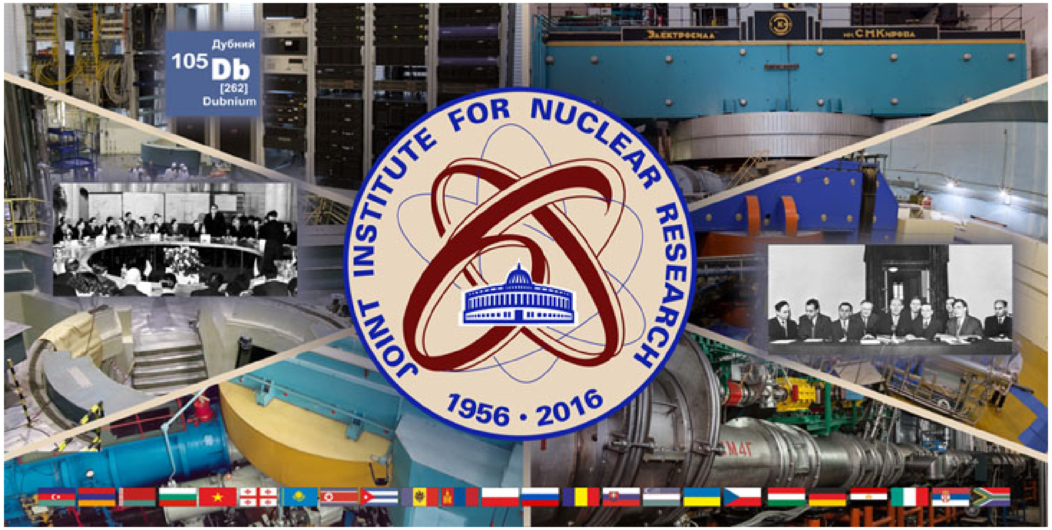

The Top Quark Physics

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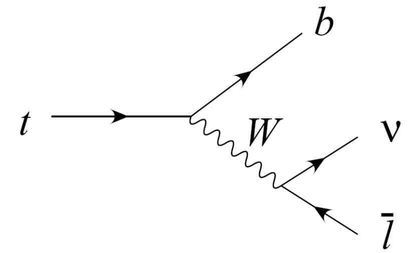
Lecture 3

Reviews: Willenbrock; Han; Hill and Simmons; Bernreuther; Rainwater; Morrissey, Plehn, and Tait; Incandela, Quadt, Wagner, and Wicke; Boos, Dudko, and Slabospitsky; ...

Wtb anomalous couplings



$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

Operators that contribute to the Wtb vertex:

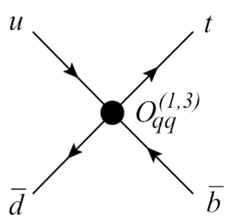
J. A. Aguilar-Saavedra, arXiv:1008.3225

$$O_{\phi q}^{(3,3+3)} = \frac{i}{2}\left[\phi^\dagger(\tau^I D_\mu - \overleftarrow{D}_\mu \tau^I)\phi\right](\bar{q}_{L3}\gamma^\mu \tau^I q_{L3}), \qquad O_{\phi\phi}^{33} = i(\tilde{\phi}^\dagger D_\mu \phi)(\bar{t}_R \gamma^\mu b_R),$$

$$O_{dW}^{33} = (\bar{q}_{L3}\sigma^{\mu\nu}\tau^I b_R)\phi\, W_{\mu\nu}^I, \qquad O_{uW}^{33} = (\bar{q}_{L3}\sigma^{\mu\nu}\tau^I t_R)\tilde{\phi}\, W_{\mu\nu}^I,$$

contact four-fermion interactions (not a part of Wtb vertex):

$$O_{qq}^{(1,3)} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$$



Cen Zhang, Scott Willenbrock, arXiv:1008.3869

one can derive vertices:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu (V_L P_L + V_R P_R)\, t\, W_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu} q_\nu}{M_W}(g_L P_L + g_R P_R)\, t\, W_\mu^- + \mathrm{h.c.}$$

$V_L \equiv F^L_T \equiv F^L_1$,
$V_R \equiv F^R_T \equiv F^R_1$
$g_L \equiv F^L_T \equiv F^L_2$,
$g_R \equiv F^R_T \equiv F^R_2$

order:

$1/\Lambda^2$	$1/\Lambda^4$
V_L	$(V_L)^2$
-	$(V_R)^2$
-	$(g_L)^2$
g_R	$(g_R)^2$

Where corrections to SM coupling:

$$V_L = V_{tb} + C_{\phi q}^{(3,3+3)} \frac{v^2}{\Lambda^2}, \qquad g_L = \sqrt{2} C_{dW}^{33} \frac{v^2}{\Lambda^2},$$

$$V_R = \frac{1}{2} C_{\phi\phi}^{33} \frac{v^2}{\Lambda^2}, \qquad g_R = \sqrt{2} C_{uW}^{33} \frac{v^2}{\Lambda^2},$$

$$\sigma \propto A\cdot(f_1^L)^2 + B\cdot(f_1^R)^2 + C\cdot(f_1^L\cdot f_2^R) + D\cdot(f_1^R\cdot f_2^L) + E\cdot(f_2^L)^2 + G\cdot(f_2^R)^2$$

Production cross section and anomalous Wtb couplings

s-channel:

$$\sigma(\hat{s})_{u\bar{d}\to t\bar{b}} = \frac{\pi \cdot V_{ud}^2 \cdot \alpha^2}{24 \sin^4 \Theta_W} \cdot \frac{\beta^4 \cdot \hat{s}}{(\hat{s} - m_W^2)^2} \times$$
$$\Big[\; (3-\beta^2) \cdot \left(f_{LV}^2 + f_{RV}^2 \right)$$
$$+ (3 - 2\beta^2) \cdot \frac{\hat{s}}{m_W^2} \cdot \left(f_{LT}^2 + f_{RT}^2 \right)$$
$$- \frac{6 m_t}{m_W} \cdot \left(f_{LV} \cdot f_{RT} + f_{RV} \cdot f_{LT} \right) \; \Big]$$

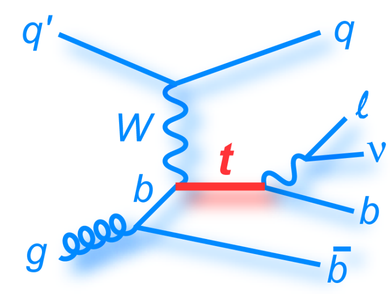
$$\beta^2 = 1 - \frac{m_t^2}{\hat{s}}, \quad a_1 = 1 + \frac{\beta^2 \hat{s}}{m_W^2}, \quad c_p = \frac{\hat{s}}{(\hat{s} - m_t^2 + m_W^2)},$$
$$c_0 = \frac{\hat{s}}{m_W^2}, \quad c_1 = \frac{2 m_W^2}{\hat{s}} + \beta^2;$$

t-channel:

$$\sigma(\hat{s})_{ub\to td} = \frac{\pi \cdot V_{ud}^2 \cdot \alpha^2}{4 \cdot \hat{s} \cdot \sin^4 \Theta_W} \times$$
$$\Big[\; c_0 c_p \beta^4 \cdot f_{LV}^2$$
$$+ \left(-(1+c_1) \cdot ln(a_1) \; + \; (2+c_0) \cdot \beta^2 \right) \cdot f_{RV}^2$$
$$+ \left(\; (2+c_0) \cdot ln(a_1) \; - \; (1+c_1) \cdot c_0 c_p \beta^2 \right) \cdot f_{RT}^2$$
$$+ \left(c_1 \cdot ln(a_1) \; - \; 2\beta^2 \right) \cdot c_0 \beta^2 \cdot f_{LT}^2$$
$$+ \frac{2 m_t}{m_W} \cdot \left((-ln(a_1) + c_p \beta^2 \right) \cdot f_{LV} \cdot f_{RT} \Big)$$
$$+ \frac{2 m_t}{m_W} \cdot \left((c_1 \cdot ln(a_1) - 2\beta^2 \right) \cdot f_{RV} \cdot f_{LT} \Big) \; \Big]$$

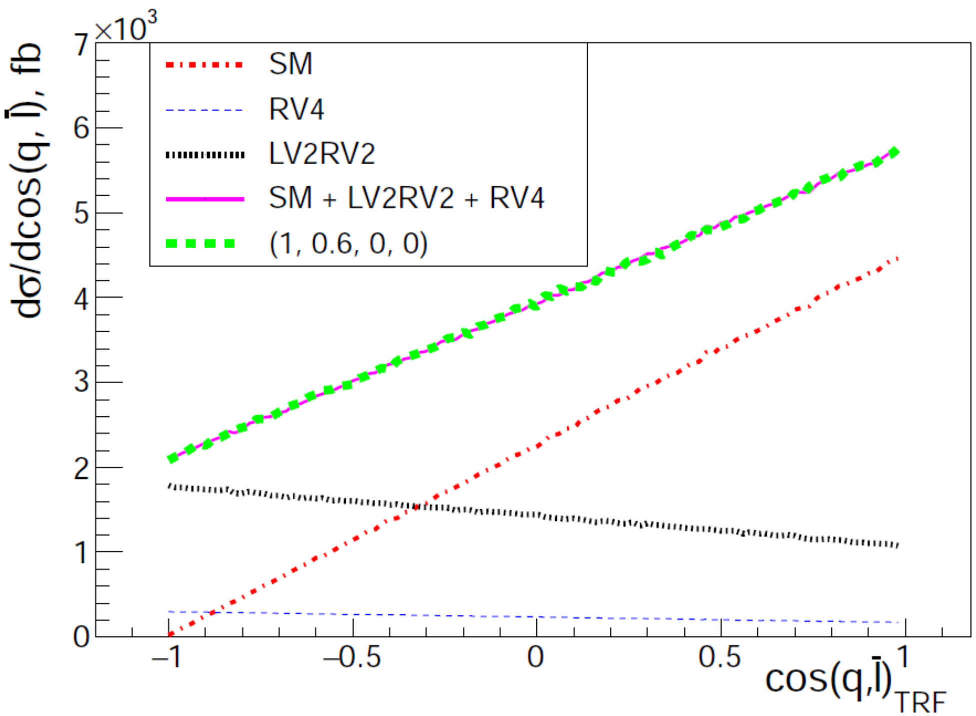
Int.J.Mod.Phys. A32 (2016) 1750008

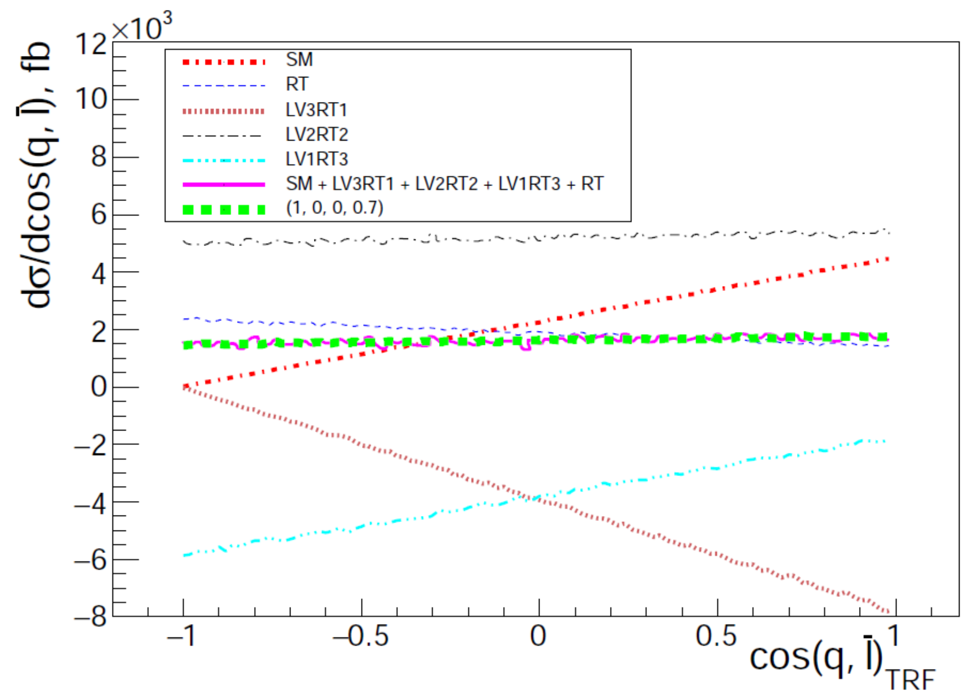
Simulation of t-channel single top with anomalous Wtb coupling in the production and in the decay of top



$$
\begin{aligned}
(f_{LV},\ 0,\ f_{LT},\ 0) = (f_{LV})^4 \frac{W_{\text{tot}}(1,0,0,0)}{W_{\text{tot}}(f_{LV},0,f_{LT},0)} \cdot (\text{LV4}) \\
+ (f_{LV})^2 (f_{LT})^2 \frac{W_{\text{tot}}(1,0,1,0)}{W_{\text{tot}}(f_{LV},0,f_{LT},0)} \cdot (\text{LV2LT2}) \\
+ (f_{LT})^4 \frac{W_{\text{tot}}(0,0,1,0)}{W_{\text{tot}}(f_{LV},0,f_{LT},0)} \cdot (\text{LT4}).
\end{aligned}
$$

