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Searching for W' using b-tagging, hadronic taus, and missing energy

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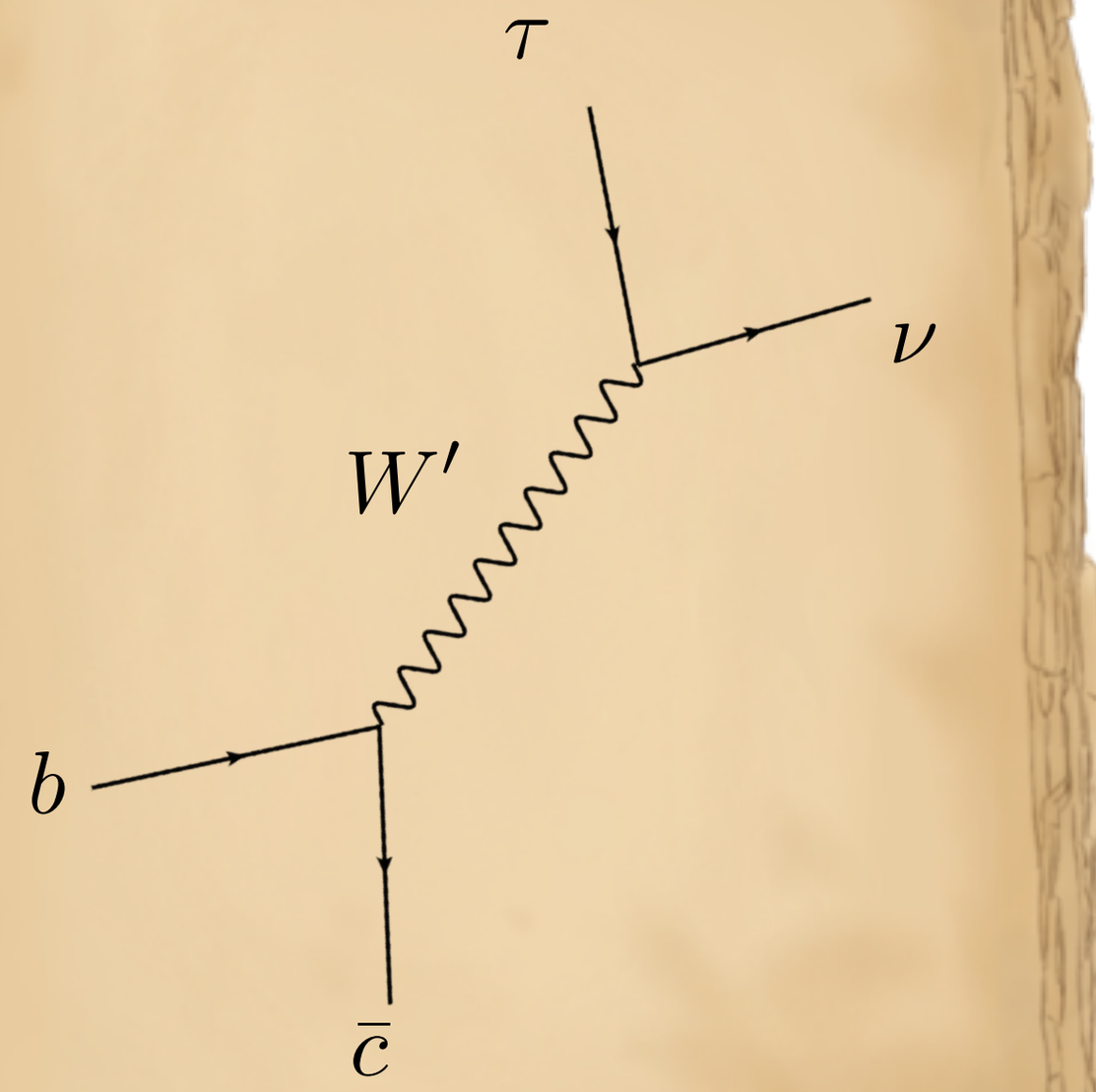
arXiv: 1805.01869

Phenomenology 2018
Monday May 7 2018

Fairy Tale of the Day

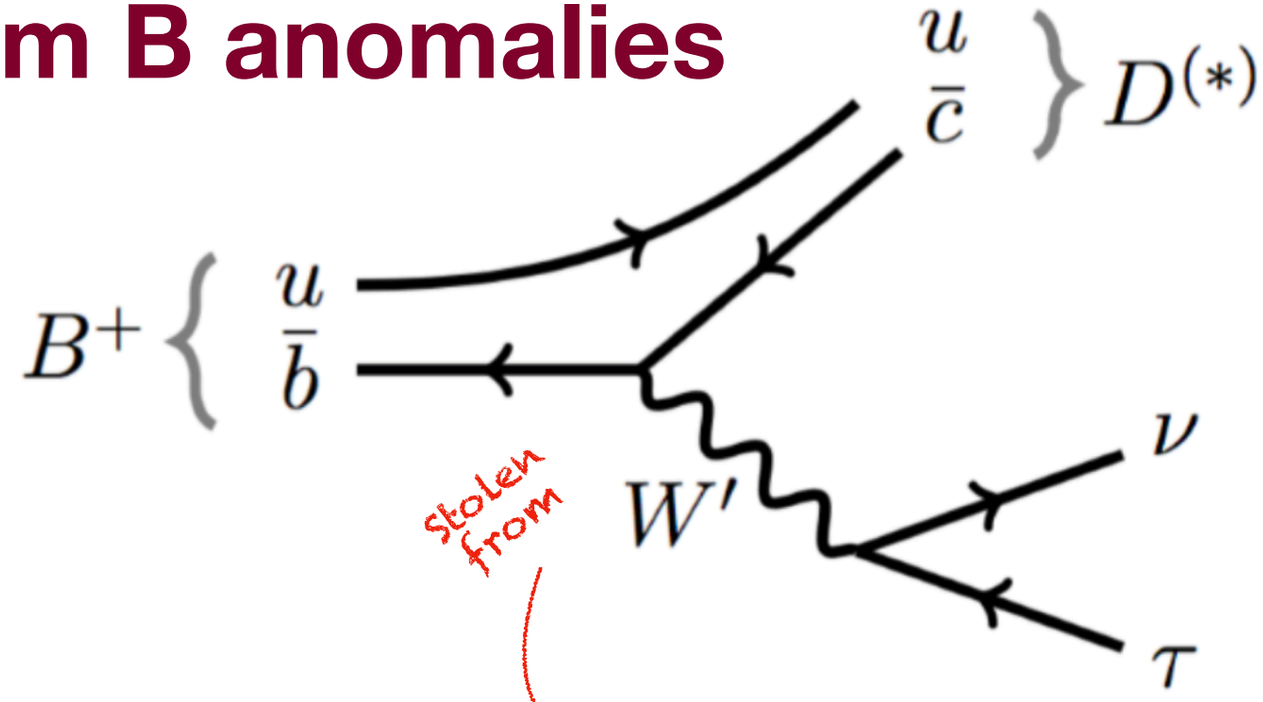
Once upon

a time…



A case from B anomalies

BaBar, Belle, and LHCb report an excess in semi-leptonic B decays ~ 4 σ



Boucenna et al 1608.01349

$$R(D) = \frac{Br(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{Br(\bar{B} \to D\ell^-\bar{\nu}_\ell)}$$

$$R(D^*) = \frac{Br(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)}{Br(\bar{B} \to D^*\ell^-\bar{\nu}_\ell)},$$

$$R(D)_{SM} = 0.298 \pm 0.003,$$
$$R(D^*)_{SM} = 0.255 \pm 0.004,$$

Bigi et al 1606.08030
Jaiswal et al 1707.09977

$$LHCb: \ \ell = \mu$$
$$BaBar\,\&\,Belle: \ \ell = (e+\mu)/2$$

$$R(D)_{Exp} = 0.407 \pm 0.039 \pm 0.024,$$
$$R(D^*)_{Exp} = 0.304 \pm 0.013 \pm 0.007.$$

