Hadronic Mono-W' Probe of Dark Matter at Colliders

Speaker: Kun Cheng (Peking University)
chengkun@pku.edu.cn

arXiv: 2311.13578

R. Holder, J. Reddick, M. Cremonesi, D. Berry,
K. Cheng, M. Low, T. Tait, D. Whiteson

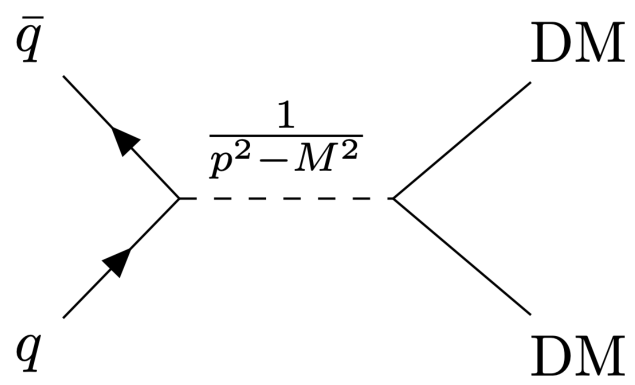
Dark Matter search at Collider

Collider signal of DM: Visible + $\not{E}_T$ (Mono-X)

DM interact with SM particles via EFT operator:

- $g/q + \not{E}_T$:1002.4137, 1108.1196, 1408.3583, 1502.01518…
- $t/b + \not{E}_T$: 1303.6638, 1410.4031, 1503.00691 ……
- $\gamma + \not{E}_T$: 1109.4398, 1410.8812, 1411.1559 ……
- $W/Z + \not{E}_T$: 1309.4017, 1408.2745, 1404.005……
- $h + \not{E}_T$: 1312.2592, 1402.7074 ……