Int.J.Mod.Phys. A32 (2016) 1750008



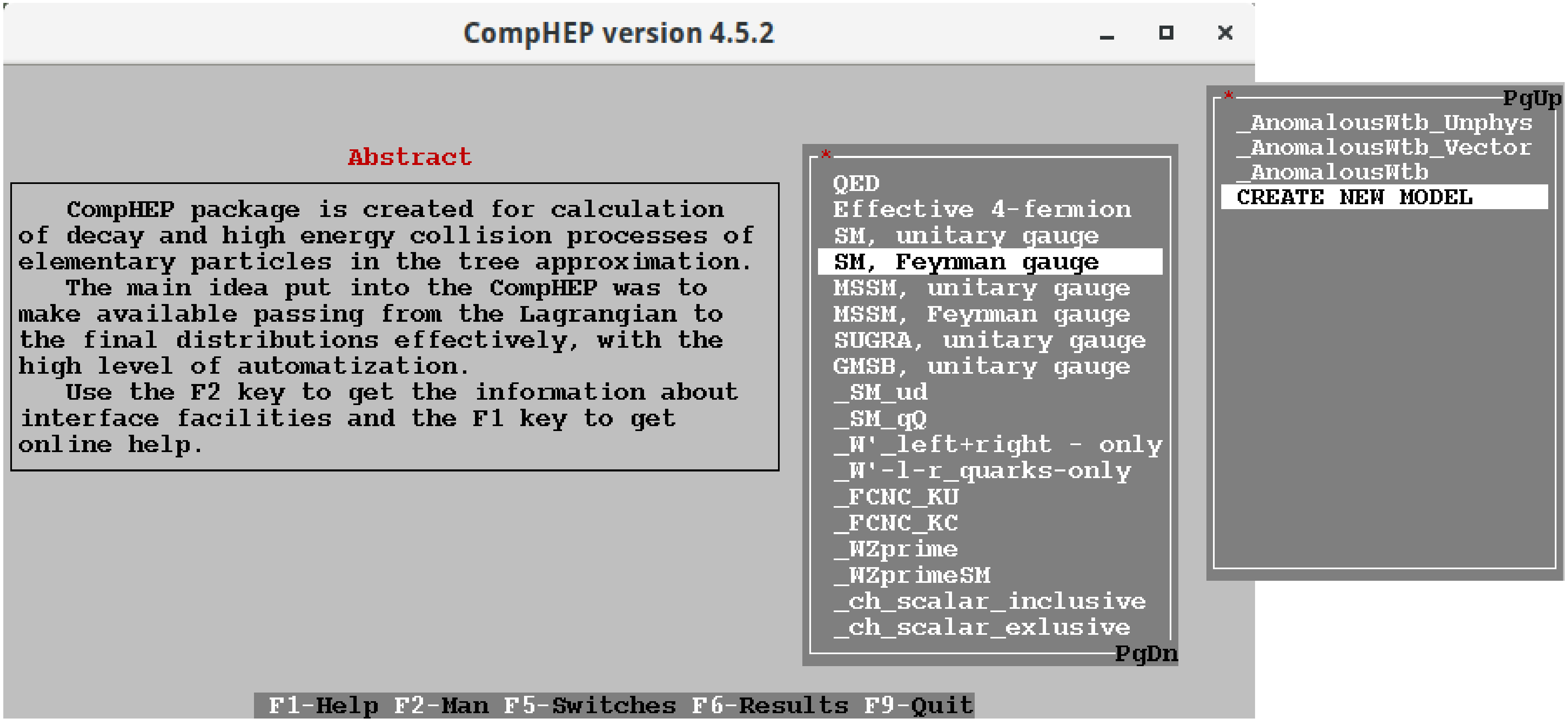


Short How To with CompHEP

Download http://comphep.sinp.msu.ru/ and unpack
cd comphep-4.5.2
./configure --with-libxml --with-m64 –with-root
make
make setup WDIR=../comphep_wdir
cd ../comphep_wdir
./comphep (run CompHEP GUI)
ls -l models/ (list models files, editable)
ls -l results/ (directory with results of calculations)

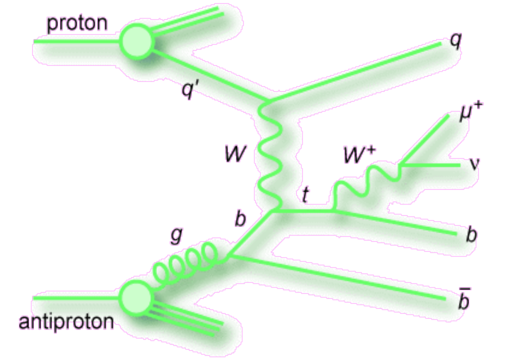
PoS ACAT08 (2008) 008, arXiv:0901.4757;
Nucl.Instrum.Meth. A534 (2004) 250-259;
hep-ph/9908288;

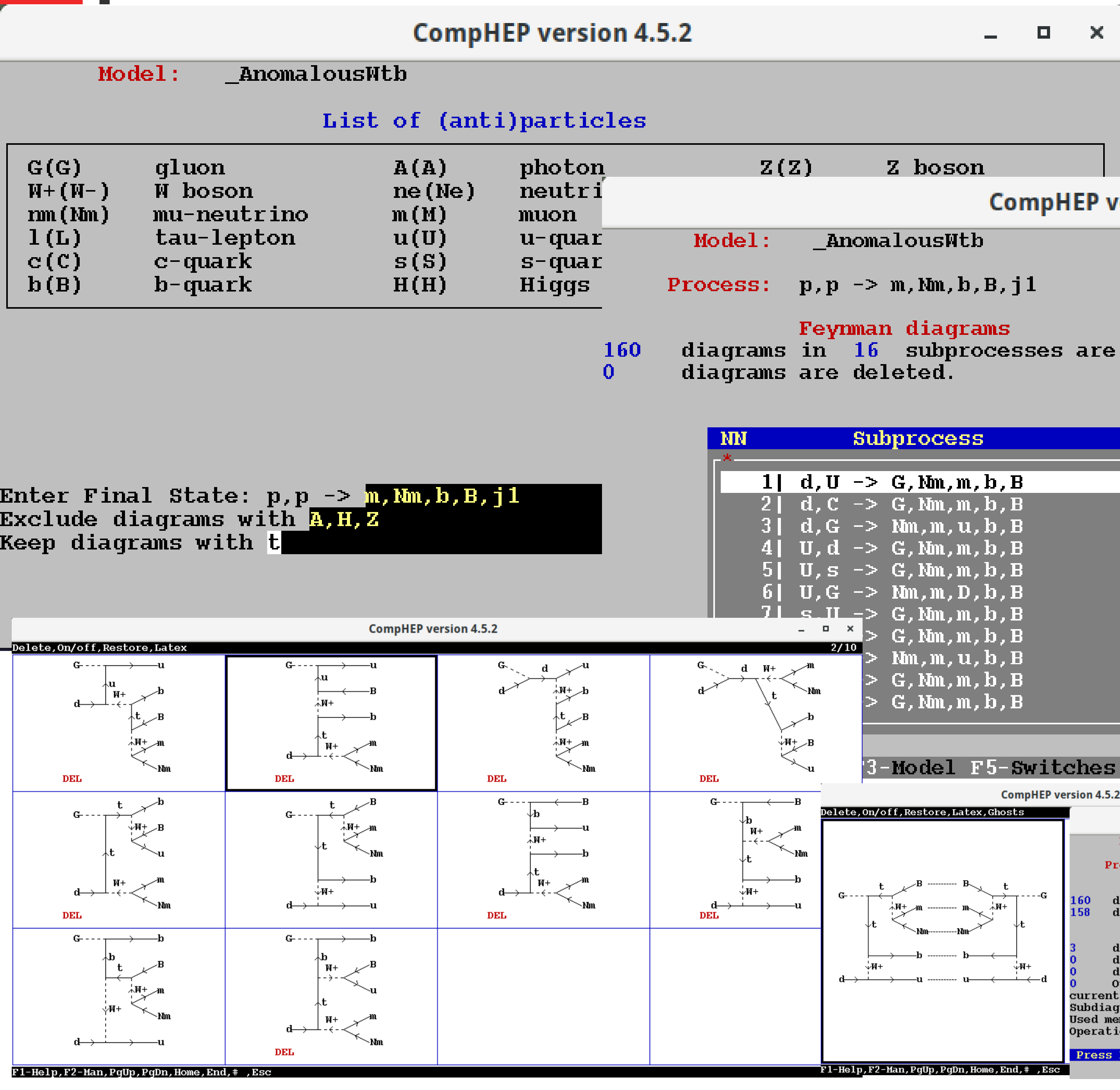
Choose existing model or create new one

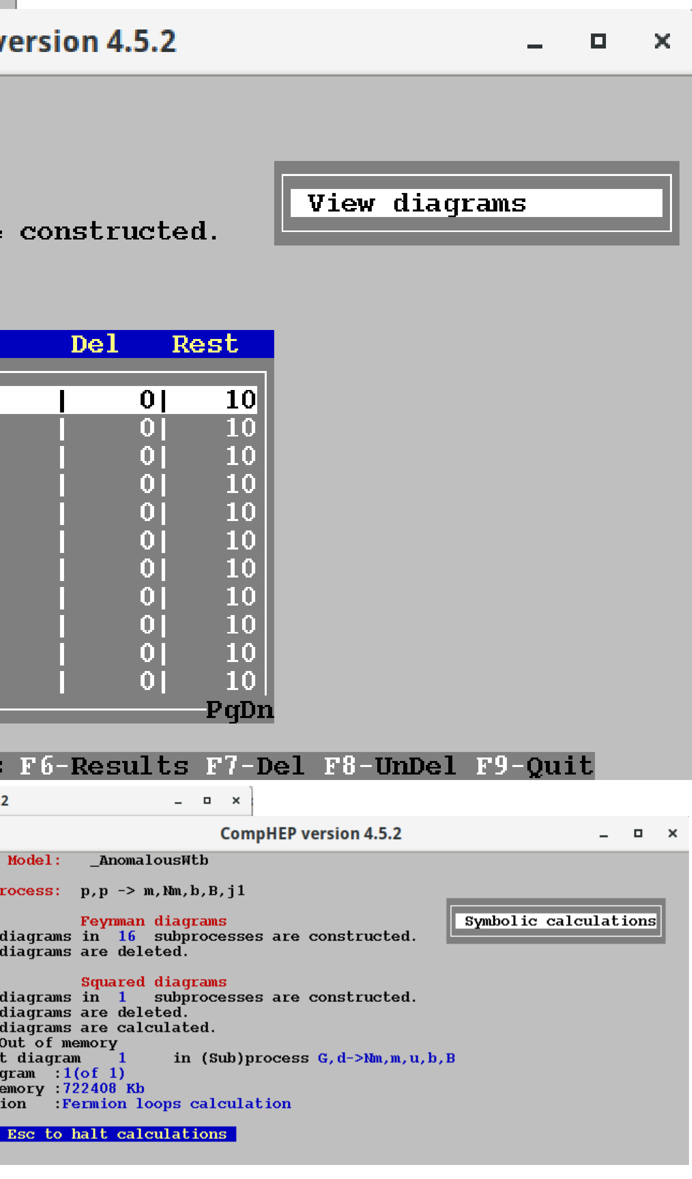


B |t |W- | |-EE/(2*Sqrt2*SW) |FL1*G(m3)*(1-G5)+FR1*G(m3)*(1+G5)+FFL2*(G(p3)*G(m3)-G(m3)*G(p3))*(1-G5)+FFR2*(G(p3)*G(m3)-G(m3)*G(p3))*(1+G5)

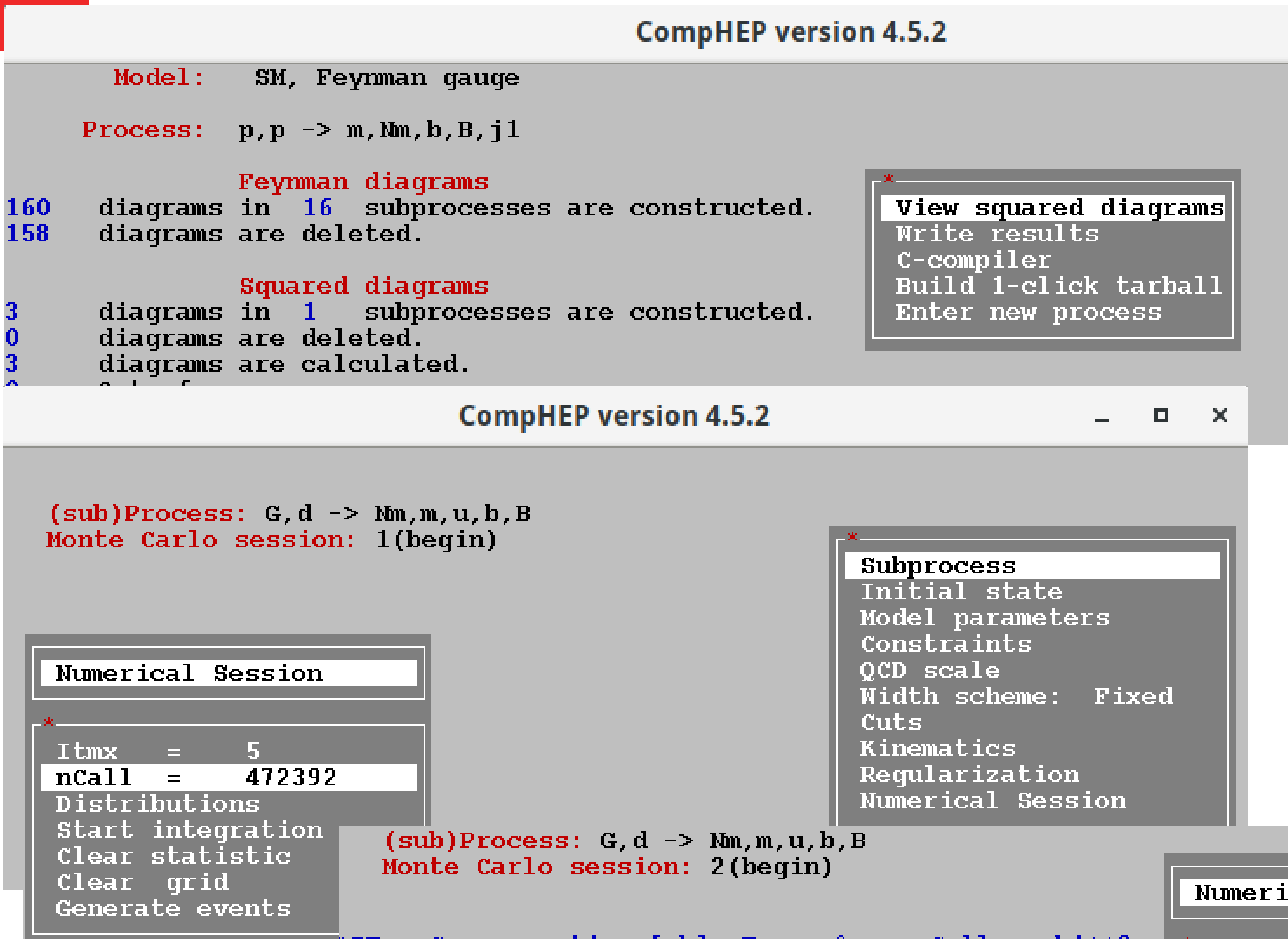
Enter scattering or decay process to calculate