HFAG http://www.slac.stanford.edu/xorg/hfag/semi/fpcp17/RDRDs.html

A case from not B anomalies

Reasons to look for W'

General

- **A heavy resonance**
- **Simple, direct SM couplings**
- **We know the W exists**

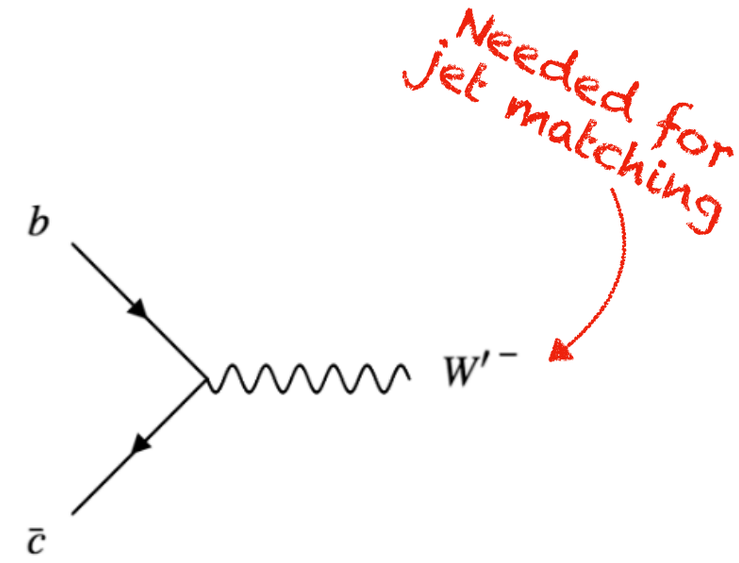
Fairly well studied

Model Specific

- **The decay is hadronic τ's + missing ET**
- **Can only be produced through b-c fusion**
- **Consequently, we expect an additional b-tag handle**

The Model

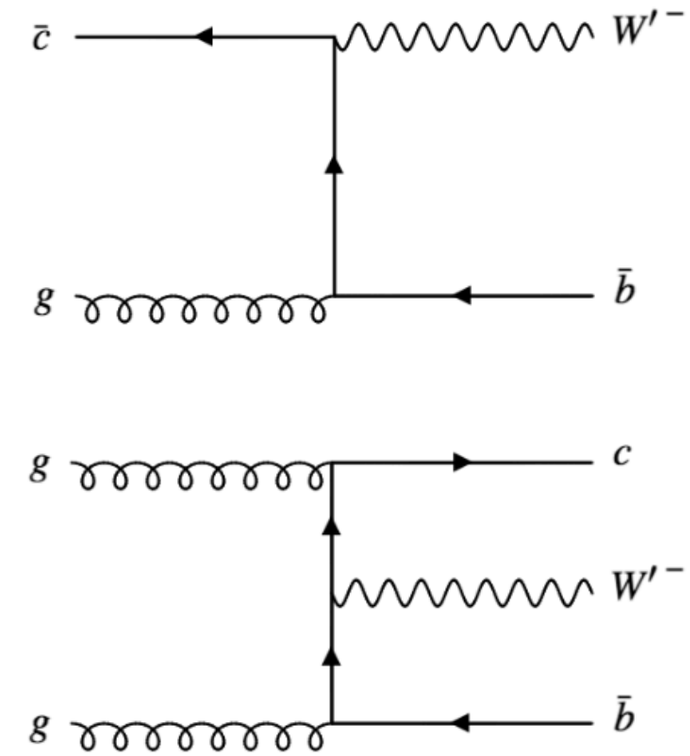
$$\mathcal{L} = (g'_q \bar{c}\gamma^\mu P_L b + g'_\tau \bar{\nu}_\tau \gamma^\mu P_L \tau^-) W'^+_\mu + h.c.$$



$$Br(W' \to bc) \simeq \frac{3g'^2_q}{3g'^2_q + g'^2_\tau}$$

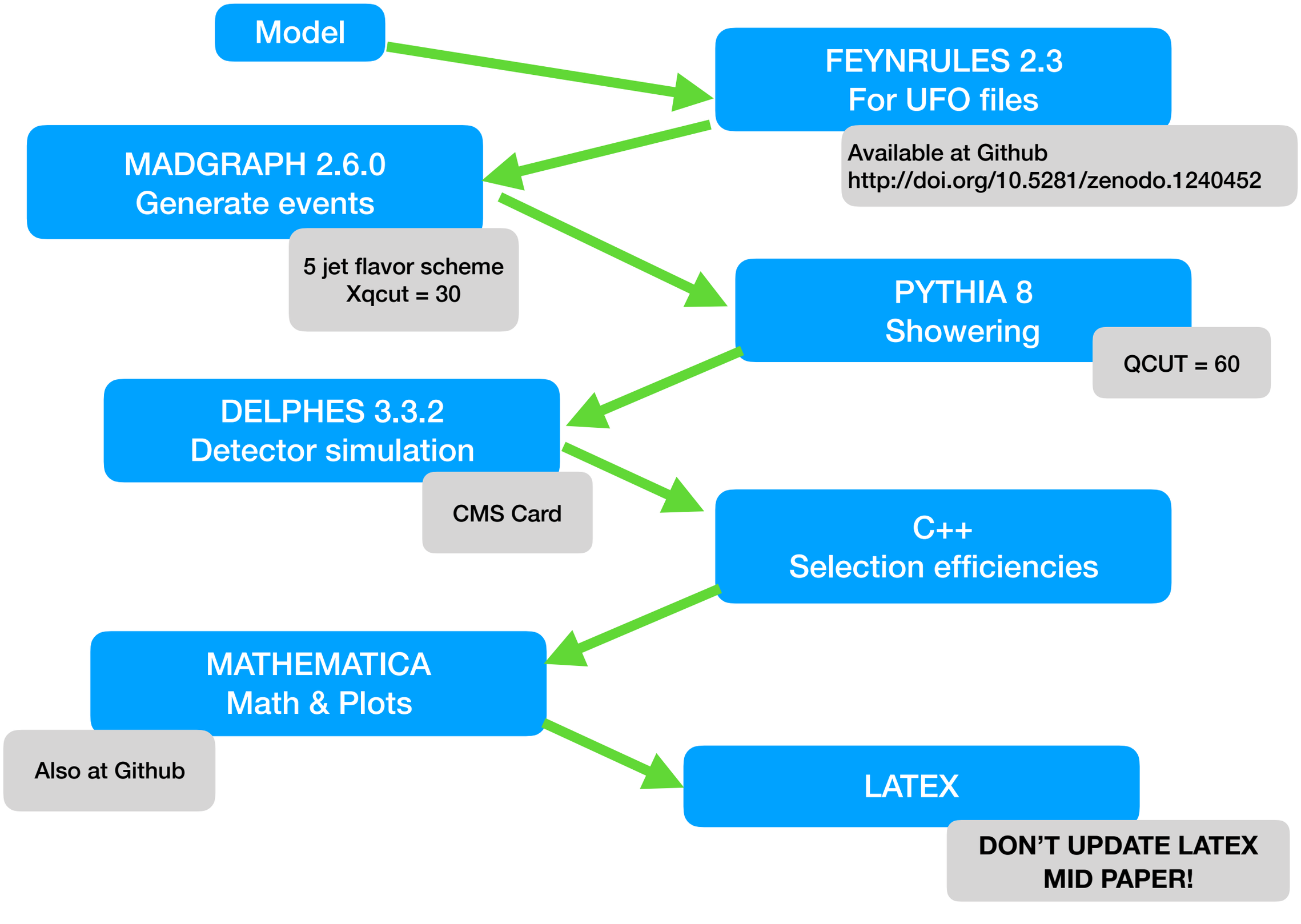
$$Br(W' \to \tau\nu) \simeq \frac{g'^2_\tau}{3g'^2_q + g'^2_\tau}$$