A large M makes the DM-SM coupling weak



When the NP particles are produced on-shell decay to SM particles

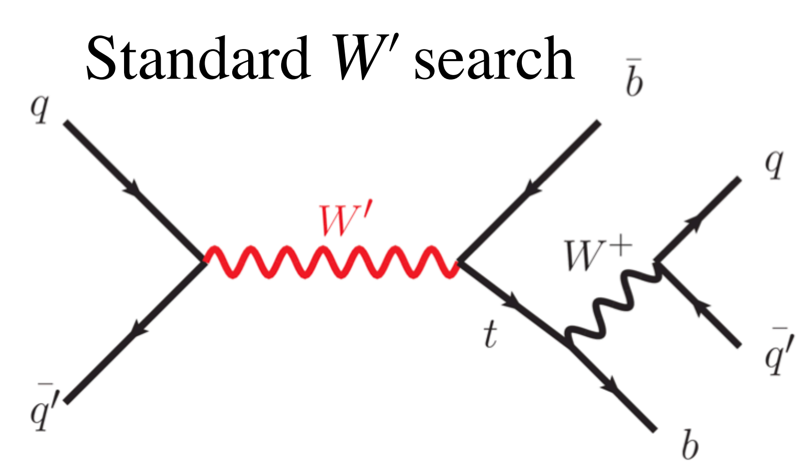
$Z' + \not{E}_T$: **1504.01386**

$W' + \not{E}_T$: **This Work:** $W' \to tb$

W' **: similar interaction with the SM** W **boson:**

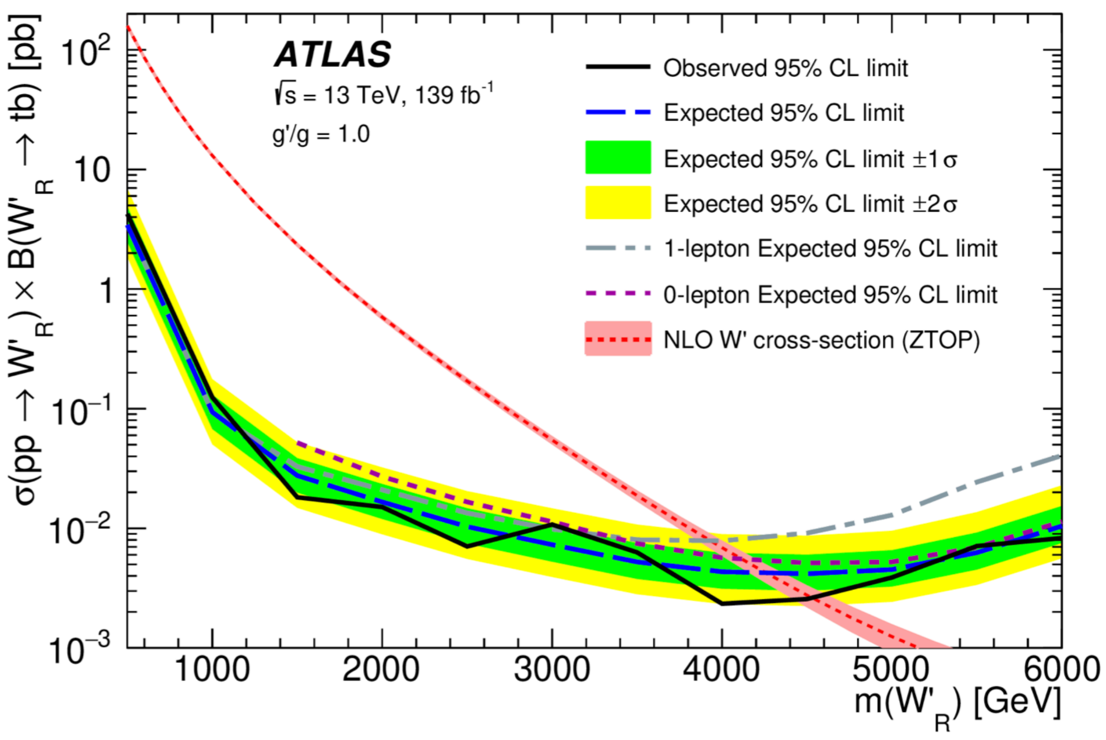
Resonant production

Stringent Limits



Resonant production of W' with a dark Higgs boson

2308.08521

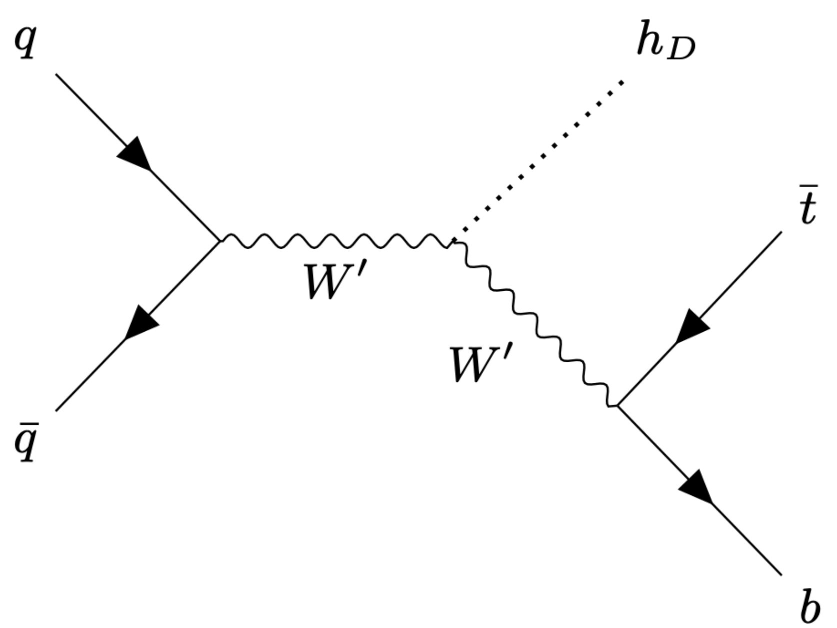


Stringent trigger requirement

$p_T > 500\,\mathrm{GeV}$

Mass region smaller than $1\,\mathrm{TeV}$ are not probed

$W' + \mathrm{DM}$ The channel we are using:



$m_{W'}$: **focus on $250 \sim 1750\,\mathrm{GeV}$**

A dark Higgs is emitted from W'

$\not{E}_T > 200\,\mathrm{GeV}$

In additional to the DM search, this channel opens up the possibility to push W' searches to lower masses

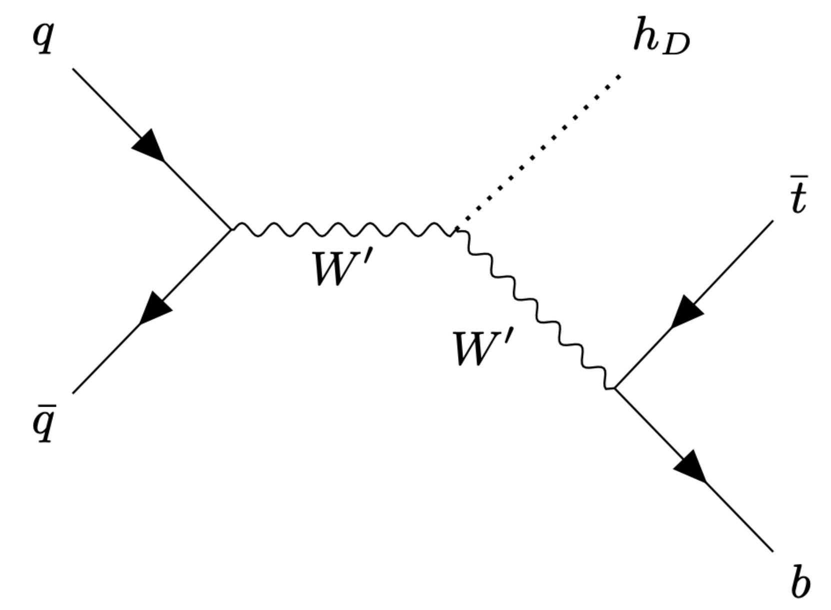
UV models with W' commonly have a dark Higgs boson

- W' comes from a new gauge symmetry that is broken before EWSB.

- There is new scalar responsible for the breaking: $\phi = h_D + v_\phi$

- The scalar gives W' mass, and couples to W': $\propto g_{new} W'^2 (h_D + v_\phi)^2$

(nearly) model-independent



Relavent Parameters

- masses: m_{h_D}, $m_{W'}$
- W'- t - b: new gauge coupling strength g_{new}
- W'- W'- h_D: new gauge coupling strength and W' mass ($m_{W'} \propto v_\phi$)

Benchmark Model: Left-Right Symmetric Model (LRSM)

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$\Downarrow$$

$$SU(2)_L \times U(1)_Y$$

Kinetic terms of fermions

$$\mathcal{L} = \frac{g_R}{\sqrt{2}} (\bar{u}_R \gamma^\mu d_R) W'^+_\mu + h.c.,$$

$$Q_{L,i} = \begin{pmatrix} u_L \\ d_L \end{pmatrix}_i : \left(\mathbf{2}, \mathbf{1}, \tfrac{1}{3}\right), \quad Q_{R,i} = \begin{pmatrix} u_R \\ d_R \end{pmatrix}_i : \left(\mathbf{1}, \mathbf{2}, \tfrac{1}{3}\right),$$