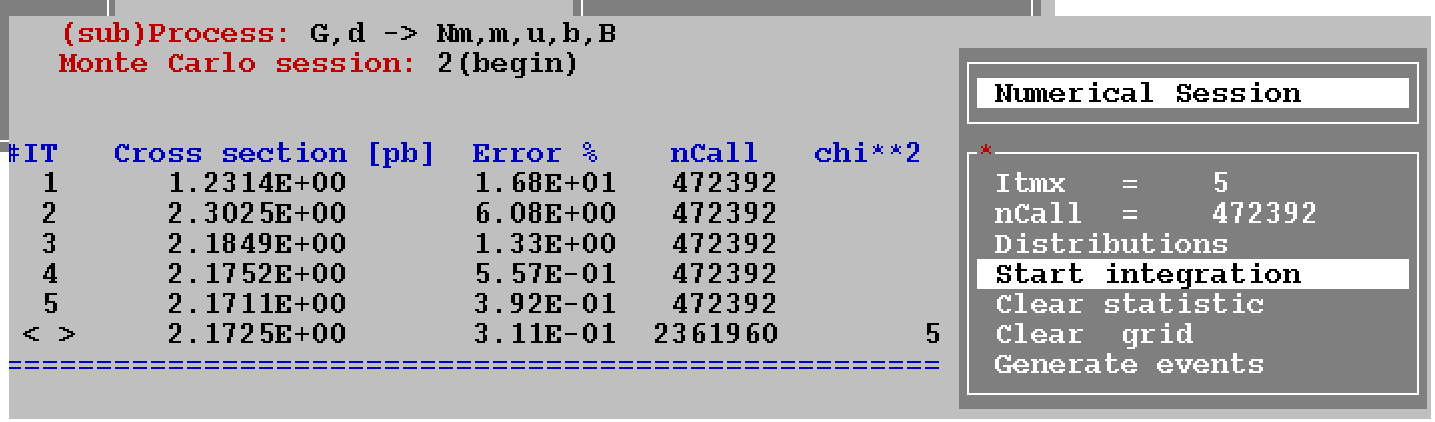






After symbolic calculations write ME in c-code, compile and go to numerical session





In numerical calculations Window check: initial states, Model parameters, Kinematics.

Set cuts (if necessary) and regularization (mapping phase space)

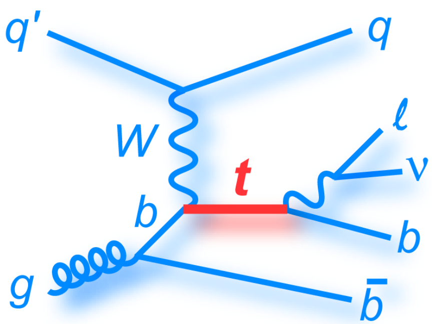
In numerical session check integration parameters, start integration and **get total LO cross section**.

At the next step **generate events in LHEF format.**

Use num_batch.pl to automate calculations for many subprocesses

JHEP 02 (2017) 028: signature, main backgrounds and event selection

Signature:



Light jet

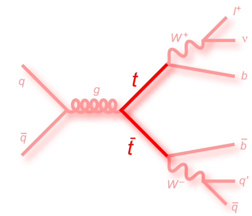
Lepton

Missing transverse energy

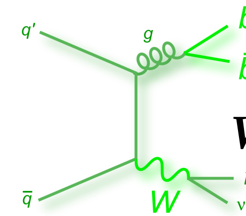
b-jet with high p_T

Additional b-jet with lower p_T

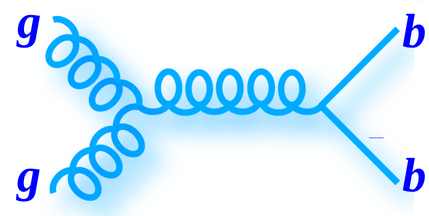
Main backgrounds:



top pairs



W+jets



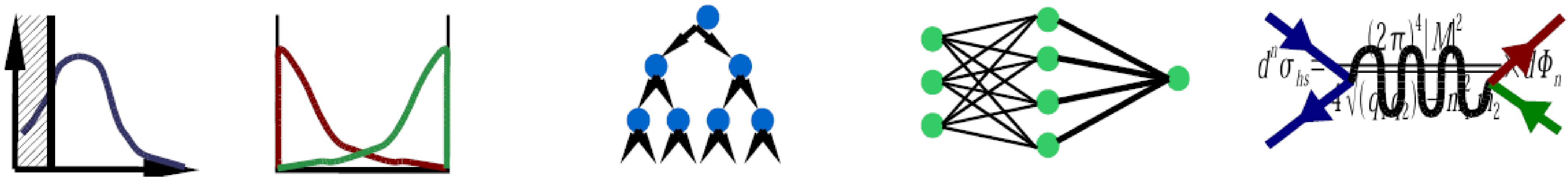
QCD

	$\sqrt{s}=7\,TeV$	$\sqrt{s}=8\,TeV$
Int. Lumi:	5.0 /fb	19.7 /fb
Triggers applied:	HLT_IsoMu17_v* HLT_IsoMu24_v* HLT_IsoMu24_eta2p1_v*	HLT_IsoMu24_eta2p1_v*

- Exactly one "tight" charged lepton:
  - muon $p_T > 20\ (27)$ GeV/c , $|\eta| < 2.1$, $relIso < 0.12$
- No additional "loose" charged leptons
- 2 or 3 jets $p_T > 30$ GeV/c, $|\eta| < 4.7$
- At least one b-tagged and at least one untagged jet according to **CSVT**

Common analysis techniques

Cut-Based Likelihoods Decision Trees Neural Networks Matrix Elements



- **Weak points of the methods**
  - Cut-based and Decision Trees methods use triangle cuts in multi-dimension space therefore it is not very efficient. Boosting algorithm helps to improve the efficiency of DT, but also can be applied with NN and other classifiers.
  - Likelihood function is usually far from some optimal function to classify the events and requires special study in each case.
  - Matrix element approach tries to use analytic form of Matrix element of signal process for the probability function. The main problem – it is mostly impossible to get analytic form for the processes of interest and backgrounds. Therefore, use events simulated by MC and other classification methods is usually more optimal.
  - NN requires different steps of optimizations and tuning to avoid known problems and prepare efficient classifier
- **Mostly all of the methods require non-trivial set of observables to analyze**

Method of "optimal observables"

- **Provides general recipe how to choose most sensitive variables to separate signal and background**
  - It is based on the analysis of Feynman diagrams (FD) contributing to signal and background processes
  - Distinguish **three classes** of sensitive variables for the signal and each of kinematically different backgrounds: **Singular** variables (denominators of FD), **Angular** variables (numerators of FD) and **Threshold** variables (Energy thresholds of the processes)
  - Set of variables can be extended with other type of information, like detector relative variables (jet width, b-tagging discriminant)

  Described in different examples for the top and Higgs searches
  - Eur.Phys.J. C11 (1999) 473-484
  - Nucl.Instrum.Meth. A502 (2003) 486-488
  - Phys.Atom.Nucl. 71 (2008) 388-393

- **Applied in different experimental analysis in D0 and CMS**
  - Phys.Lett. B517 (2001) 282-294 and other D0 publications
  - JHEP02(2017)028 (CMS-TOP-14-007)

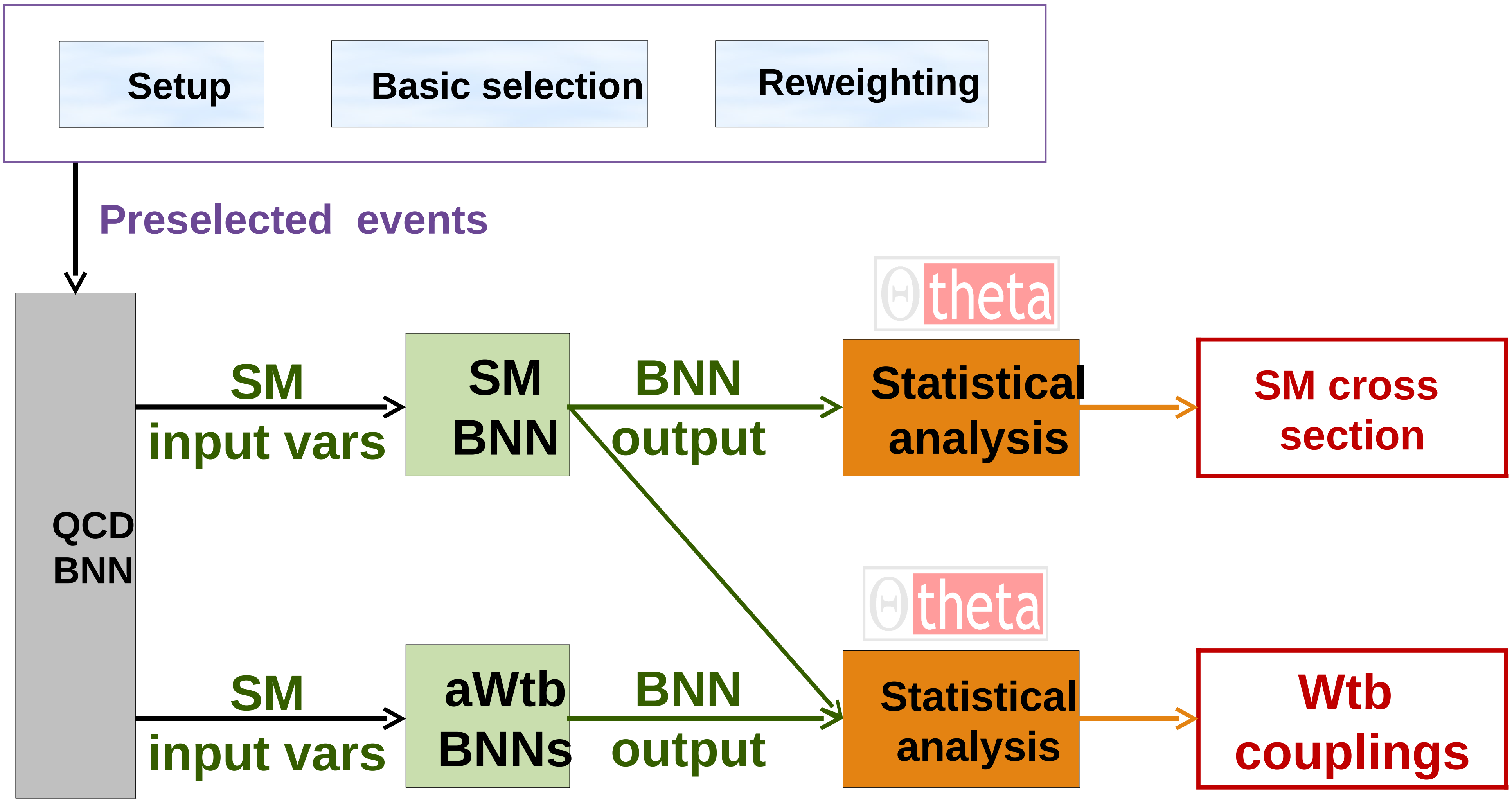
Deep Learning Neural Networks (DNN)

- Started from [Hinton, G. E., Osindero, S., & Teh, Y. W. (2006). «A fast learning algorithm for deep belief nets.» Neural computation, 18(7), 1527-1554]
- DNN is able to construct huge networks with automatic interpretation of input data, therefore it does not require accurate preprocessing of input data and can extract non trivial correlations and optimal observables from RAW variables
- Example of usage in HEP [**Nature Commun. 5 (2014) 4308**] increase sensitivity from 3.1σ to 5σ :

$$gg \to H^0 \to W^\mp H^\pm \to W^\mp W^\pm h^0$$

	Discovery significance		
Technique	Low-level	High-level	Complete
NN	2.5σ	3.1σ	3.7σ
DN	4.9σ	3.6σ	5.0σ