$$R(D^{(*)})_{NP} = \left(1 + \frac{g'_q g'_\tau}{m^2_{W'}} \frac{\sqrt{2}}{4G_F V_{cb}}\right)^2 R(D^{(*)})_{SM}$$



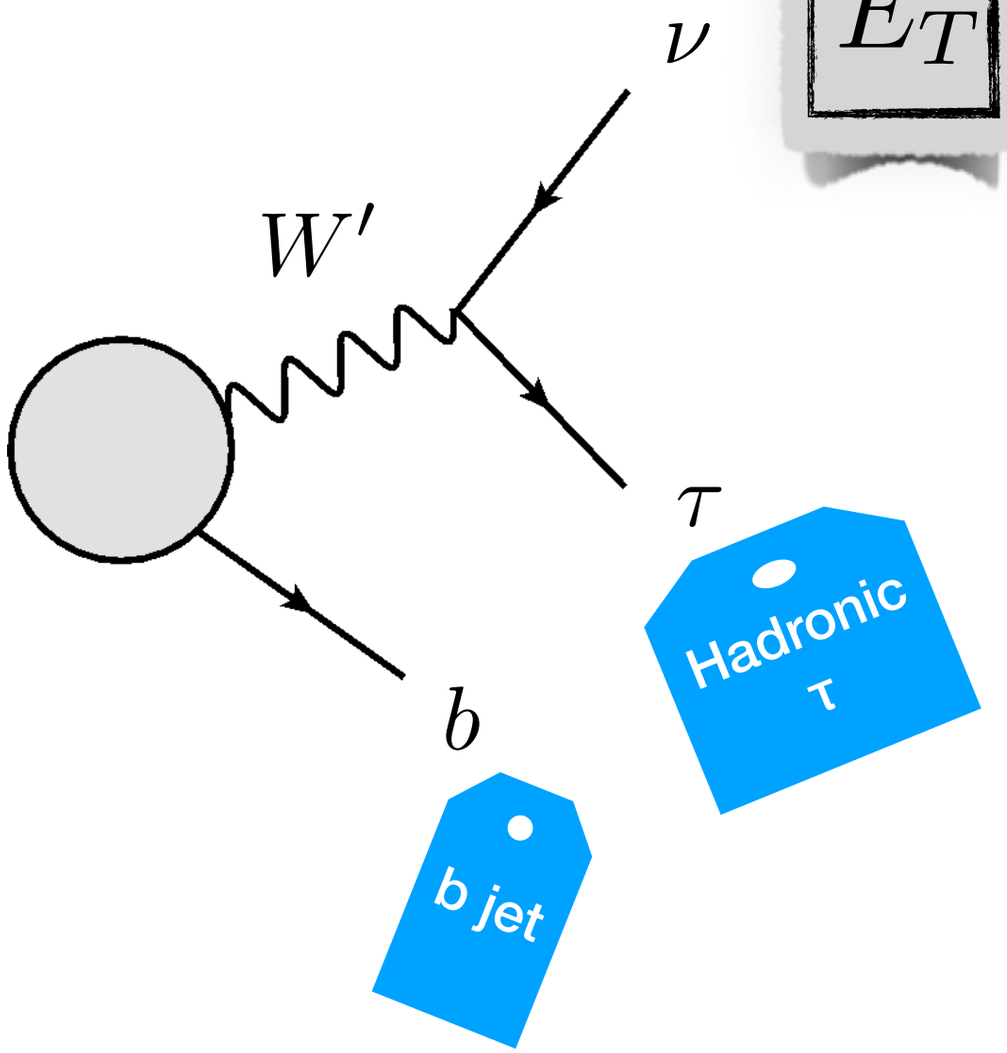
Boucenna et al 1608.01349

The Pipeline



The Selection

Signal



Backgrounds

$t\bar{t}$

mono-t

$W + j$

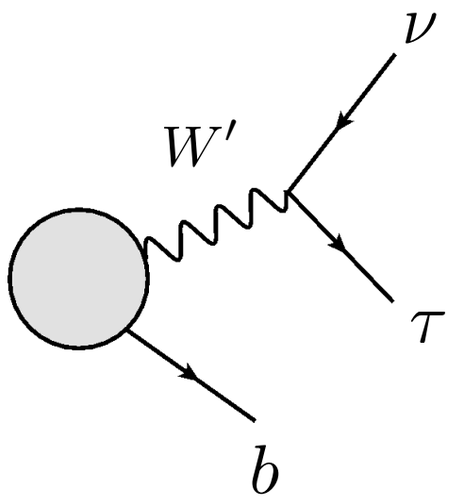
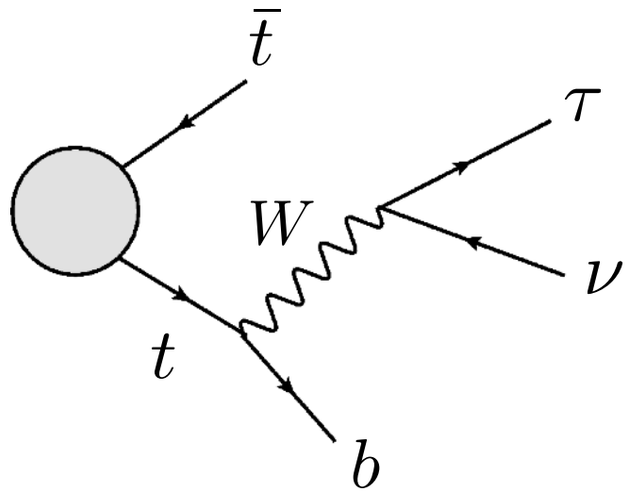
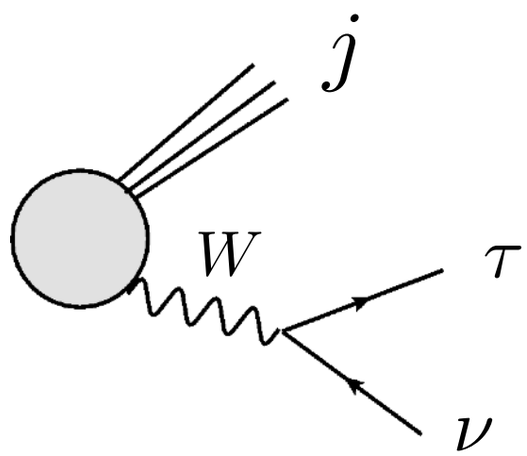
$Z + j$