Kinetic terms of scalars

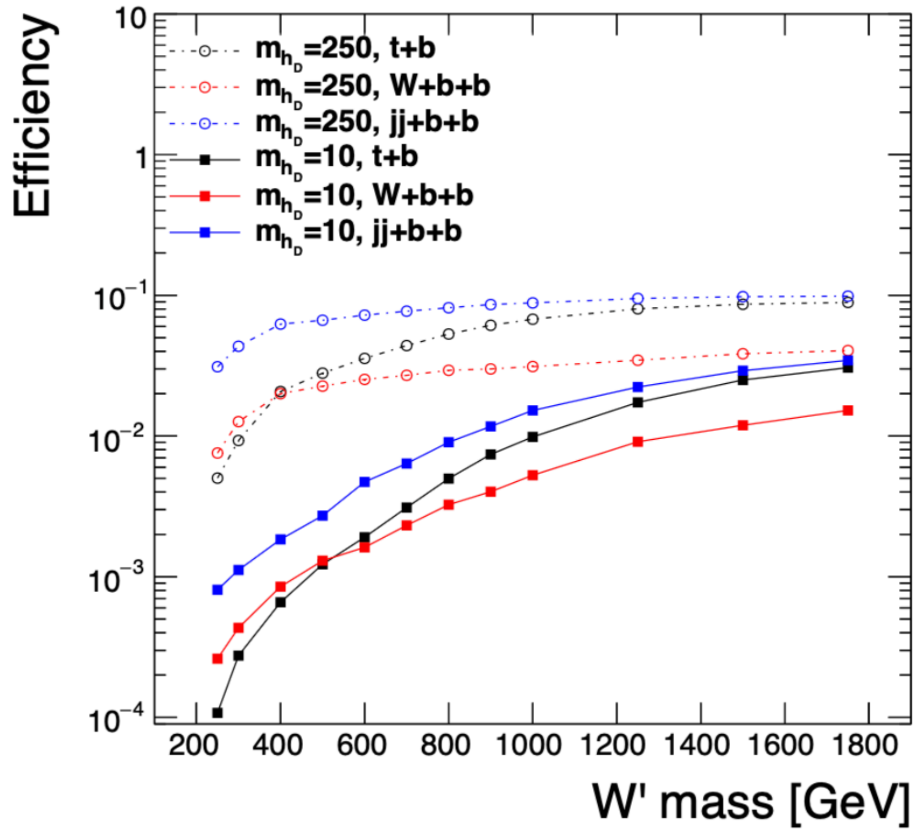
$$\mathcal{L}_{W' h_D} = g_R^2 v_R h_D (W'_\mu)^\dagger W'^\mu$$

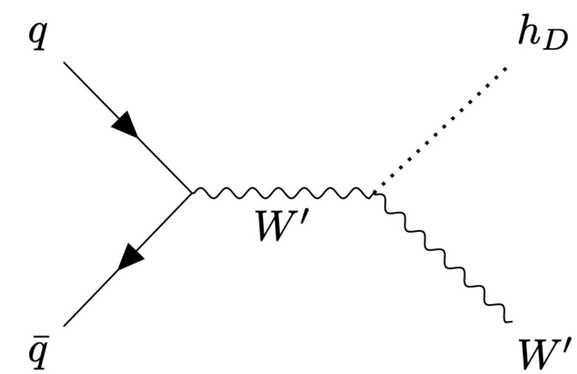
$$\Delta_R = \begin{pmatrix} \delta_R^+/\sqrt{2} & \delta_R^{++} \\ \delta_R^0 & -\delta_R^+/\sqrt{2} \end{pmatrix} : (\mathbf{1}, \mathbf{3}, 2)$$

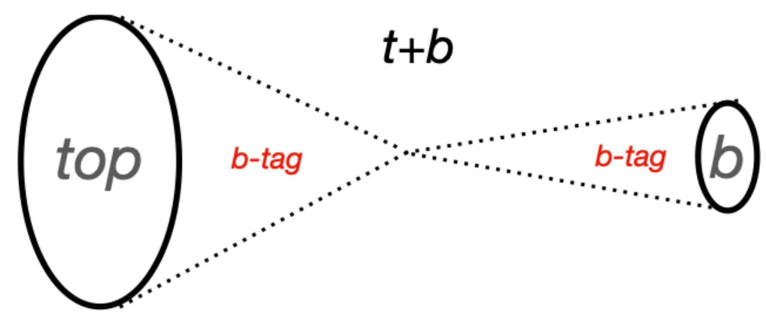
$$= \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 \\ v_R & 0 \end{pmatrix} + \begin{pmatrix} \ldots & \ldots \\ h_D & \ldots \end{pmatrix}$$

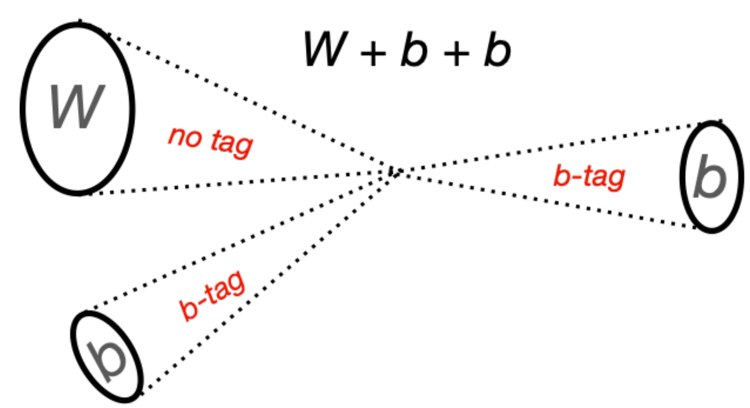
g_R	$> e/c_W (0.35)$
$m_{W'}$	$\approx g_R v_R / \sqrt{2}$
m_{h_D}	Potential parameters