Scheme of the analysis



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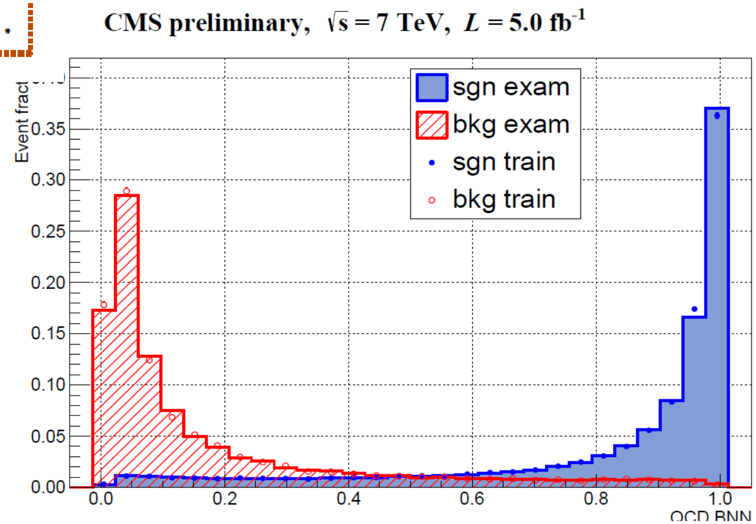
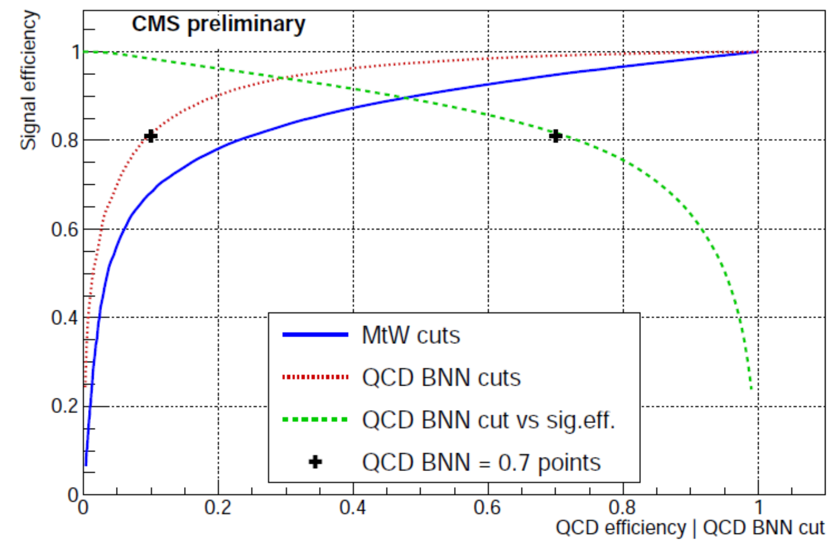
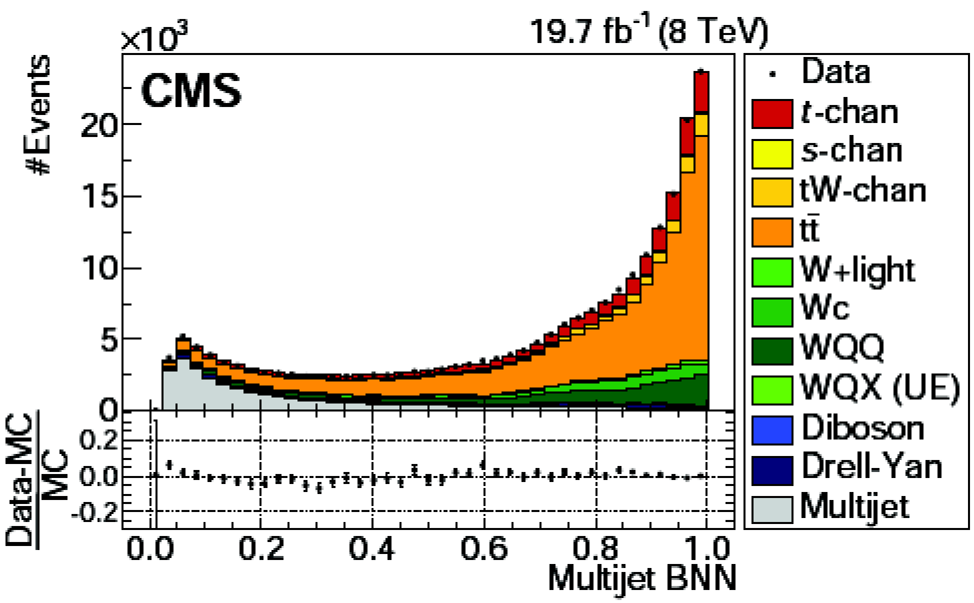
QCD multijet rejection

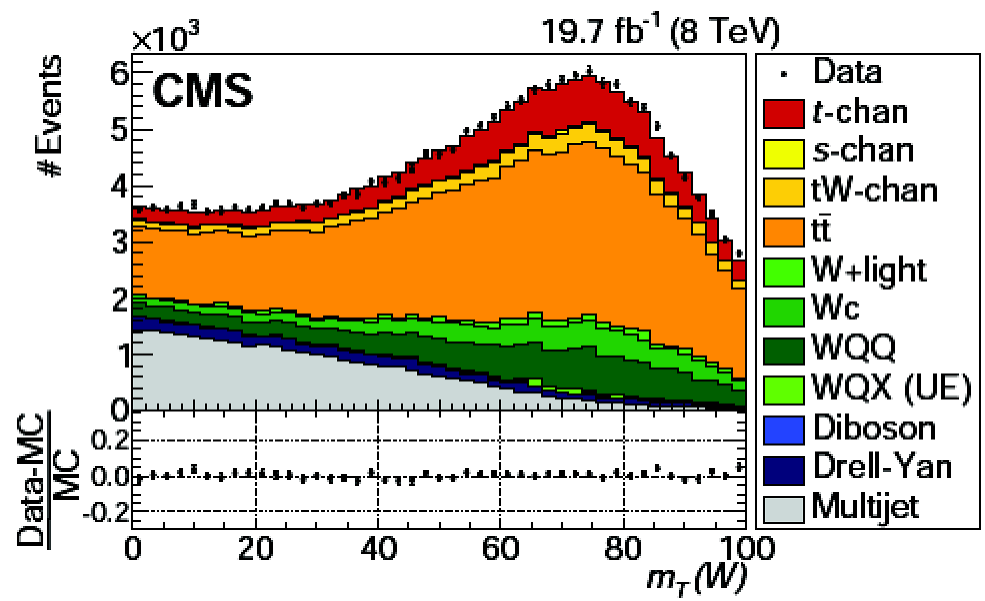
$relIso(mu) < 0.12$

$0.35 < relIso(mu) < 1.$









Event yields

	$\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
Process	Basic selection	Multijet BNN > 0.7	Basic selection	Multijet BNN > 0.7
t channel	$5\,580^{+220}_{-160}$	$4\,560^{+180}_{-130}$	$21\,900^{+980}_{-840}$	$14\,800^{+660}_{-560}$
s channel	373^{+16}_{-14}	301^{+13}_{-12}	$1\,307\pm47$	865 ± 31
tW	$2\,080\pm160$	$1\,760\pm130$	$9\,220\pm620$	$6\,620\pm450$
$t\bar{t}$	$20\,450^{+770}_{-900}$	$17\,360^{+660}_{-770}$	$101\,100^{+5100}_{-6100}$	$72\,200^{+3\,600}_{-4\,300}$
W+jets	$16\,100\pm800$	$12\,700\pm630$	$36\,100^{+1200}_{-1200}$	$23\,700\pm800$
Dibosons	380 ± 10	300 ± 8	780 ± 20	537 ± 14
Drell–Yan	$1\,520\pm80$	660 ± 40	$5\,960\pm320$	$2\,060\pm110$
Multijets	$7\,340^{+3\,700}_{-3\,400}$	740^{+380}_{-350}	$30\,200^{+6\,000}_{-6\,300}$	$2\,630^{+520}_{-550}$
Total	$53\,800^{+3\,900}_{-3\,700}$	$38\,380^{+1\,000}_{-1\,100}$	$206\,650^{+8\,100}_{-8\,900}$	$123\,400^{+3\,800}_{-4\,500}$
Data	56 145	40 681	222 242	135 071

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Systematics

Measurements are limited by statistical and systematic uncertainties. The statistical uncert. can be improved by collider upgrade. Systematic unc. comes from different sources: from theory calculations (to improve need to increase precision of calculations), from detector performance (to decrease unc. need to improve detector or reconstruction programs).

Different types of systematic uncert. are taken into account in different ways:

1. uncertainties of the normalization (all bins are normalized to the same coefficient)
2. distribution shape uncertainties (content of the distribution bins can be changed by some function)
3. uncorrelated changes in the distribution bins (need pseudoexperiments to estimate prob.)
4. sys. uncert. due to finite statistics in MC samples (Barlow-Beeston method)

Sources of systematic uncertainties:

Marginalized

- XSections
- JER
- JEC (without separation)
- Unclustered MET
- b-tagging and mistag
- PileUp
- Lepton ID, Iso
- Trigger Sfs
- Luminosity (2.2% / 2.6%)

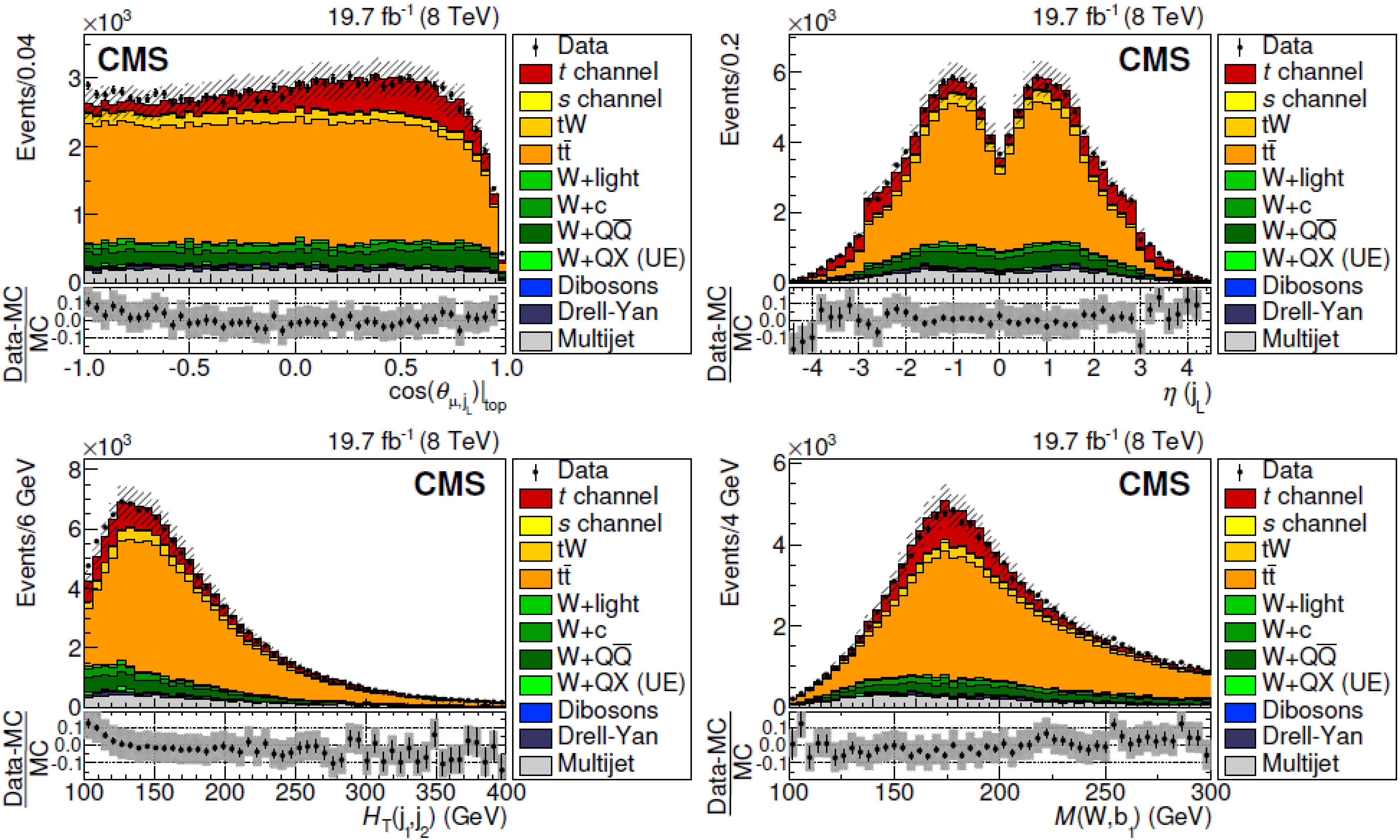
Unmarginalized

- PDF
- Q^2 uncertainty
- Matching threshold
- Comparison of different generators