WW

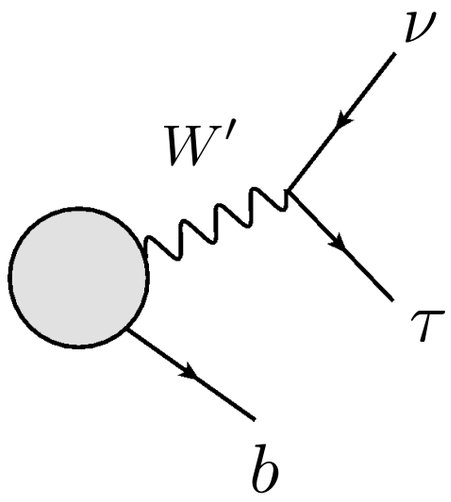
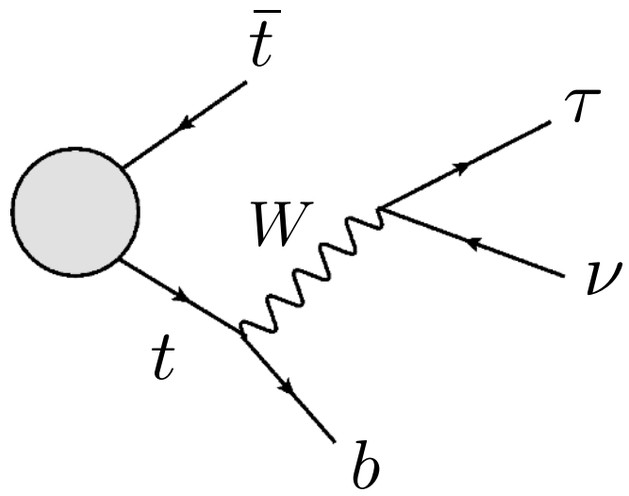
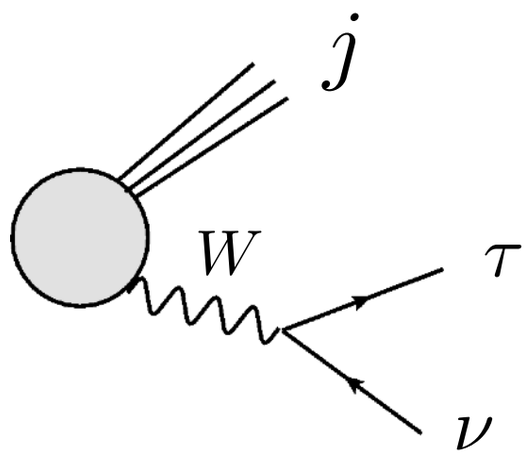
WZ

ZZ

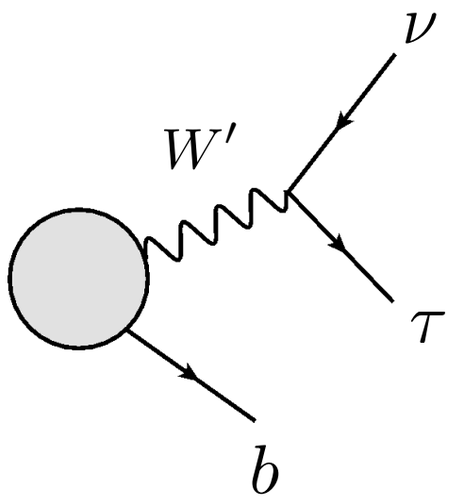
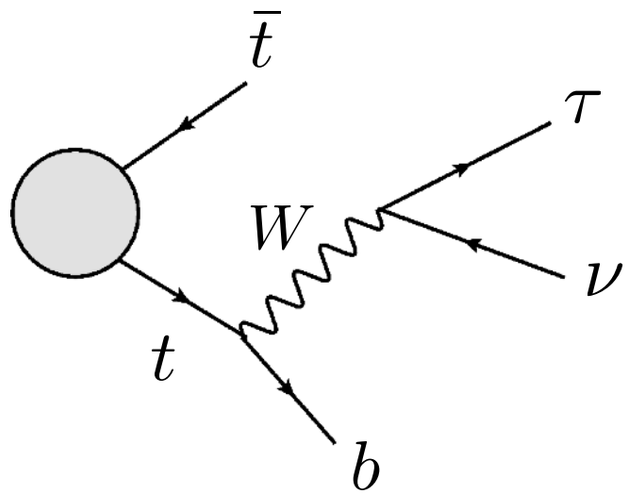
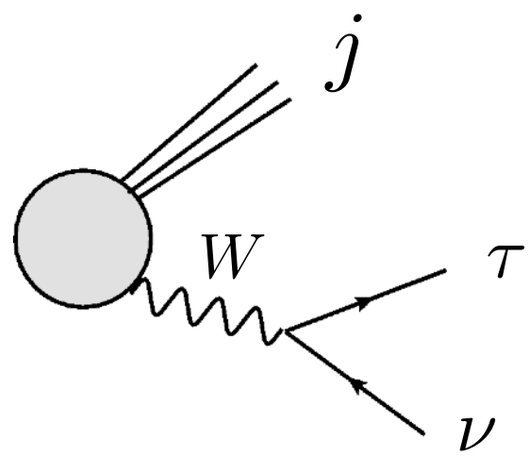
The Selection

Cut	Signal MW' = 500 GeV	Background ttbar	Background W+j
$p_T(\tau_{h1}) > 80\,\mathrm{GeV}$ $p_T(\tau_{h2}) < 50\,\mathrm{GeV}$ $\lvert\eta_\tau\rvert < 2.3$	Only 1 τ	2 τs possible pT is softer	Only 1 τ pT is softer
			
Cut efficiency:	**27.5%**	**3.29%**	**2.97%**
Accumulative:	**27.5%**	**3.29%**	**2.97%**
Total # of events:	**6.05 x10^3**	**6.75 x10^5**	**1.49 x10^6**
(per 100 fb^{-1})			

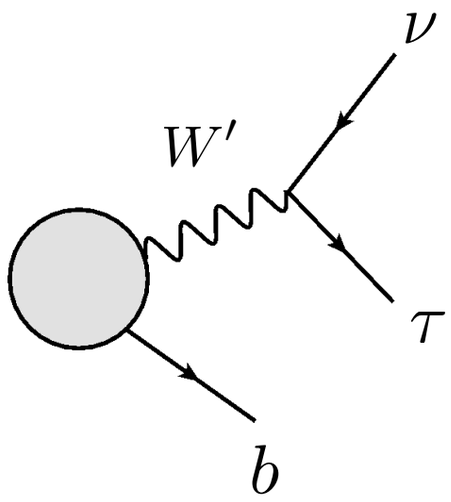
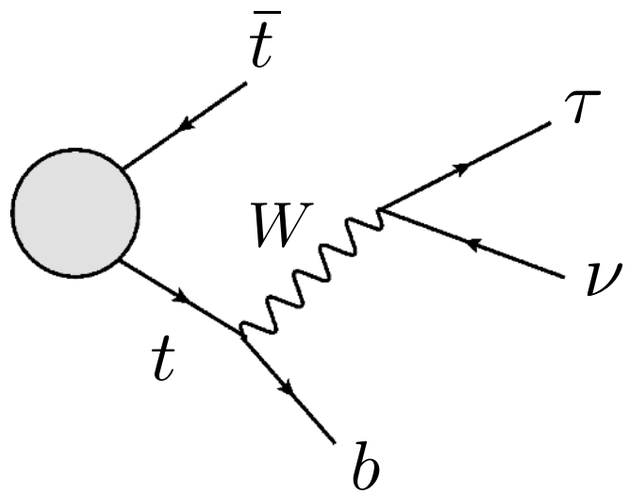
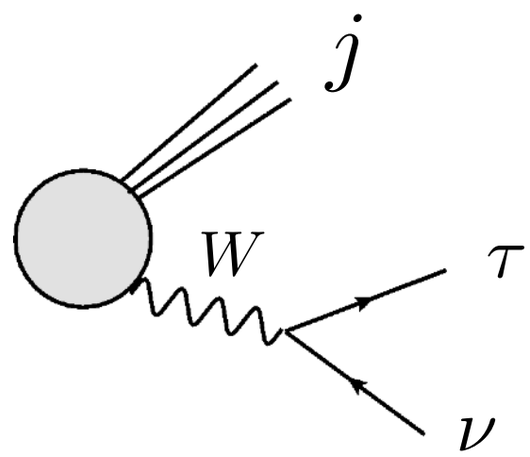
The Selection