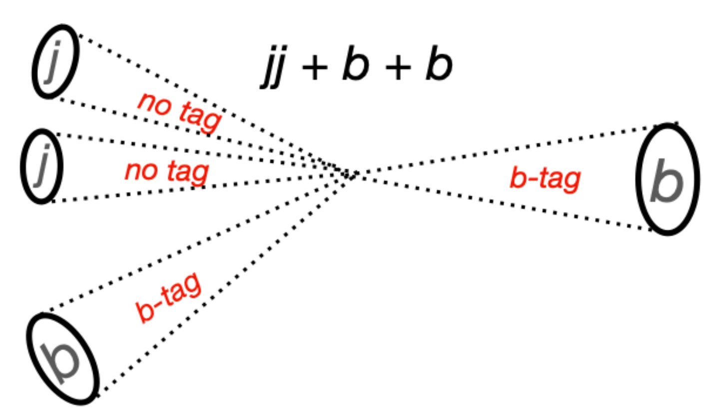
W' Candidate Reconstruction







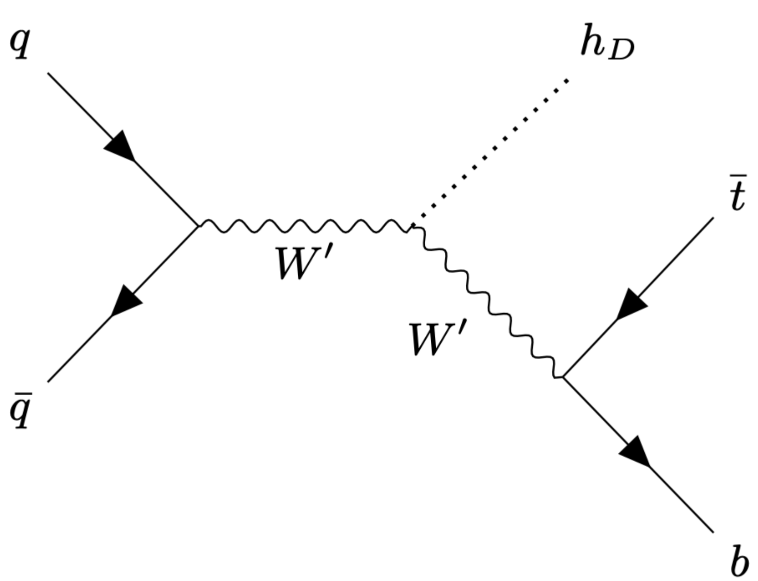




Process	σ [fb]	ε	N
$t\bar{t}$	6.74×10^5	1.42×10^{-3}	2.89×10^5
$Z + b\bar{b}, Z \to \nu\nu$	2.47×10^5	1.42×10^{-4}	10560
$t\bar{b} + \bar{t}b$	1.00×10^4	2.7×10^{-4}	820
$W^\pm + b\bar{b}, W^\pm \to \ell^\pm\nu$	1.74×10^5	1.2×10^{-5}	620
$M_W' = 300, M_{h_D} = 10$	2280	0.0016	1060
$M_W' = 800, M_{h_D} = 100$	66	0.056	1120
$M_W' = 1250, M_{h_D} = 250$	16.9	0.129	650

Production cross section

The W' can be on-shell before or after emitting a dark Higgs, and this two channel have comparable contribution