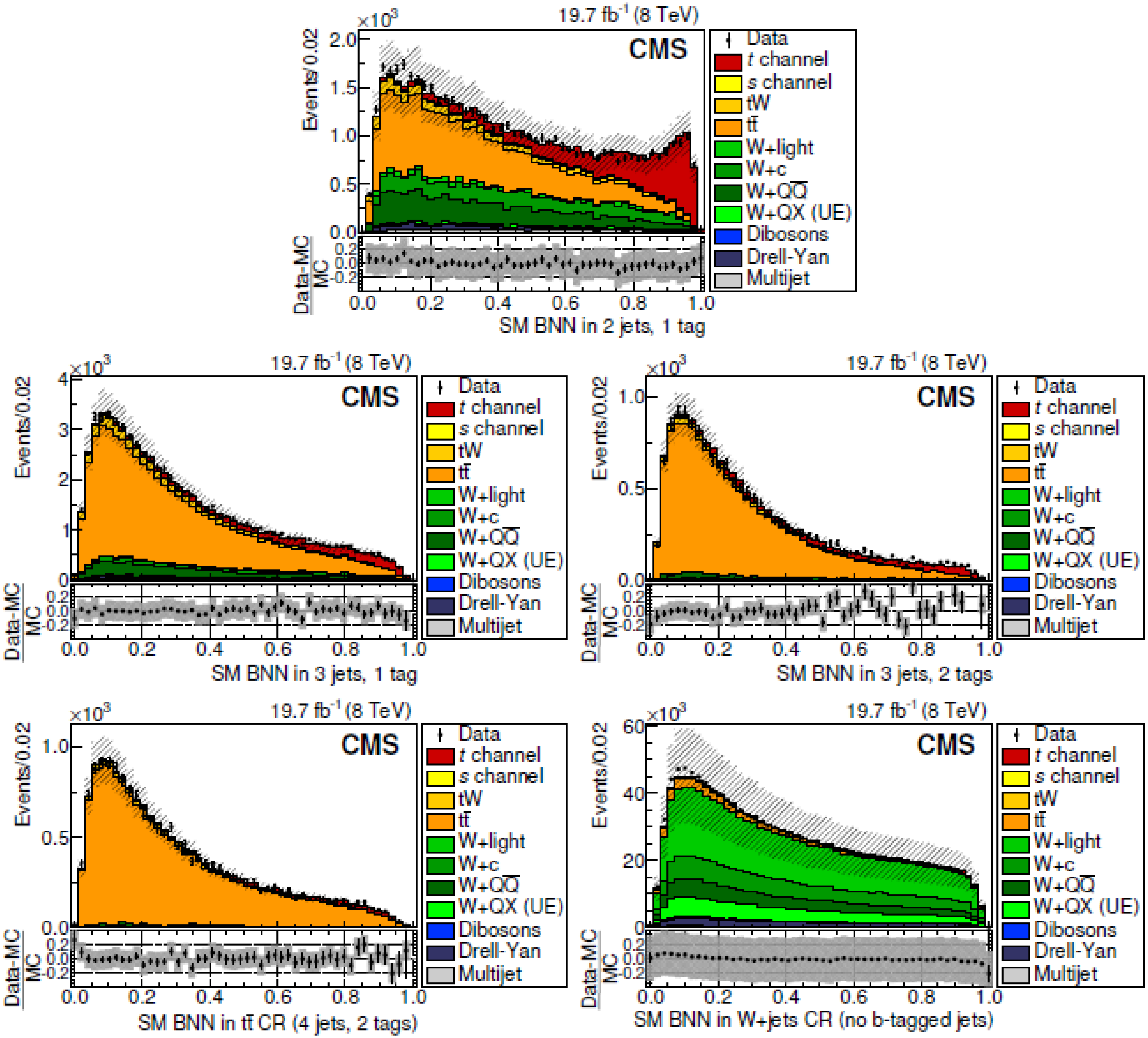
Barlow-Beeston method in THETA package

- Finite MC statistics

Distributions of some of the input variables for BNN

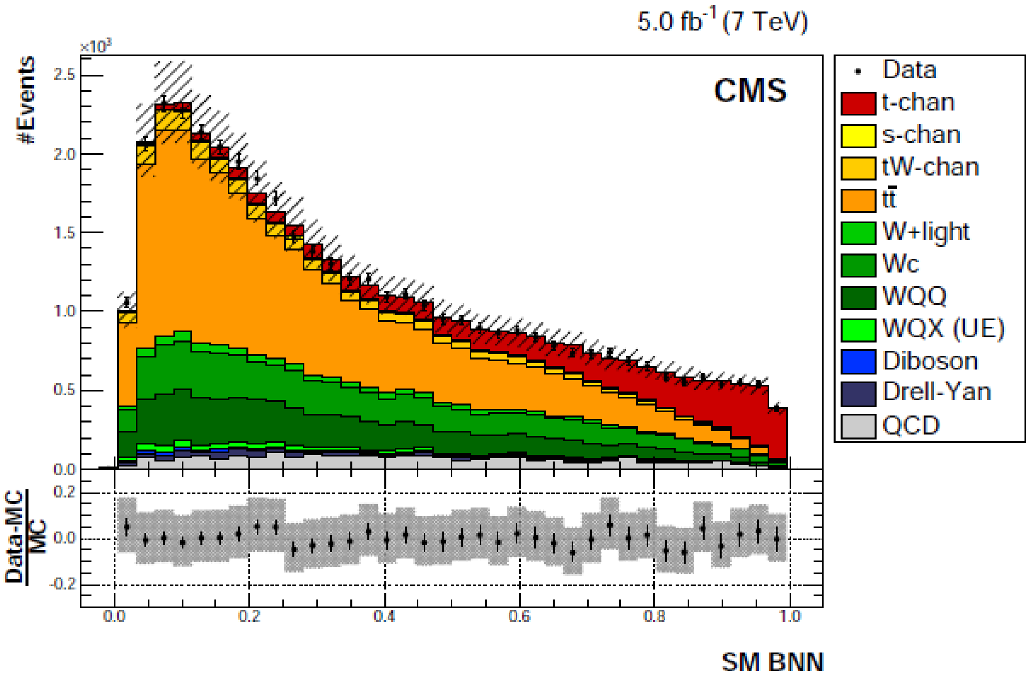


Cross checks in different phase space regions

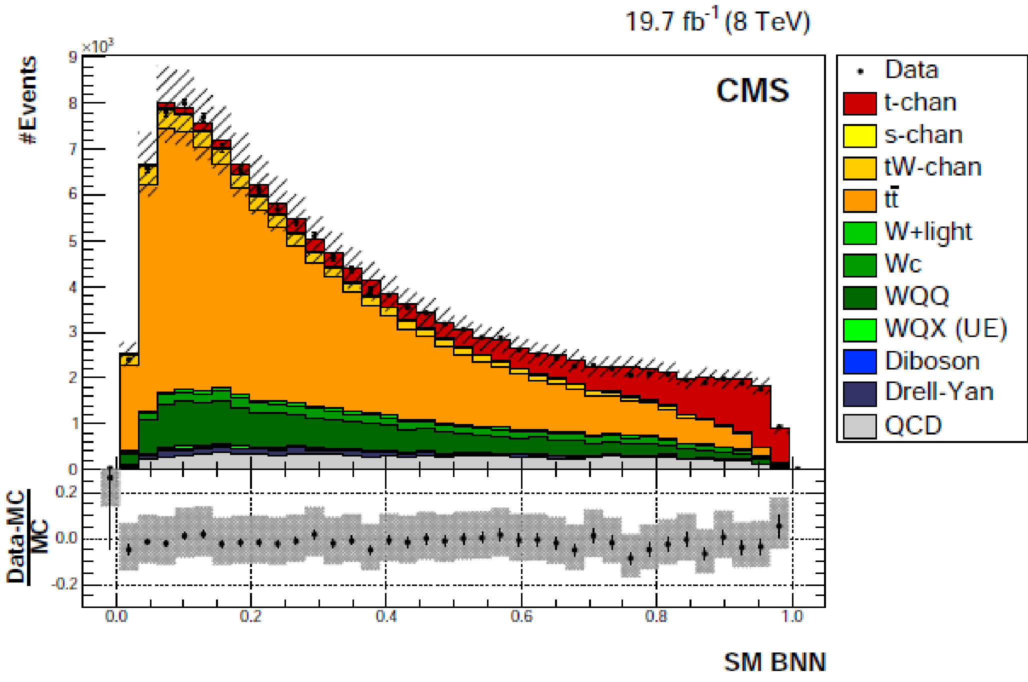


SM BNN post-fit normalization and uncert.

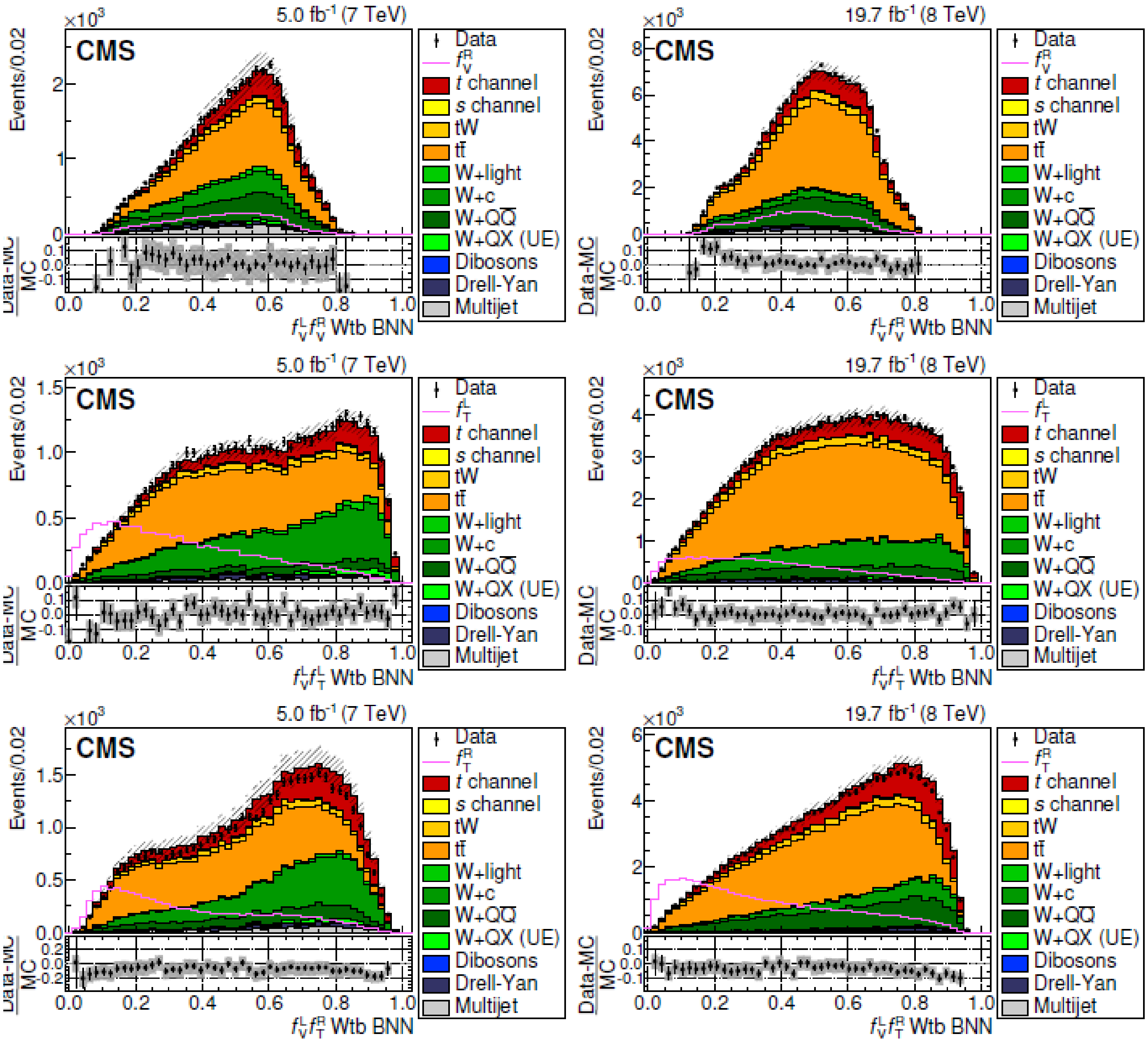
7 TeV:



8 TeV:

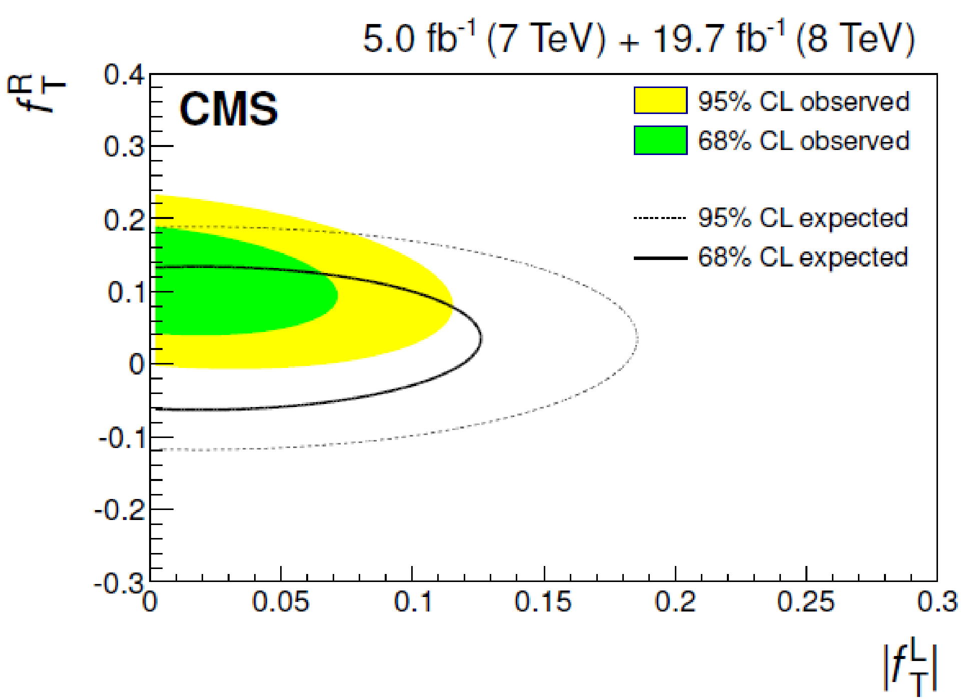


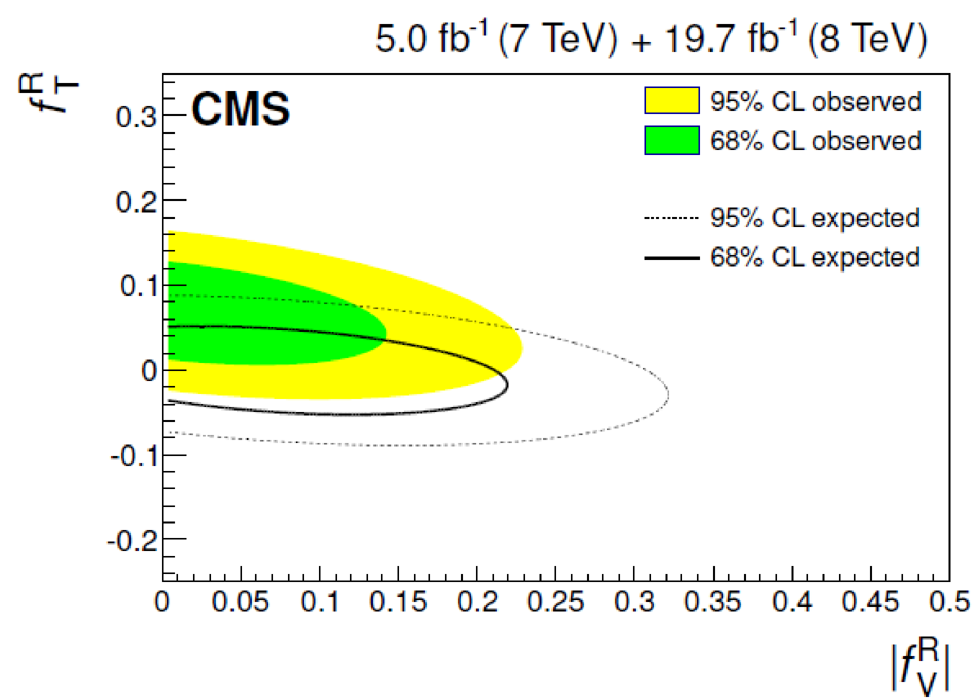
BNNs sensitive to anomalous contirbutions