Cut	Signal MW' = 500 GeV	Background ttbar	Background W+j
	1 hard b	2 hard b's	Soft b (tag)
$p_T(b) > 20\,\mathrm{GeV}$			
$\lvert\eta_b\rvert < 2.5$			
$N_B = 1$			
Cut efficiency:	**19.6%**	**49.8%**	**8.4%**
Accumulative:	**5.39%**	**1.64%**	**0.25%**
Total # of events: (per 100 fb^{-1})	**1.19 x10^3**	**3.36 x10^5**	**1.25 x10^5**

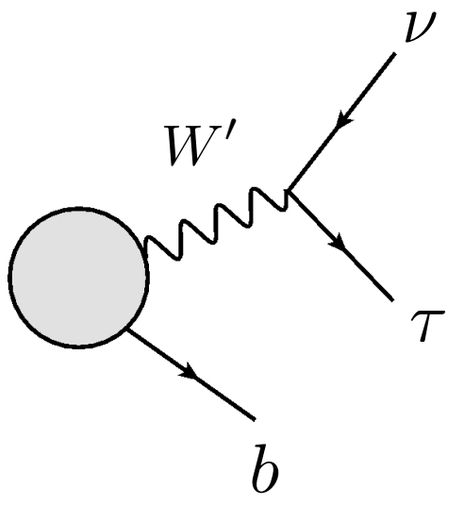
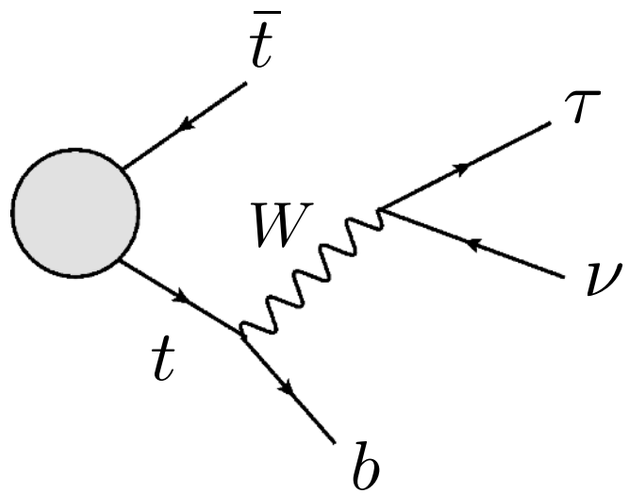
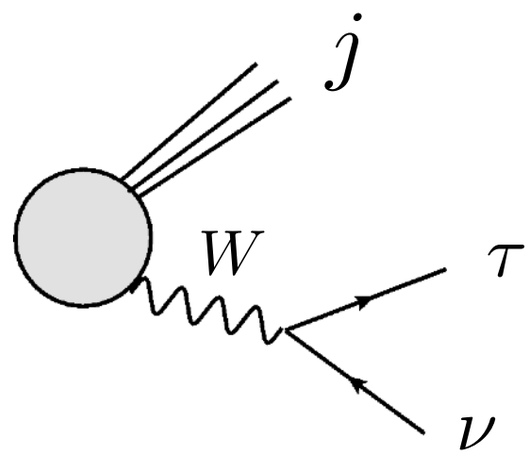
The Selection

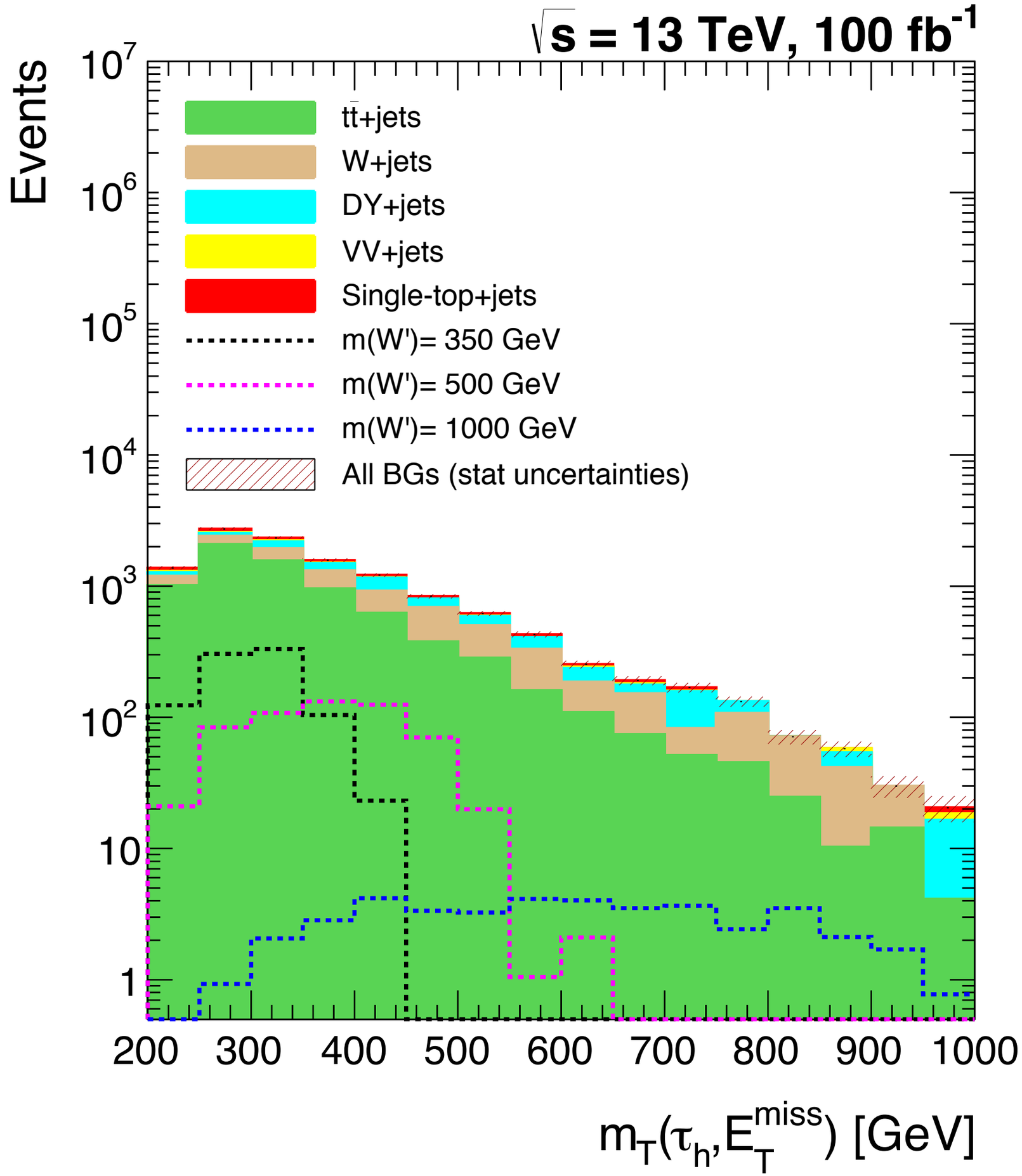
Cut	Signal MW' = 500 GeV	Background ttbar	Background W+j
	Rare hard e or μ	Sometimes	Rare
$p_T(e/\mu) < 15\ GeV$			
Cut efficiency:	**99.9%**	**71.8%**	**94.1%**
Accumulative:	**5.38%**	**1.18%**	**0.23%**
Total # of events: (per 100 fb^{-1})	**1.18 x10^3**	**2.41 x10^5**	**1.18 x10^5**