2-body: $pp \rightarrow W'h_D$ **then** $W' \rightarrow tb$

$\propto \left(g_R g_{W'W'h}\right)^2$ $\propto constant$

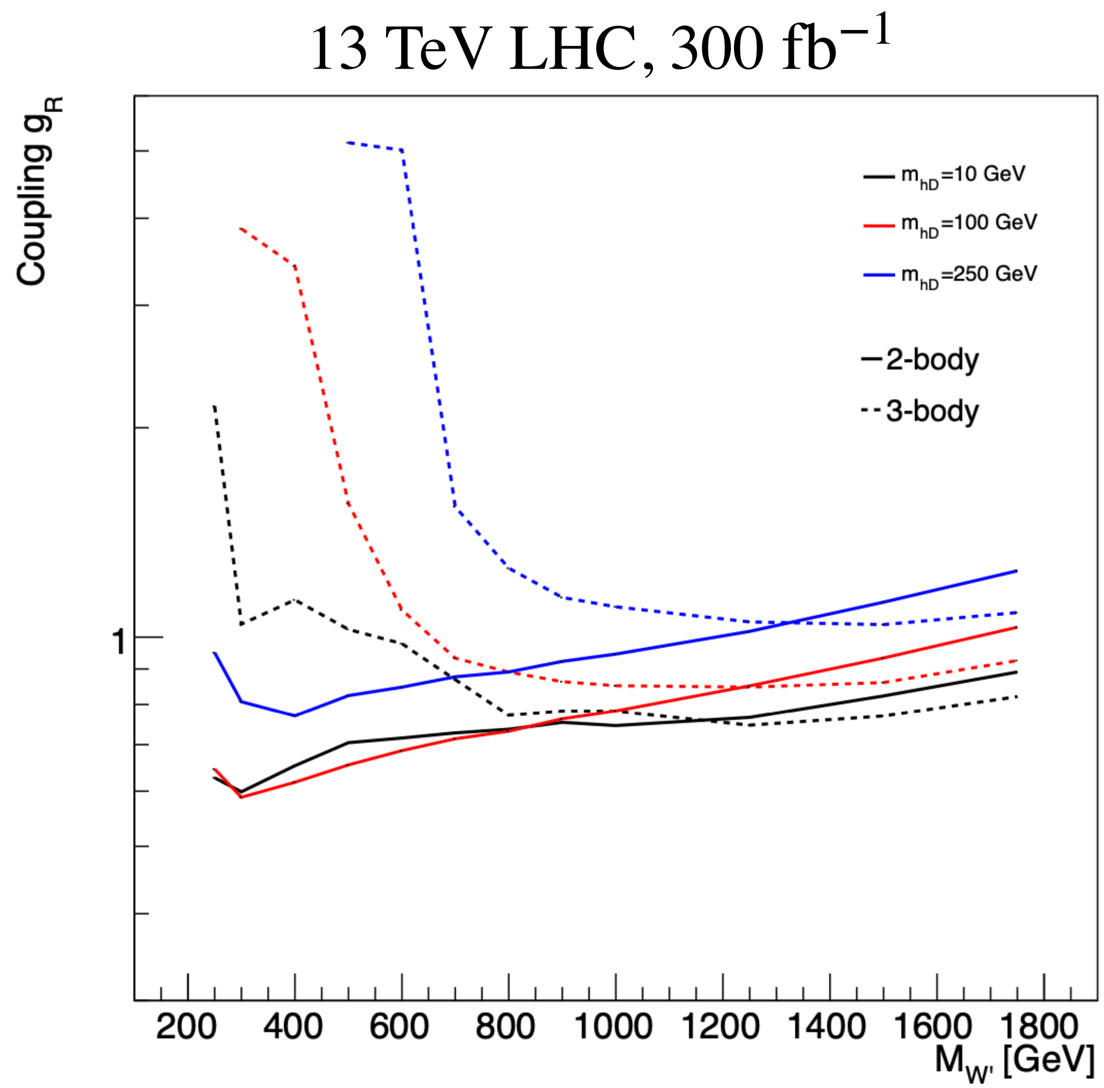
3-body: $pp \rightarrow W'$ **then** $W' \rightarrow tbh_D$

$\propto g_R^2$ $\propto g_{W'W'h}^2$

We always have contribution from both channel. $\propto g_R^4$

Which cross section is larger? Only depends on the mass of W' and h_D

Results and Discussion

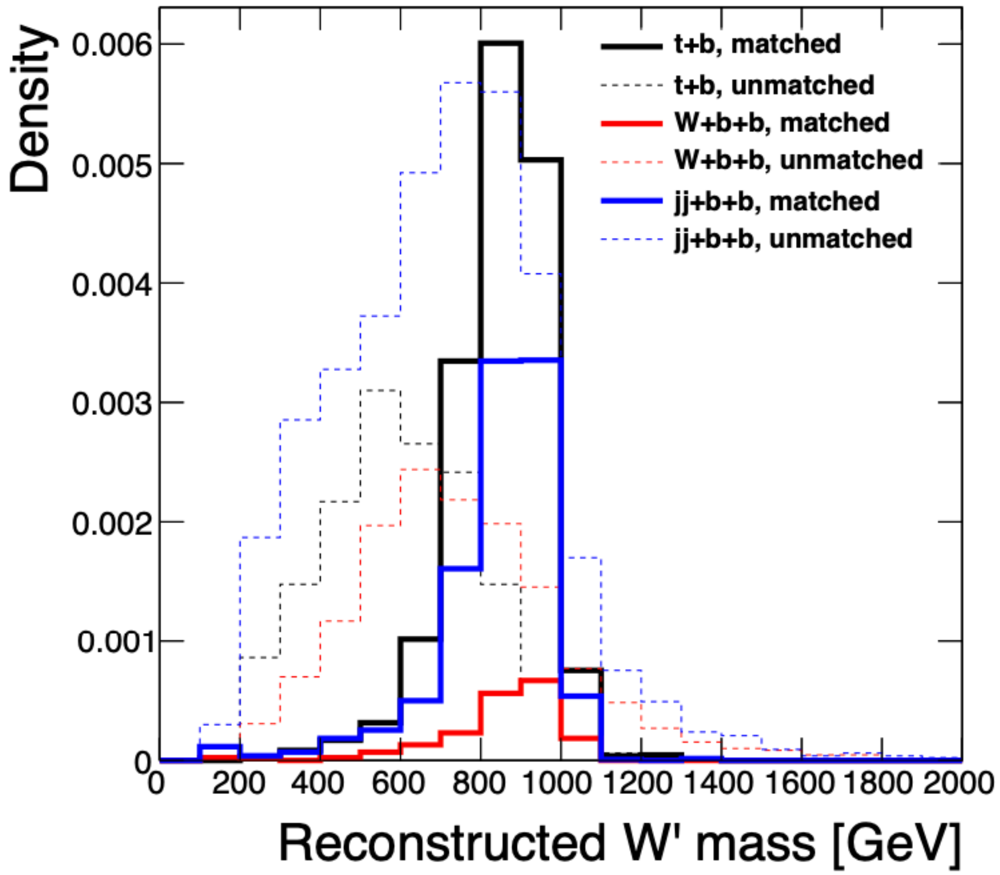


Current LHC data is sensitive to $W' + h_D$ production in the range of 20 fb to 30 pb. The corresponding limit on g_R can be as low as 0.6