1D and 2D 95% CL Limits

Scenario	$f_V^L >$	$\lvert f_V^R \rvert <$	$\lvert f_T^L \rvert <$	$< f_T^R <$	
$\sqrt{s} = 7$ and $8\,\mathrm{TeV}$					
(f_V^L, f_V^R)	0.97 (0.92)	0.28 (0.31)			
(f_V^L, f_T^L)	0.92 (0.92)		0.10 (0.14)		
(f_V^L, f_T^R)	0.94 (0.93)			−0.046 (−0.050)	0.046 (0.041)
(f_V^L, f_T^L, f_T^R)	0.98 (0.97)		0.057 (0.10)	−0.049 (−0.051)	0.048 (0.046)
(f_V^L, f_V^R, f_T^R)	0.98 (0.97)	0.16 (0.22)		−0.049 (−0.049)	0.039 (0.037)





Anomalous couplings in W helicity fractions

The anomalous couplings could be obtained from partial width for the top decay into a W boson with -1 (left), 0 or +1 (right) helicity:

Eur.Phys.J.C50:519-533,2007

$$\Gamma_0 = W_0\,\Gamma = \frac{g^2|\vec{q}|}{32\pi} A_0 \qquad \Gamma_\pm = W_\pm\,\Gamma = \frac{g^2|\vec{q}|}{32\pi}\left(B_0 \pm 2\frac{|\vec{q}|}{m_t} B_1\right)$$

Where

$$A_0 = \frac{m_t^2}{M_W^2}\left[|V_L|^2 + |V_R|^2\right](1 - x_W^2) + \left[|g_L|^2 + |g_R|^2\right](1 - x_W^2) - 4x_b\,\mathrm{Re}\left[V_L V_R^* + g_L g_R^*\right] - 2\frac{m_t}{M_W}\mathrm{Re}\left[V_L g_R^* + V_R g_L^*\right](1 - x_W^2) + 2\frac{m_t}{M_W} x_b\,\mathrm{Re}\left[V_L g_L^* + V_R g_R^*\right](1 + x_W^2)\,,$$

$$B_0 = \left[|V_L|^2 + |V_R|^2\right](1 - x_W^2) + \frac{m_t^2}{M_W^2}\left[|g_L|^2 + |g_R|^2\right](1 - x_W^2) - 4x_b\,\mathrm{Re}\left[V_L V_R^* + g_L g_R^*\right] - 2\frac{m_t}{M_W}\mathrm{Re}\left[V_L g_R^* + V_R g_L^*\right](1 - x_W^2) + 2\frac{m_t}{M_W} x_b\,\mathrm{Re}\left[V_L g_L^* + V_R g_R^*\right](1 + x_W^2)\,,$$

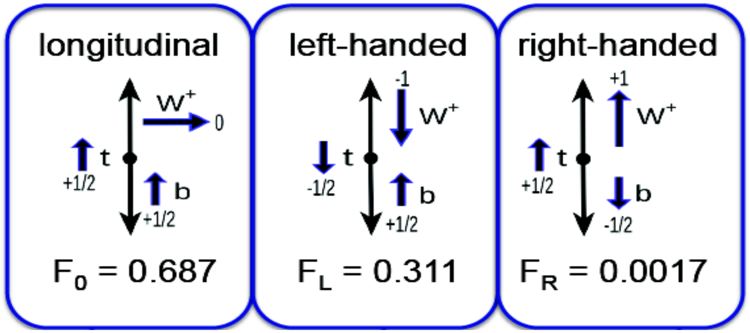
$$B_1 = -\left[|V_L|^2 - |V_R|^2\right] + \frac{m_t^2}{M_W^2}\left[|g_L|^2 - |g_R|^2\right] + 2\frac{m_t}{M_W}\mathrm{Re}\left[V_L g_R^* - V_R g_L^*\right] + 2\frac{m_t}{M_W} x_b\,\mathrm{Re}\left[V_L g_L^* - V_R g_R^*\right]\,,$$

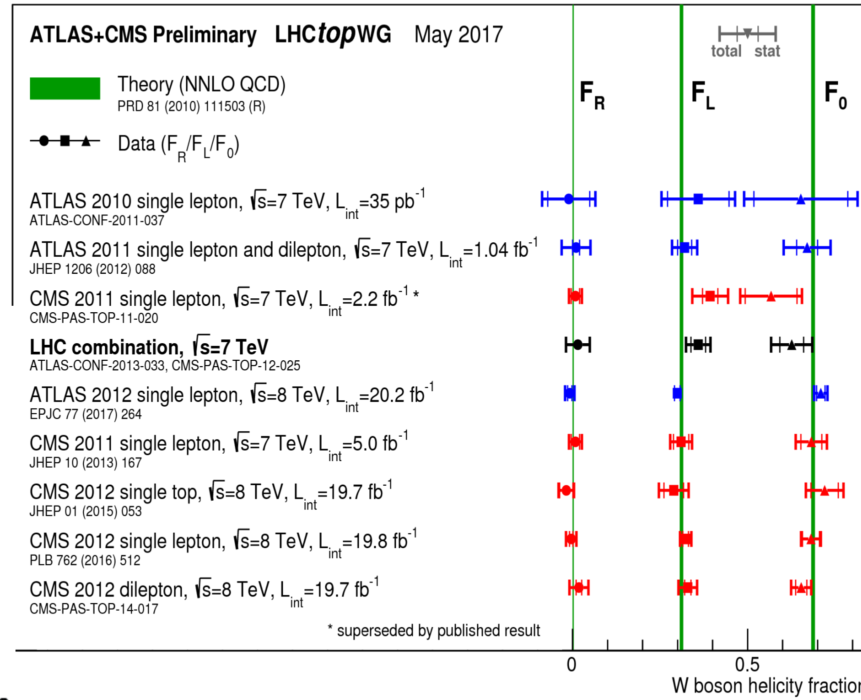
$$x_W = M_W / m_t \qquad x_b = m_b / m_t$$

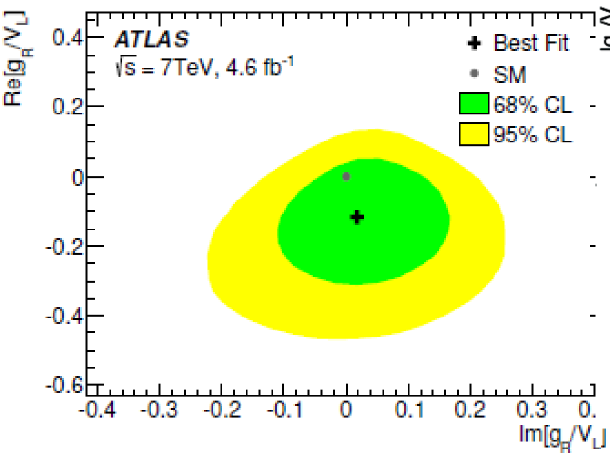
$$f_V^{L,R} = \mathrm{Re}(V_{L,R}) \qquad f_T^{L,R} = \mathrm{Re}(g_{L,R})$$

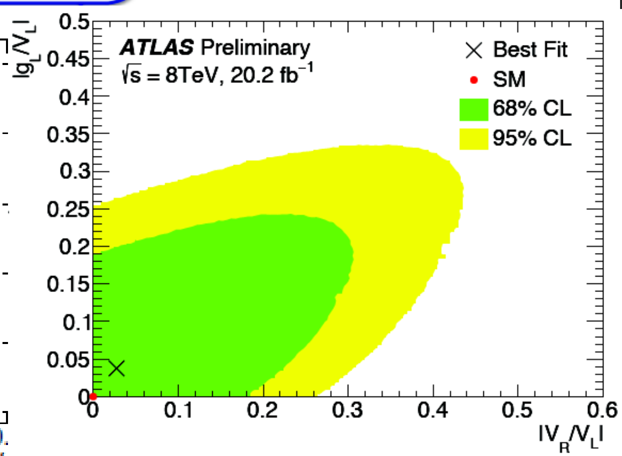
If CP is conserved, the couplings could be taken as real

W helicity, top polarisation and Wtb

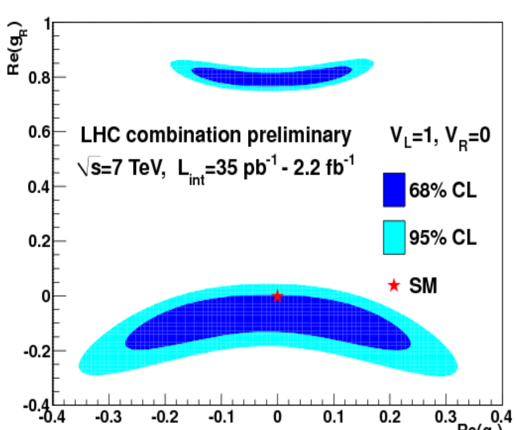


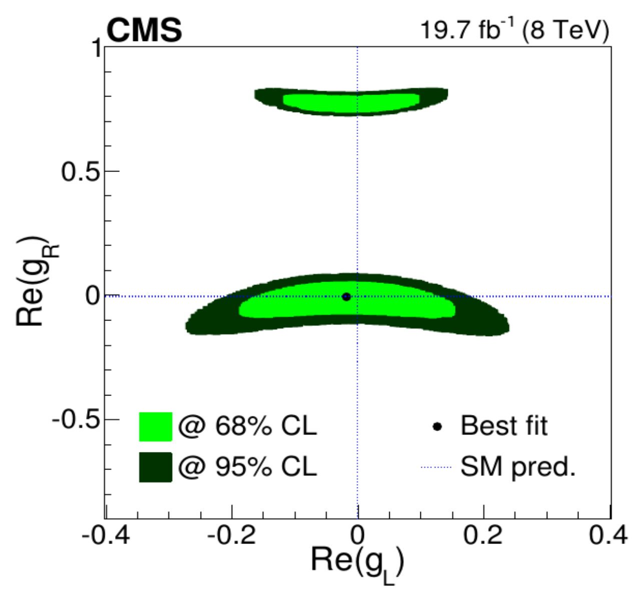


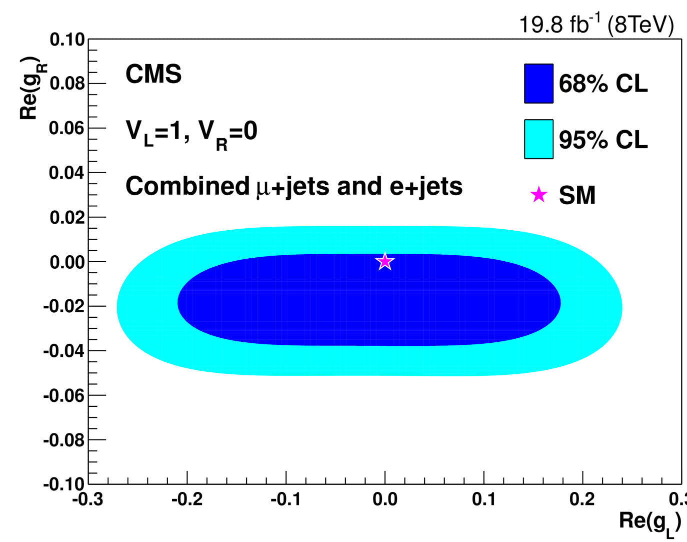




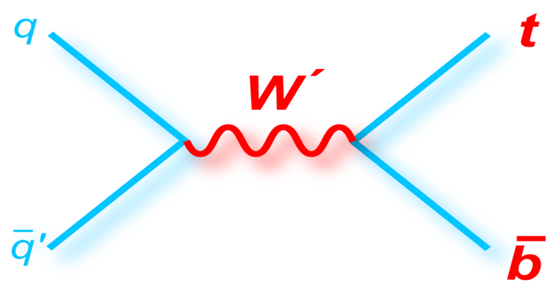
$$\mathrm{Im}\, g_R \in [-0.18,\, 0.06]$$







W' searhes



Heavy gauge boson

W'

models of
Universal Extra Dimensions
*Datta et al, Phys. Lett B **483**, 203 (2000)*

top-flavor models
*Malkawi et al, Phys Lett. B **385**, 304 (1996)*

Left-Right symmetric models
Pati, Salam, Phys Rev D 10, 275 (1974)
*Mohapatra, Pati, Phys Rev. D **11**, 566 (1975)*

Technicolor models
*Chivukula et al, Phys Rev D **53**, 5258 (1996)*

composite models , Little Higgs models
Grand Unification Theory

Search for W' decaying to top quark : W' theory

Effective lagrangian of W' interaction to fermions in model-independent form:

$$L = \frac{V_{q_i q_j}}{2\sqrt{2}} g_W \bar{q}_i \gamma_\mu [a^R_{q_i q_j}(1+\gamma_5) + a^L_{q_i q_j}(1-\gamma_5)] W' q_j + H.C.$$