The Selection

Cut	Signal MW' = 500 GeV	Background ttbar	Background W+j
	Missing ET ~ MW'	Missing ET ~ MW, Mt	Missing ET ~ MW
$E_T^{miss} > 140\ GeV$			
Cut efficiency:	**61.5%**	**12.4%**	**9.65%**
Accumulative:	**3.31%**	**0.15%**	**0.02%**
Total # of events: **(per 100 fb^{-1})**	**7.29 x10^2**	**2.99 x10^4**	**1.13 x10^4**

The Selection

Cut	Signal MW' = 500 GeV	Background ttbar	Background W+j
$\|\Delta\phi(\tau_h, E_T^{\mathrm{miss}})\| > 2.4$	Large MW' ⇒ lower boost ⇒larger angle 	Mt , MW < MW' 	Mt , MW < MW' 
Cut efficiency:	**77.5%**	**24.8%**	**23.0%**
Accumulative:	**2.57%**	**0.04%**	**0.01%**
Total # of events: **(per 100 fb^{-1})**	**5.65 x10^2**	**7.43 x10^3**	**2.61 x10^3**


$\sqrt{s}$ = 13 TeV, 100 fb^{-1}
Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
$t\bar{t}$+jets
W+jets
DY+jets
VV+jets
Single-top+jets
m(W')= 350 GeV
m(W')= 500 GeV
m(W')= 1000 GeV
All BGs (stat uncertainties)
200
300
400
500
600
700
800
900
1000
$m_T(\tau_h, E_T^{miss})$ [GeV]

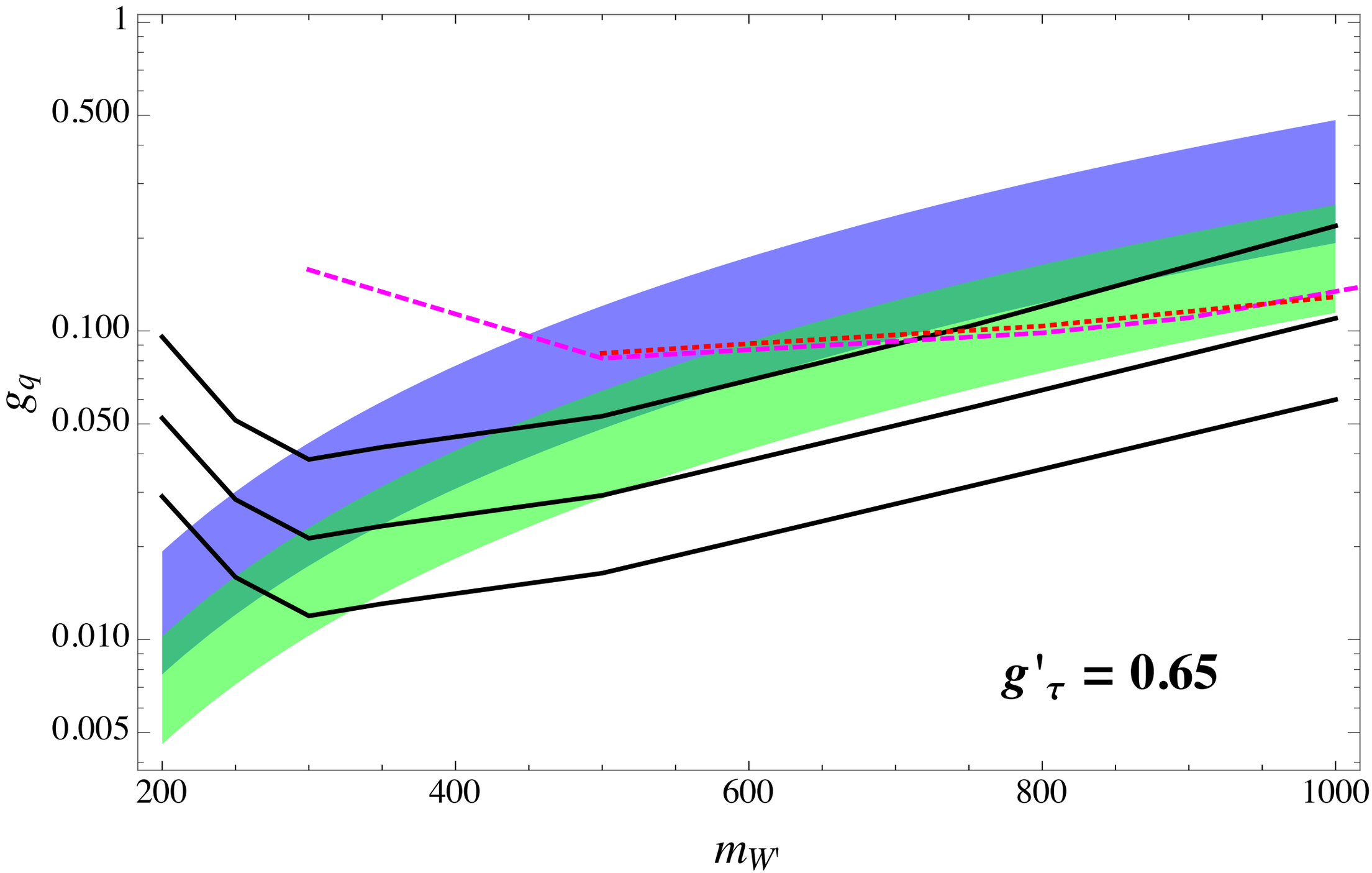
Projected 3σ sensitivity (L = 30, 300, 3000 fb^{-1})