We studied the p_T^{miss} with hadronically-decaying W', which:

- **Describes a new search mode of DM**
- **Expand the W' boson searches to small mass region**

Backup



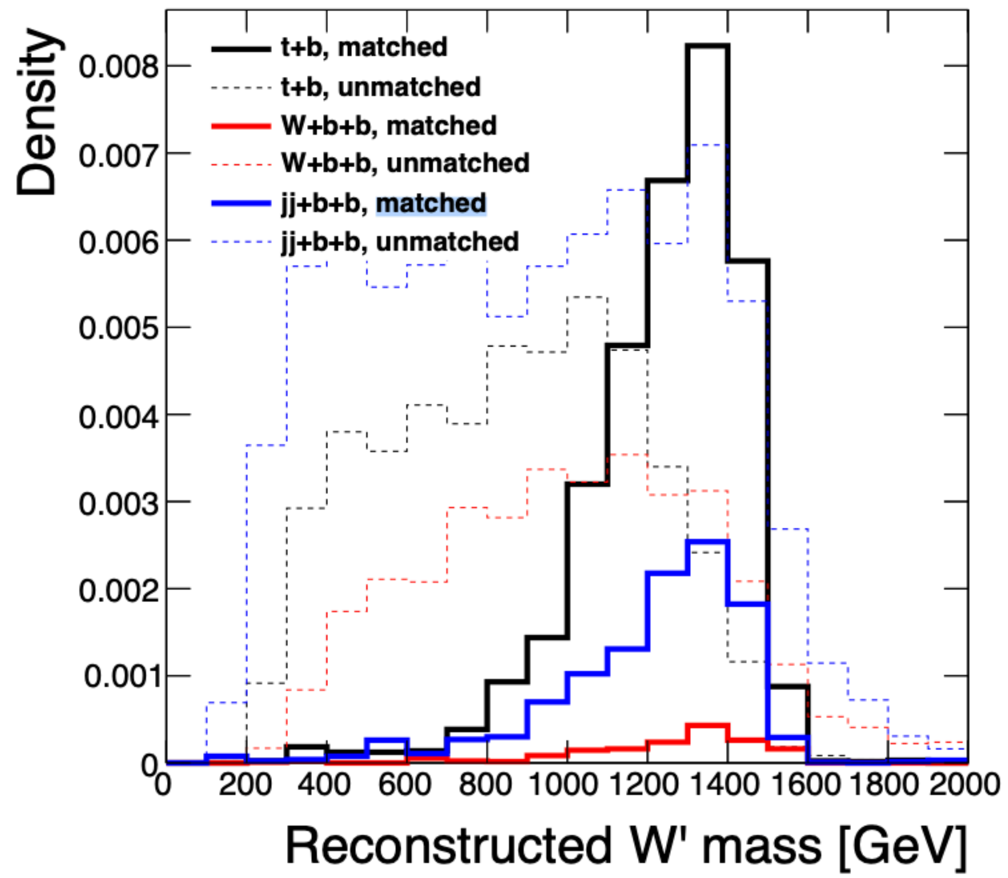
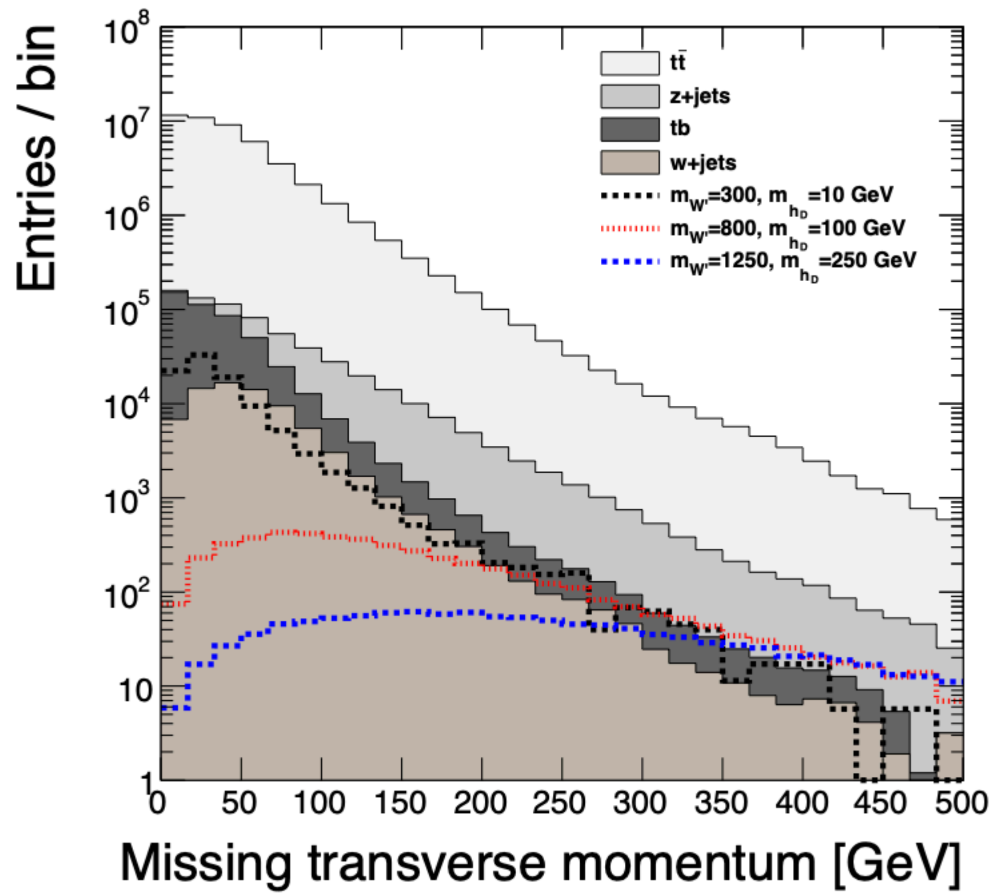