$a^R_{q_i q_j}, a^L_{q_i q_j}$ - *left and right couplings of W' to fermions*

$g_W = \frac{e}{\sin(\theta)}$ - *Standard Model weak coupling constant*

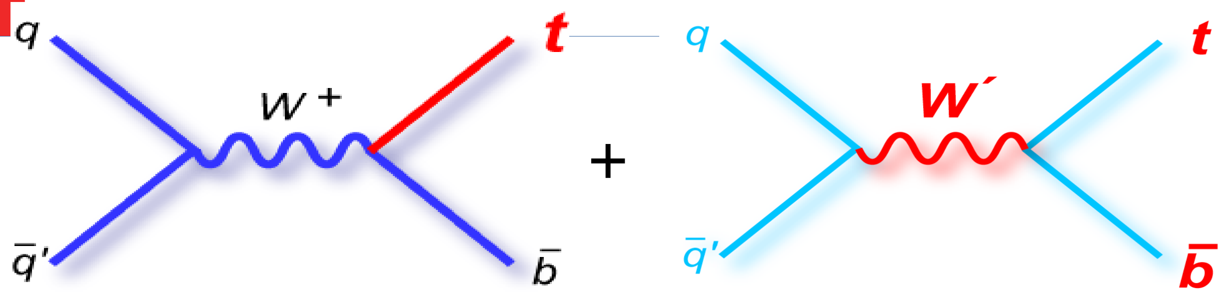
$V_{q_i q_j}$ - *Standard Model CKM matrix element*

- Different scenarios of W' interaction to fermions:

Left-Handed W' (SM-like couplings)	Right-Handed W'	Mixed case
$a^L_{q_i q_j} = 1, a^R_{q_i q_j} = 0$	$a^L_{q_i q_j} = 0, a^R_{q_i q_j} = 1$	$a^L_{q_i q_j} = 1, a^R_{q_i q_j} = 1$

$$M_{W'} > M_{\nu_R} \; ; \; M_{W'} < M_{\nu_R}$$

W' search: W — W' interference

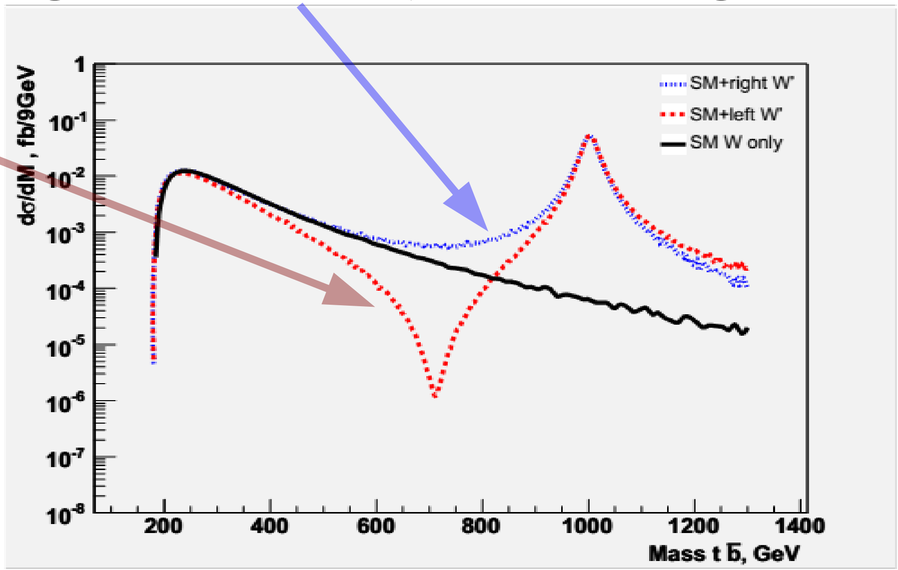


- considered three scenarios of W' interaction to fermions:

    1) SM + purely left-handed W' , 2)purely right-handed W' 3) mixed left-right W’

- Interference of W and W'

  is destructive

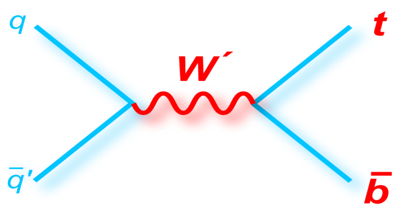


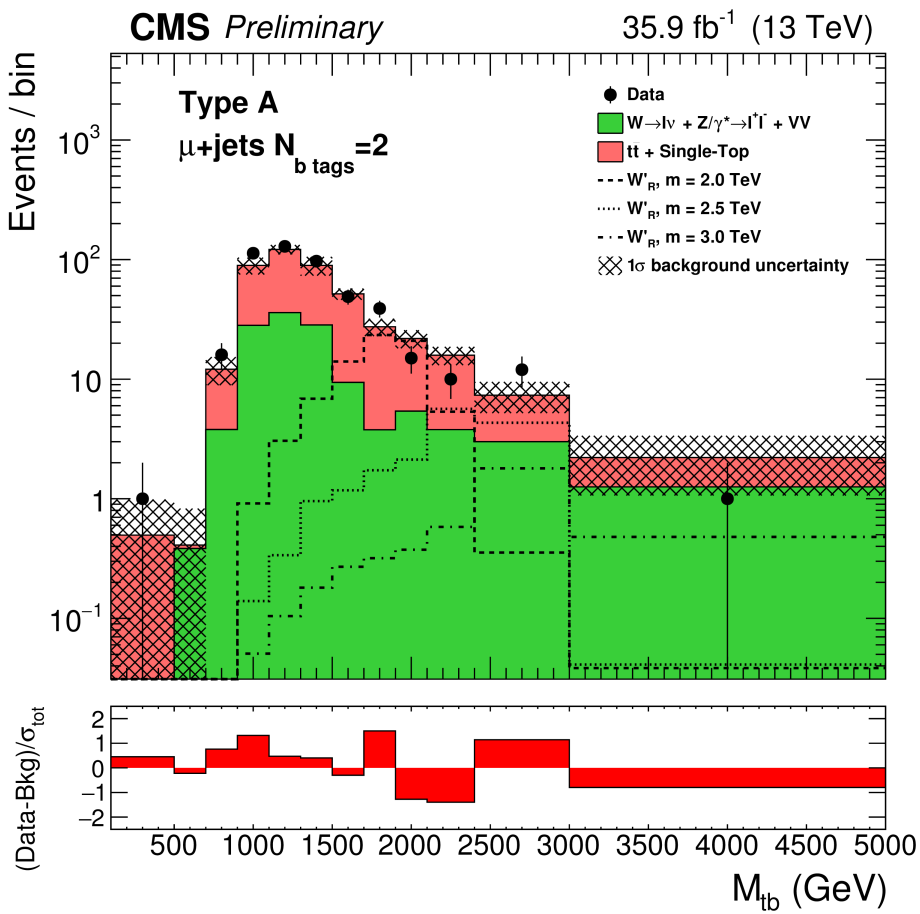
- squared matrix element of the process:

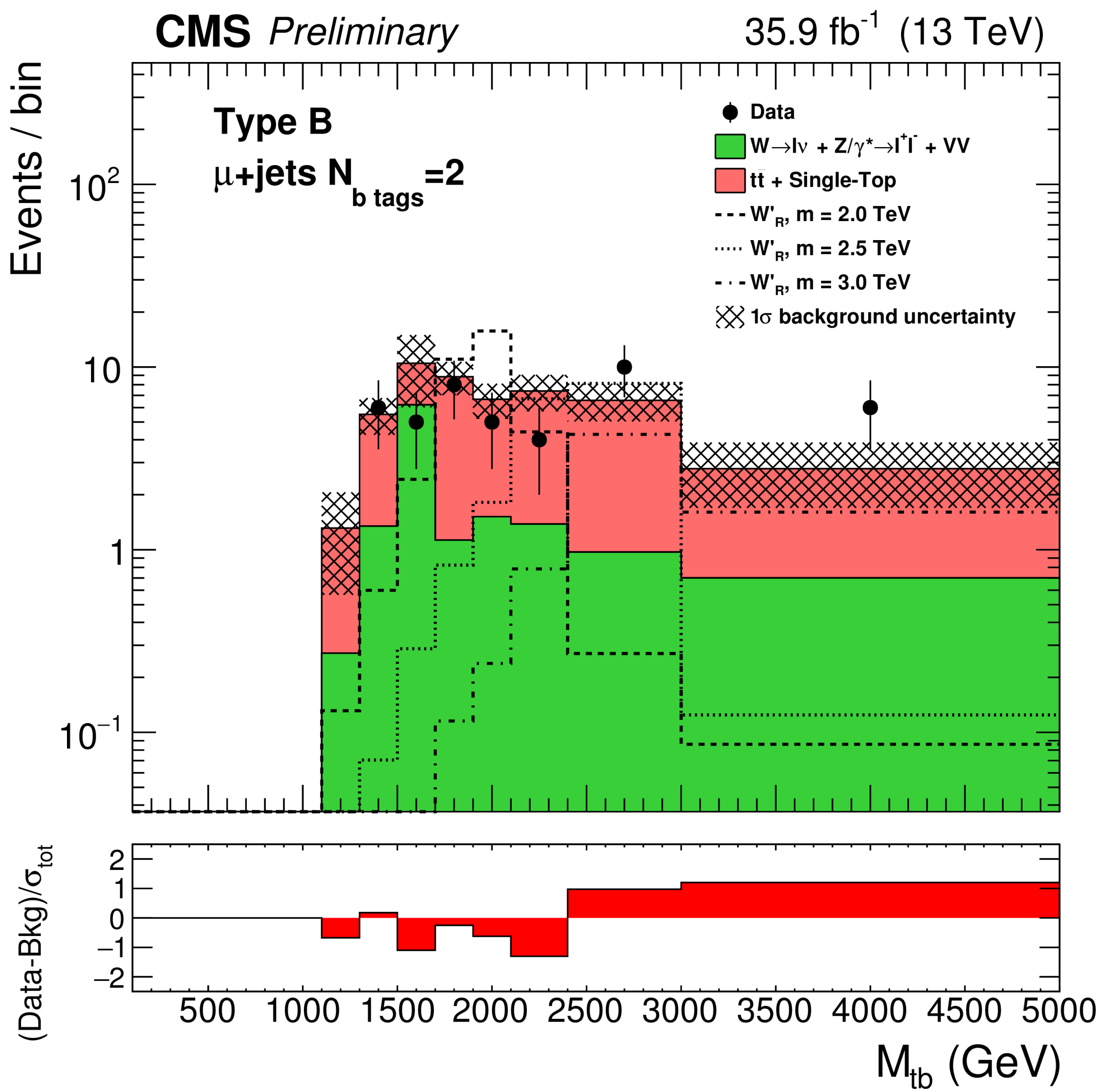
$$|M|^2 = \text{SM} + 2 \cdot a^L_{ud} \cdot a^L_{tb} \text{ Interference of W and W'} + \text{W' part}$$

Phys.Lett.B655:245-250,2007

Search for W’->tb

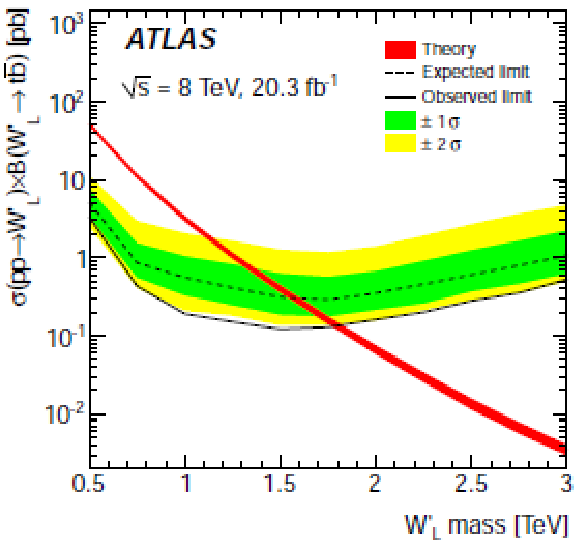


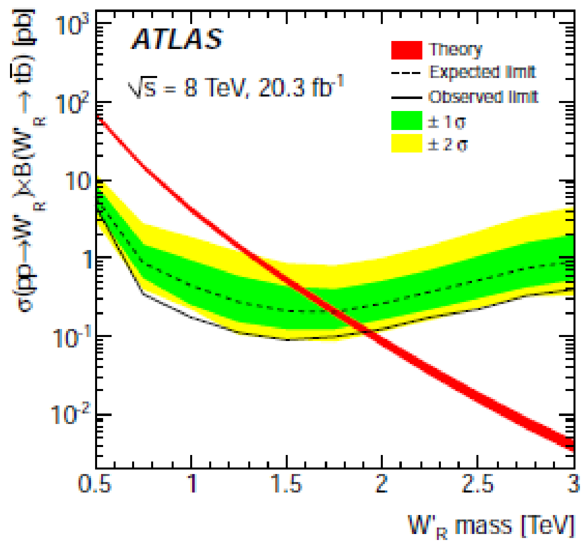


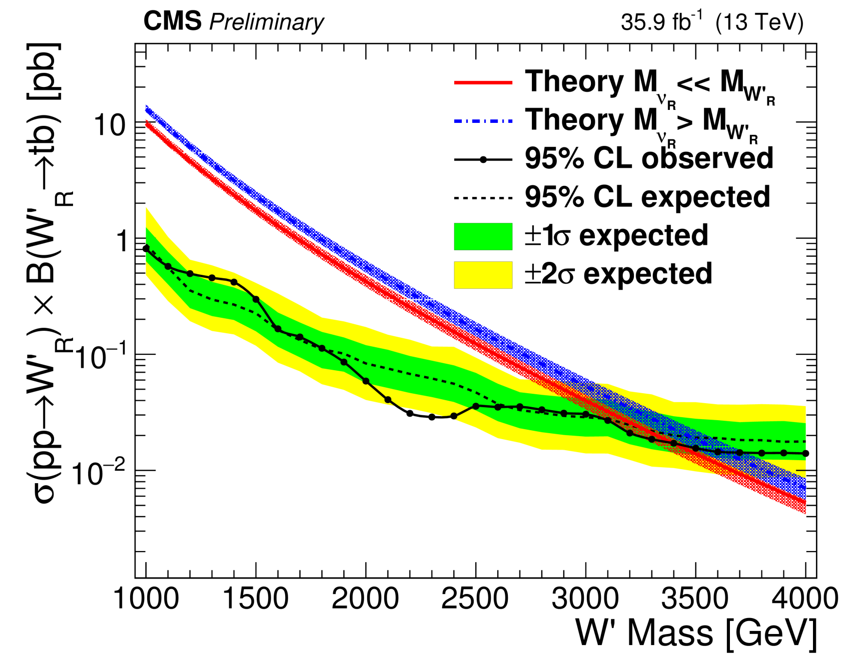


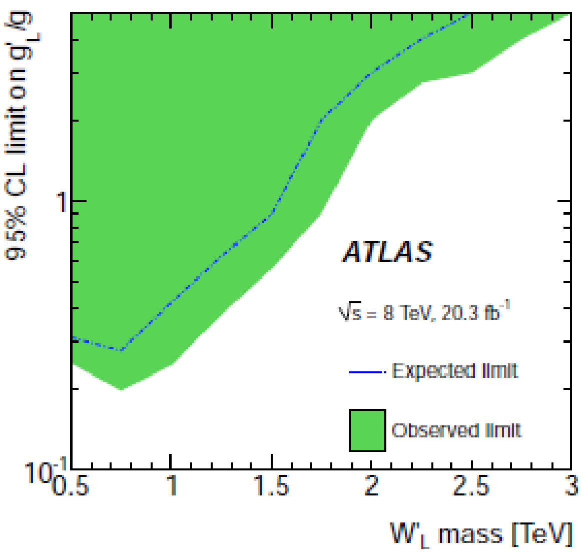
p_T^{top} >650 GeV and $p_T^{j_1+j_2}$ >700 GeV

