glueball $\hat{G}_{0^{++}}$
- $(\chi^{\pm}\chi^{0}) \to (\hat{g}\hat{g})W^{\pm} \to \hat{G}_{0^{++}}W^{\pm}$
- Main decay channels: $V \to W^* \to l\nu$(mono-lepton) and $V \to W\hat{G}_{0^{++}}$

Conclusion

Takeaway message:
With simple extension of SM di-boson search, we can look for
electroweakly charged resonance and set constraint on the strength
of hidden force

$V^{\pm} \to W^{\pm} + \phi$ with a prompt $\phi \to b\bar{b}$

Looking for:

- two b-tagged jets with $p_T > 100(30)$ GeV for (sub-)leading candidate
- one lepton ($e^{\pm}$ or $\mu^{\pm}$) with $p_{Tl} > 30$ GeV
- MET > 30 GeV

Cuts:
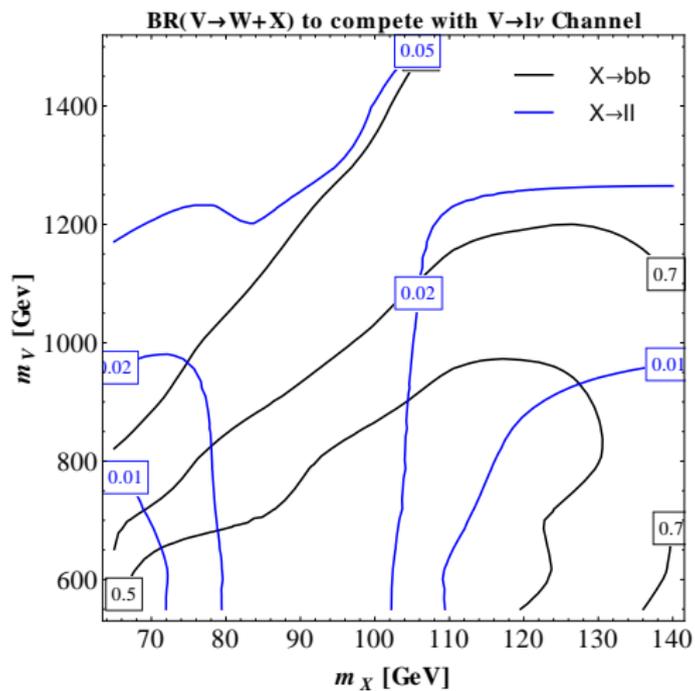
$N_j \leq 3$

$10 < m_T^W < 100$ GeV

$p_T^W > 200$ GeV

$m_{b\bar{b}} \in (m_\phi - 15, m_\phi + 10)$

$m_{W\phi} \in (m_V - 50, m_V + 100)$

Details on DV search

- $p_T^l > 100$, $|\eta^l| < 2.5$, lepton identification rate 90%
- decay in $1 < r < 28$ cm (ID) or $200 < r < 750$ cm (HCAL and MS), 10% reconstruction efficiency
- $p_T^b > 30$, $|\eta^b| < 2.0$

Mono-lepton

data based on [ATLAS-CONF-2016-069]

Twin-Higgs Model

The gauge group:

$$SU(3)_{SM} \times SU(3)_{Twin} \times SU(2)_{SM} \times SU(2)_{Twin}$$

- χ=exotic quarks $(\mathcal{K}^{0,\pm})$ charged under $SU(3)_{Twin} \times SU(2)_{SM}$
  ϕ=twin glueball $\hat{G}_{0^{++}}$ see [arXiv:1512.02647]

- The twin glueball mass is essential in that

$$m(\hat{G}_{0^{++}}) \Rightarrow \hat{\Lambda} \Rightarrow \hat{g}_s(\mu, \hat{\Lambda})$$

- Main decay channels: $V \to W^* \to l\nu$(mono-lepton) and
  $V \to W \hat{G}_{0^{++}}$

- $c\tau \simeq 1\text{cm}\left(\frac{5 \text{ GeV}}{m_{0^{++}}}\right)^7 \left(\frac{f}{1 \text{ TeV}}\right)$

Twin Strong Coupling

Twin-confinement scale is estimated by

$$\frac{\hat{\Lambda}}{\mu} = \exp\left(-\frac{1}{2b_0\hat{g}_3^2(\mu)}\right)\left(b_0\hat{g}_3^2\right)^{-b_1/2b_0^2}\left(1 + \frac{b_1}{b_0}\hat{g}_3^2(\mu)\right)^{b_1/2b_0^2}$$

where $b_{0,1}$ are the one- and two-loop twin QCD beta functions respectively, and $\hat{g}_3(\mu)$ is the twin QCD coupling at the cutoff scale, which is taken to be 5 TeV in this work.