FIG. 3: Top (bottom): Distribution of the reconstructed W' boson candidate mass in simulated events with m'_W = 1000 (1500) GeV, for each of the three reconstruction strategies (see Fig 2), where the selected objects are angled-matched ($\Delta R < 0.4$) and -unmatched ($\Delta R > 0.4$) to the correct parton-level objects

Backup: backgrounds



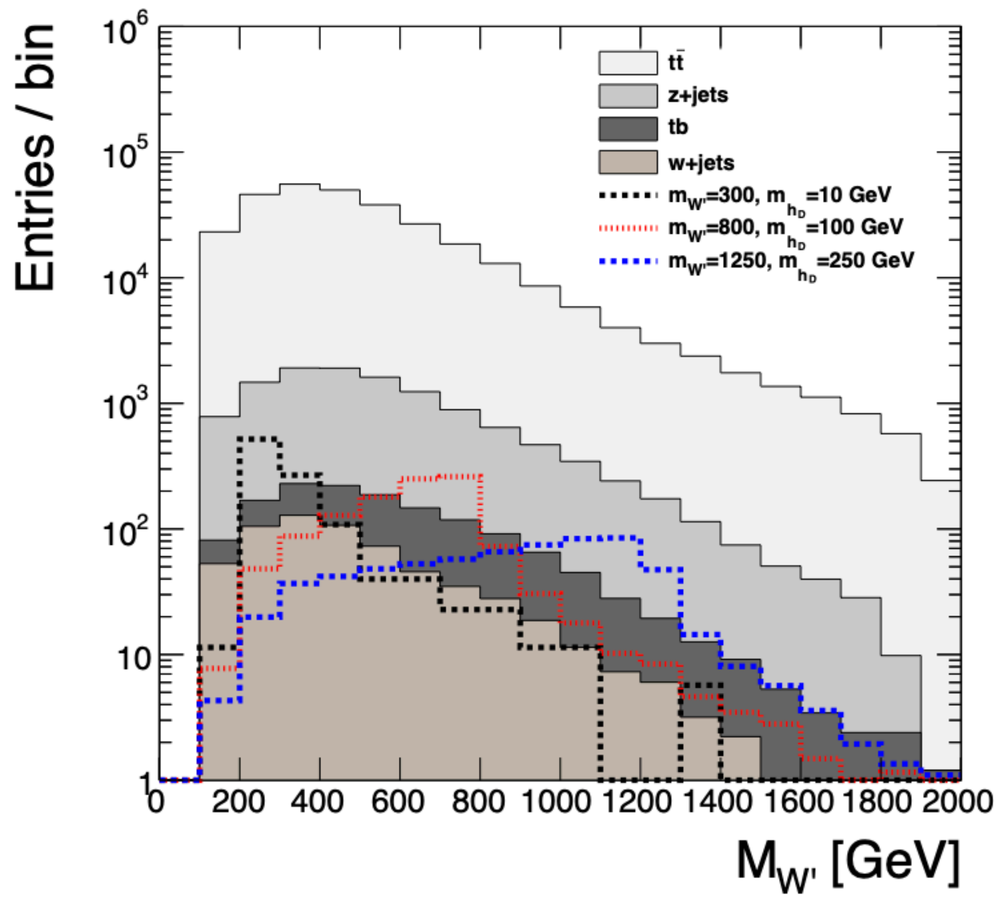


FIG. 5: Top: Distribution of the missing transverse momentum (p_T^{miss}) for the expected background and selected signals normalized to an integrated luminosity of 300 fb^{-1} after all requirements other than $p_T^{miss} > 200$ GeV are met. Bottom: Distribution of the reconstructed W' boson 2-body candidate mass for the expected background and selected signals normalized to an integrated luminosity of 300 fb^{-1} after the full selection.