CMS Inclusive 8 TeV, 19.7 fb^{-1}

ATLAS Inclusive 13 TeV, 36.1 fb^{-1}

$R(D)\,1\sigma$

$R(D^*)\,1\sigma$



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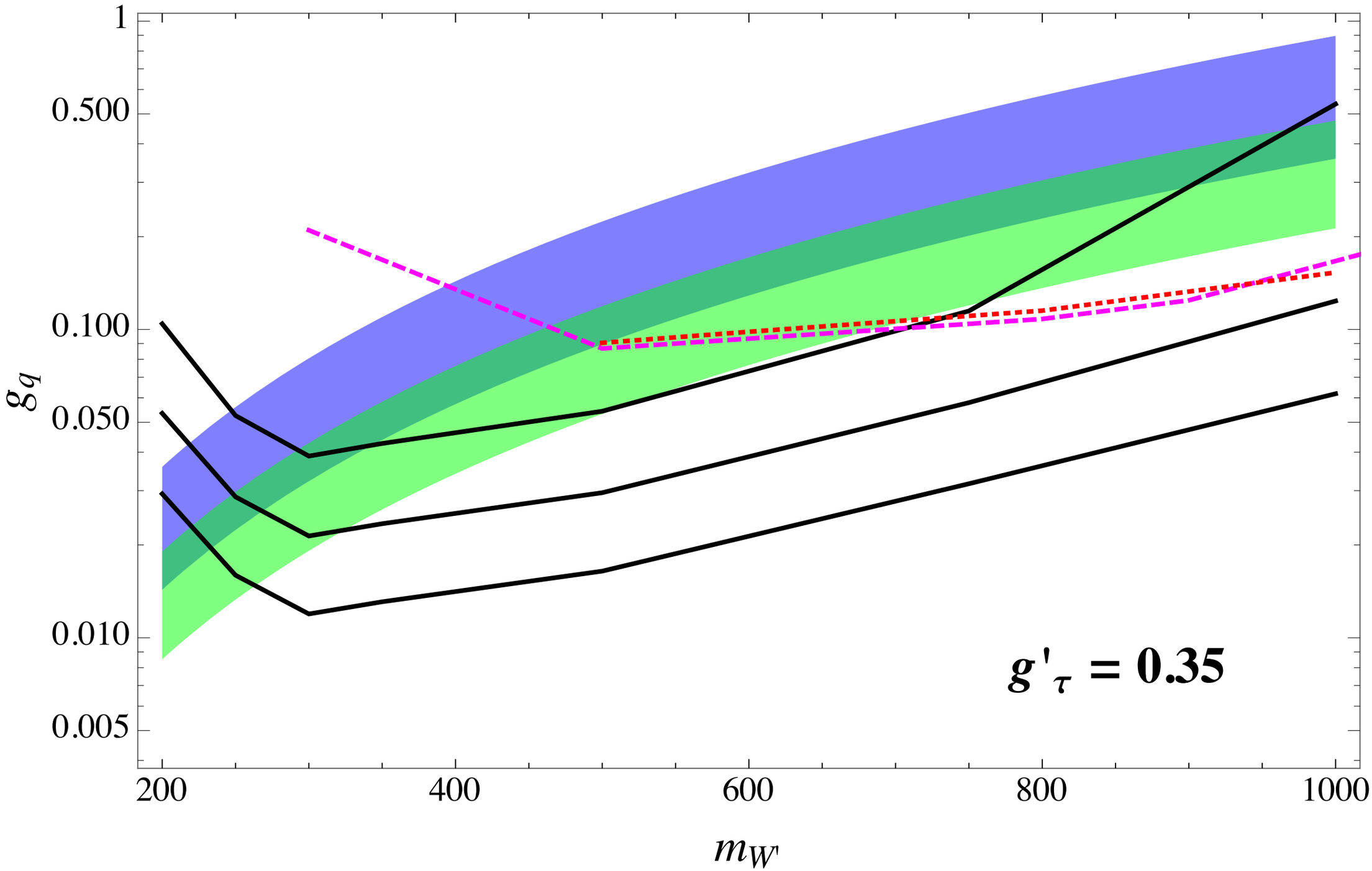

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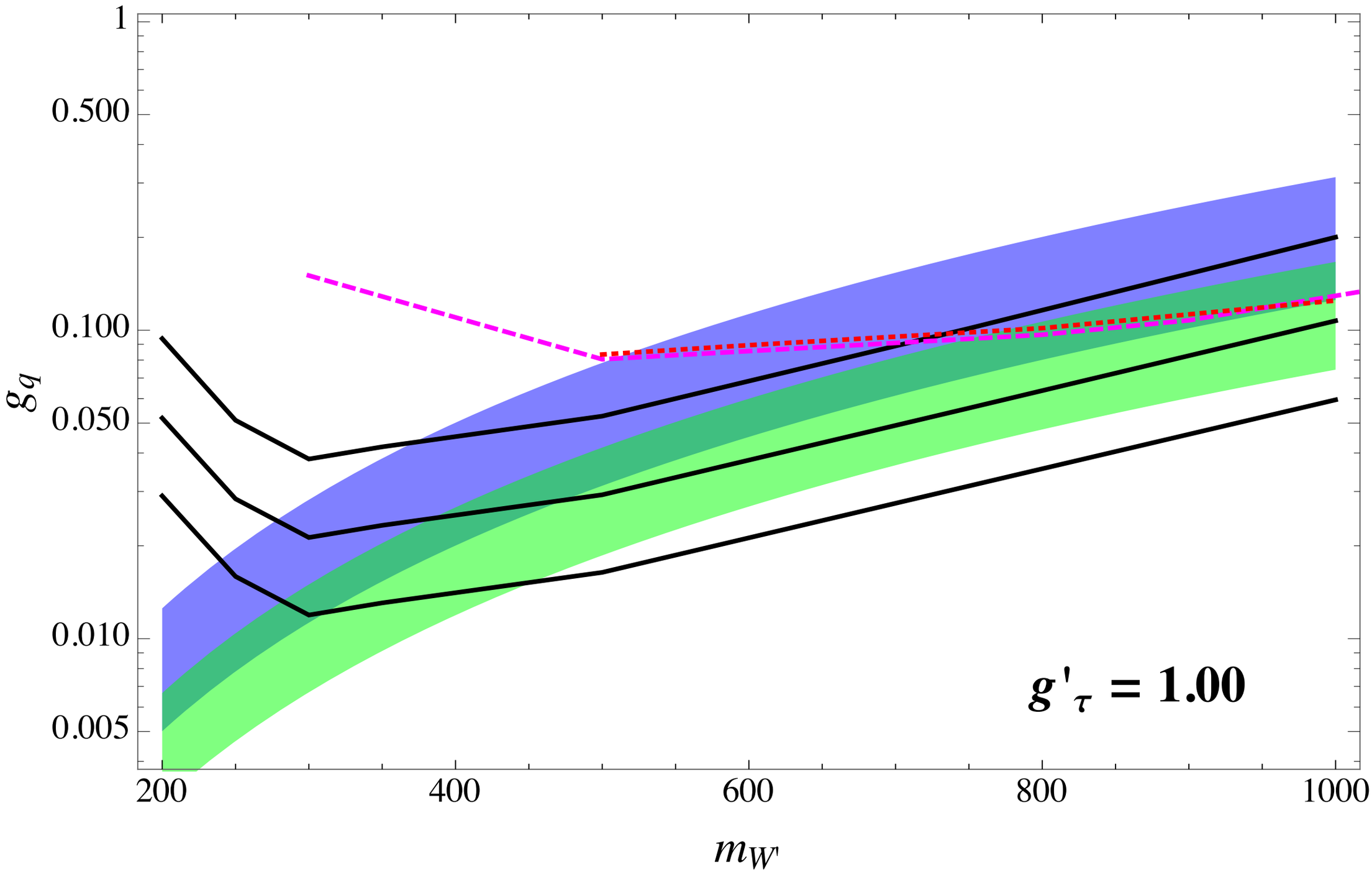
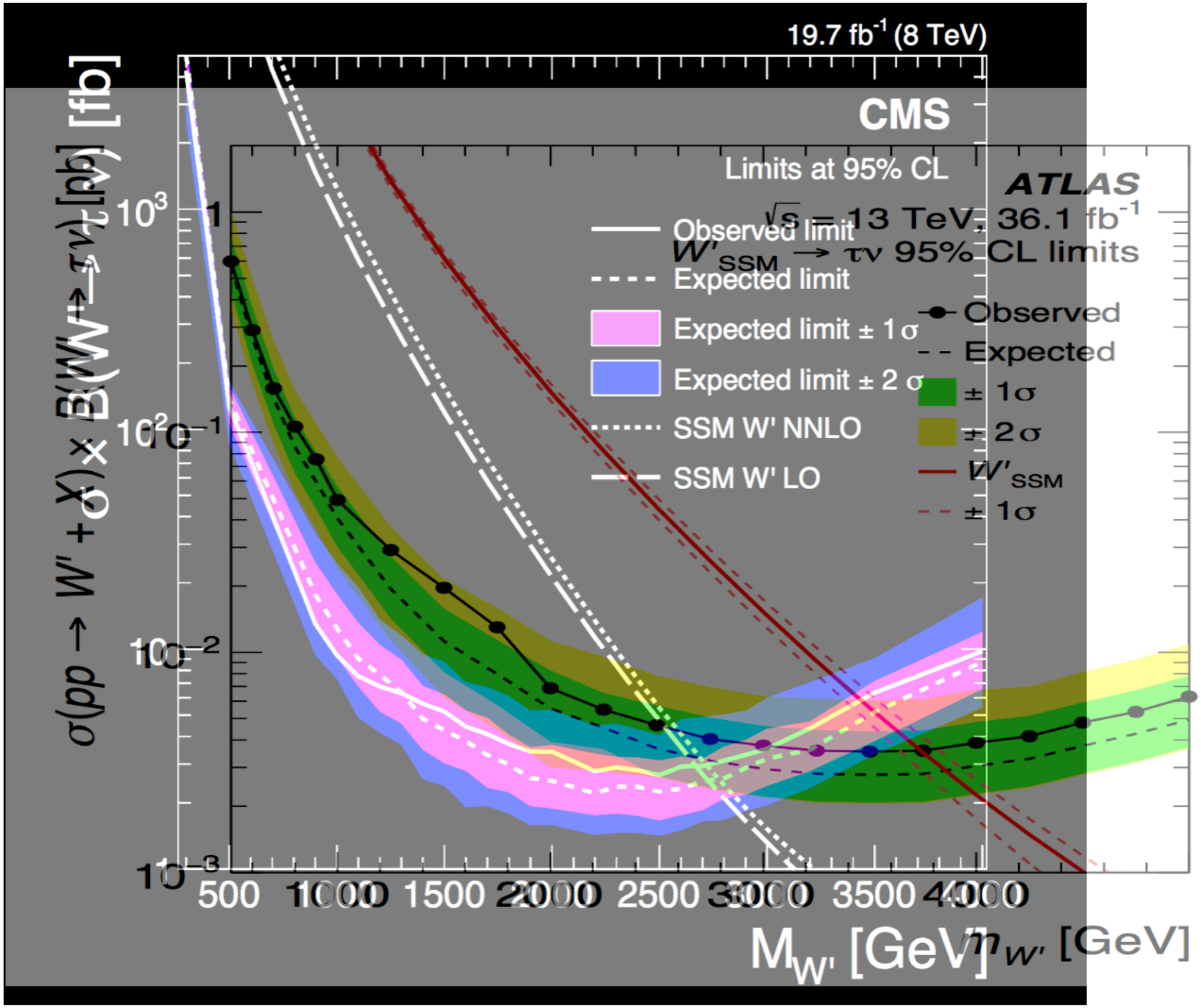


ATLAS v. CMS

ATLAS: 1801.06992

CMS: 1508.04308



Summary

- The R(D), R(D*) anomalies of B decays can be explained with a W' that couples to:
  - Bottom and charm quarks
  - τ-flavor leptons
- The couplings lead to an associated b-jet when produced at the LHC
- This additional b-tag can
  - Improve the sensitivity over an inclusive analysis for MW' < 700 GeV, and
  - Provide some discriminating power between different W' models
- Most of the parameter space explaining the B anomalies is within reach of Runs 2 through 4 of the LHC

Appendix

Efficiencies

	$p_T(\tau)$	$p_T(b)$	e/μ veto	E_T^{miss}	$\lvert\Delta\phi(\tau_h, E_T^{\text{miss}})\rvert$	$N/(100\ \text{fb}^{-1})$
$t\bar{t}$	3.29 ± 0.0056	49.8 ± 0.087	71.8 ± 0.11	12.4 ± 0.096	24.8 ± 0.36	7.41×10^3
mono-t	1.13 ± 0.0035	40.4 ± 0.0035	90.5 ± 0.14	2.55 ± 0.082	31.4 ± 1.5	5.95×10^2
$W + j$	2.97 ± 0.0094	8.4 ± 0.09	94.1 ± 0.26	9.65 ± 0.34	23 ± 1.6	2.61×10^3
$Z + j$	2.87 ± 0.014	14.1 ± 0.18	97.4 ± 0.21	6.45 ± 0.34	32.4 ± 2.5	1.37×10^3
WW	0.575 ± 0.0042	7.66 ± 0.19	92.5 ± 0.7	6.63 ± 0.68	21.6 ± 4.4	3.80×10^1
WZ	0.638 ± 0.0071	11.9 ± 0.36	93.2 ± 0.82	6.7 ± 0.84	39 ± 6.3	1.08×10^2
ZZ	0.673 ± 0.012	17.8 ± 0.67	92.7 ± 1.1	6 ± 1	65.6 ± 8.4	1.77×10^1
					Total Background	1.22×10^4

	$p_T(\tau)$	$p_T(b)$	e/μ veto	E_T^{miss}	$\lvert\Delta\phi(\tau_h, E_T^{\text{miss}})\rvert$	$N/(100\ \text{fb}^{-1})$	$\frac{S}{\sqrt{S+B}}$
200 GeV	8.34 ± 0.081	18.1 ± 0.39	99.6 ± 0.15	5.97 ± 0.57	25.7 ± 4.3	1.80×10^2	1.62
250 GeV	13.9 ± 0.15	17.2 ± 0.44	99.9 ± 0.078	15.1 ± 1	49 ± 3.6	5.98×10^2	5.30
300 GeV	18.3 ± 0.24	17.4 ± 0.56	99.9 ± 0.13	28.6 ± 1.6	69.2 ± 3.1	1.06×10^3	9.26
350 GeV	22.2 ± 0.27	17.1 ± 0.52	99.7 ± 0.19	37.6 ± 1.6	67.8 ± 2.5	8.88×10^2	7.77
500 GeV	27.5 ± 0.31	19.6 ± 0.52	99.9 ± 0.089	61.5 ± 1.4	77.5 ± 1.6	5.63×10^2	5.00
750 GeV	31.5 ± 0.34	21.7 ± 0.54	99.7 ± 0.16	79.1 ± 1.2	82.4 ± 1.2	1.55×10^2	1.40
1000 GeV	32.8 ± 0.37	21.6 ± 0.56	99.7 ± 0.17	87.2 ± 0.98	83.4 ± 1.2	4.33×10^1	0.39