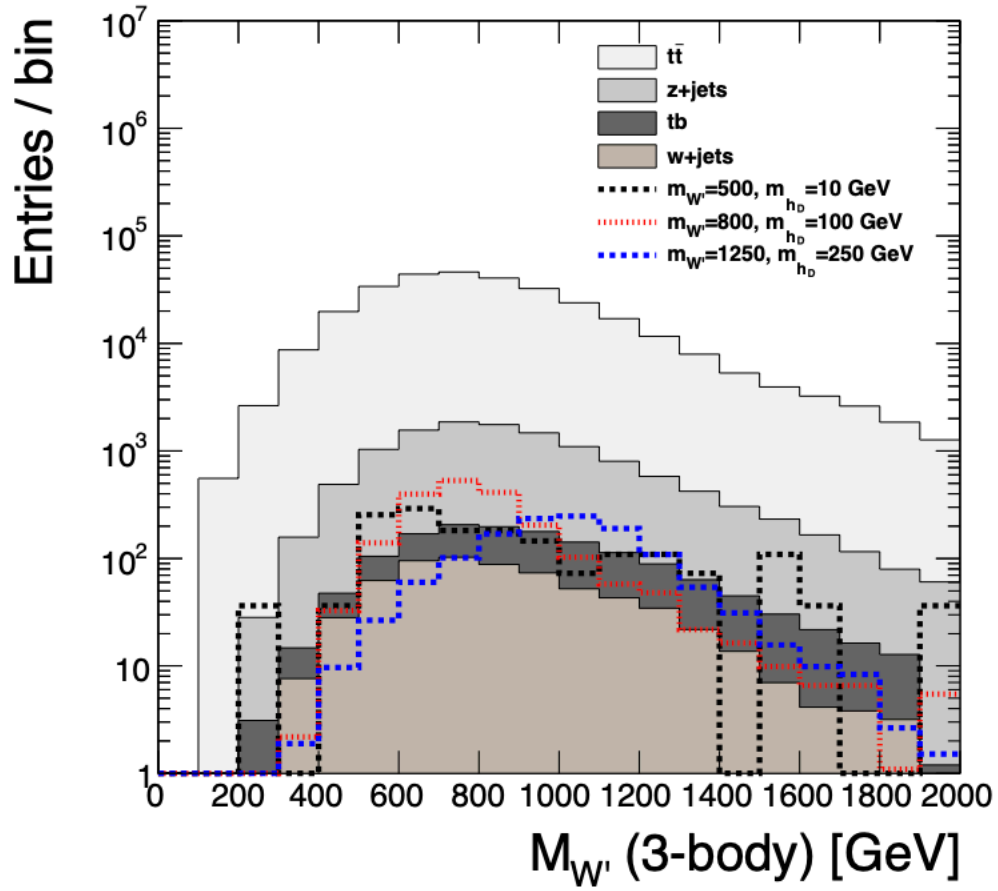


FIG. 6: Distribution of the reconstructed W' boson 3-body candidate mass for the expected background and selected signals normalized to an integrated luminosity of 300 fb^{-1} after the full selection.

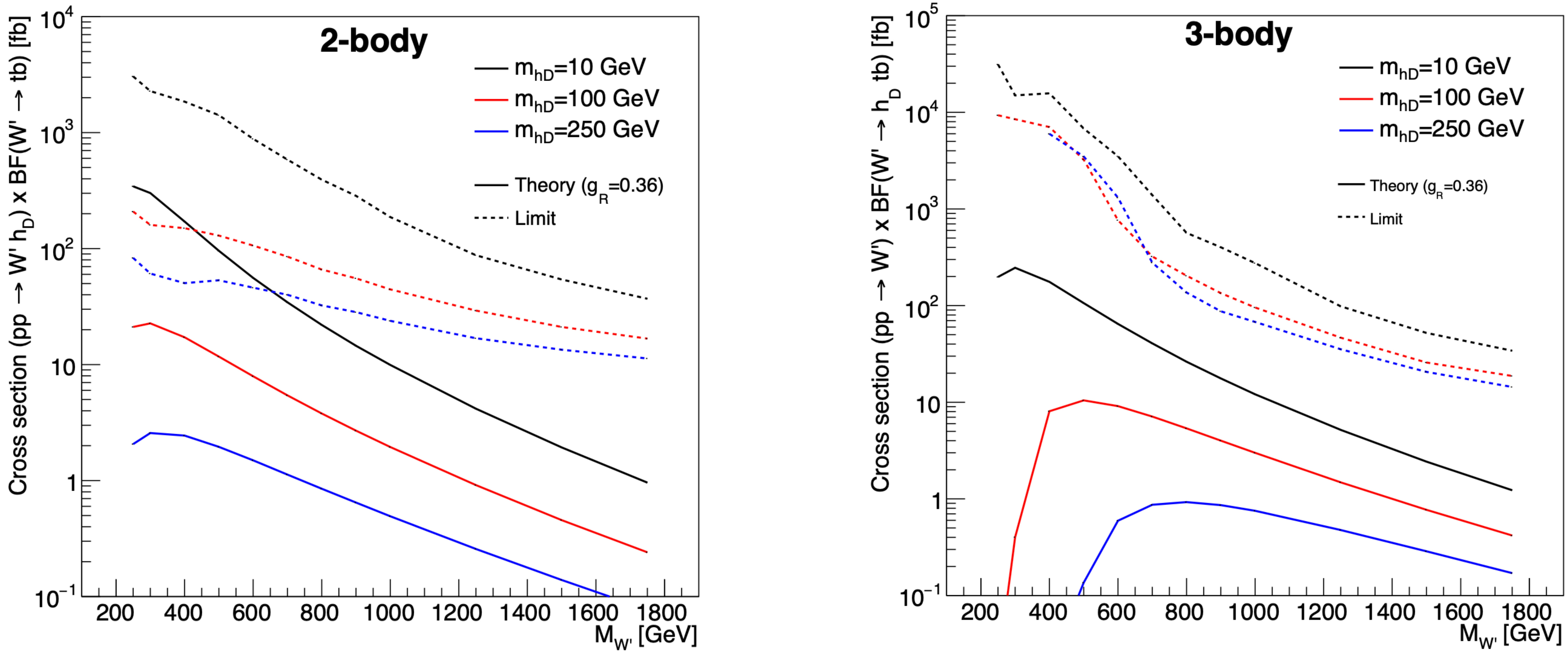


FIG. 7: Top: Summary of expected upper limits at 95% CL on the $h_D W'$ production cross section and the 2-body decay branching fraction of W' as a function of the W' boson mass normalized to an integrated luminosity of 300 fb^{-1} for three choices of the h_D boson mass. Also shown are expected theoretical cross sections and branching fractions at leading order for a coupling value of $g_R = 0.36$. Bottom: The same distributions as above except for the 3-body decay of the W' boson.