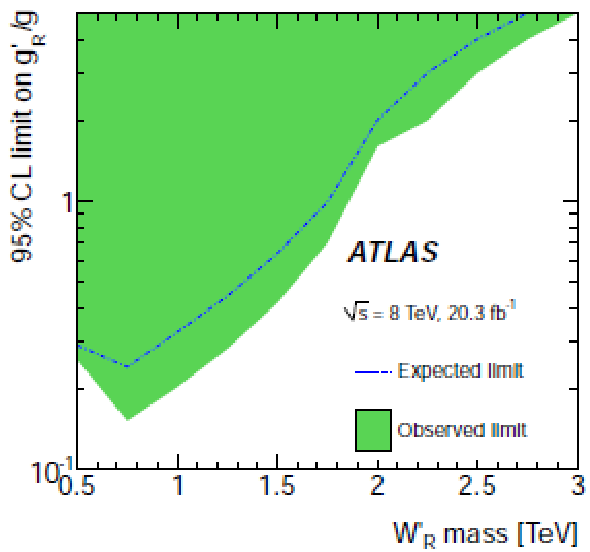
Search for W' in single top

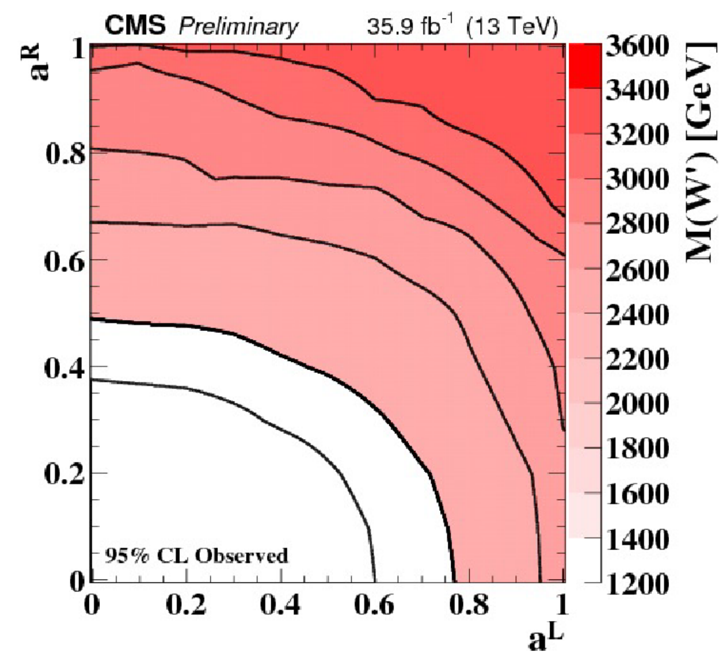






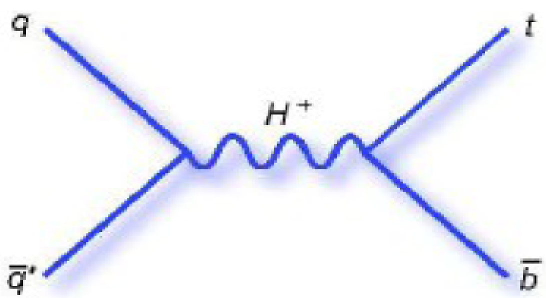


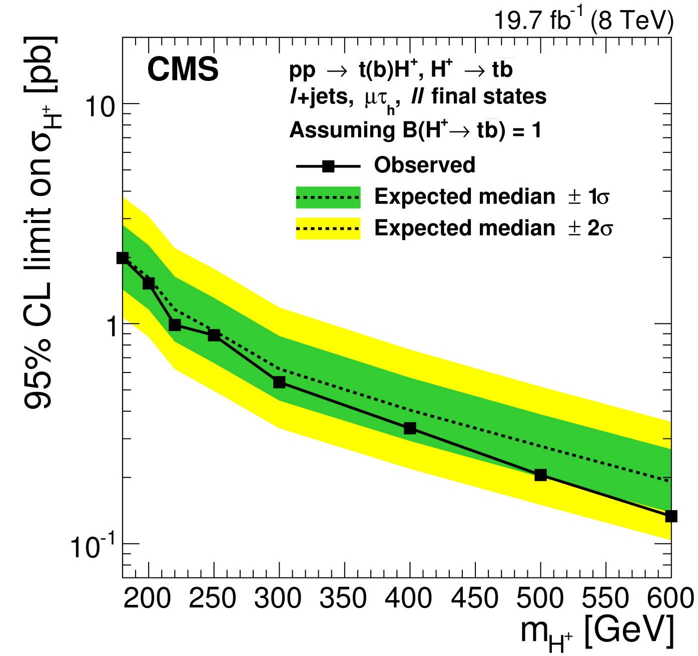


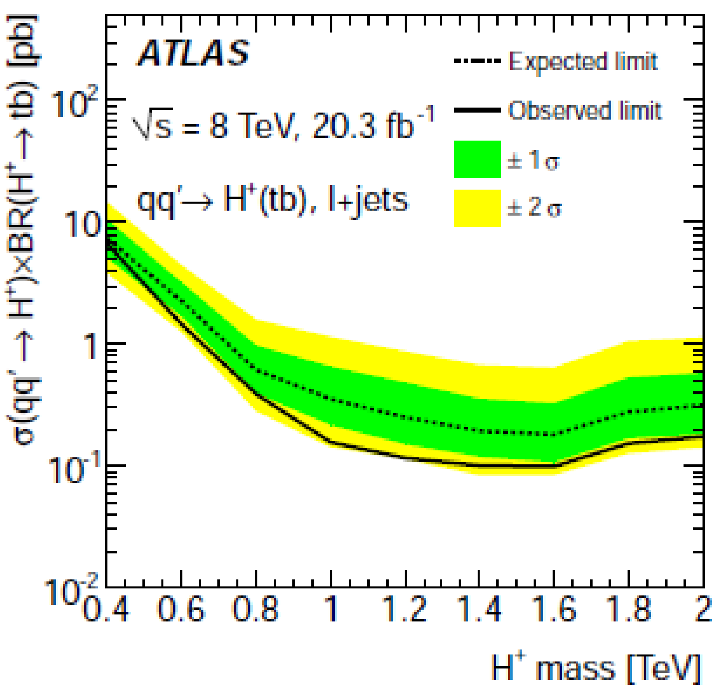


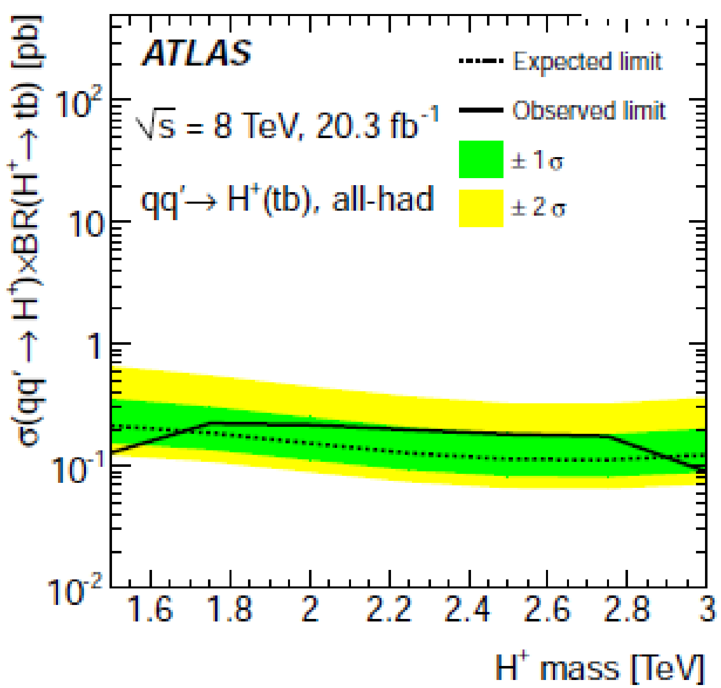
Search for charged scalar (H+)

$$\mathcal{L} = \frac{g_w V_{q_i q_j}}{2\sqrt{2}} H^+ \overline{q}_i \left(a^L_{q_i q_j} (1 - \gamma^5) + a^R_{q_i q_j} (1 + \gamma^5) \right) q_j$$



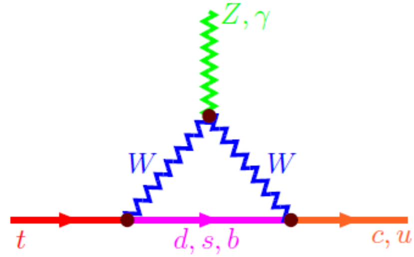






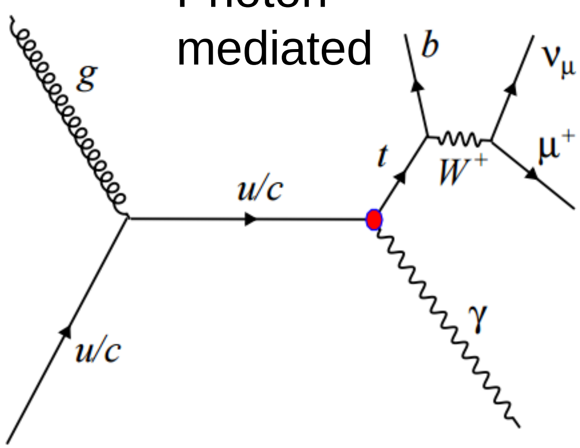
Flavor changing neutral currents (FCNC) in the production of top quark

Flavor Changing Neutral Currents (FCNC) $t \to qg, \quad t \to q\gamma, \quad t \to qZ$

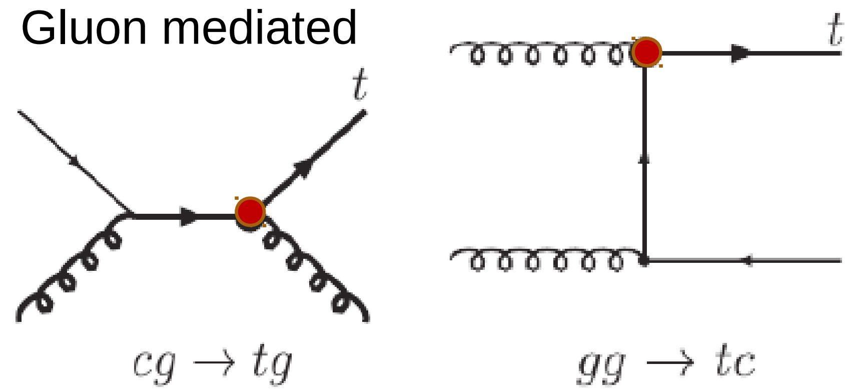


	SM	two-Higgs	SUSY
$B(t \to cg)$	$5 \cdot 10^{-11}$	10^{-6}	10^{-3}
$B(t \to c\gamma)$	$5 \cdot 10^{-13}$	10^{-6}	10^{-5}
$B(t \to cZ)$	$\sim 10^{-13}$	10^{-9}	10^{-4}

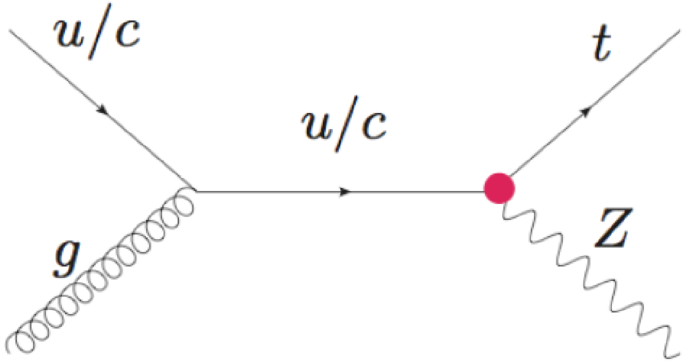
Photon mediated



Gluon mediated



Z mediated

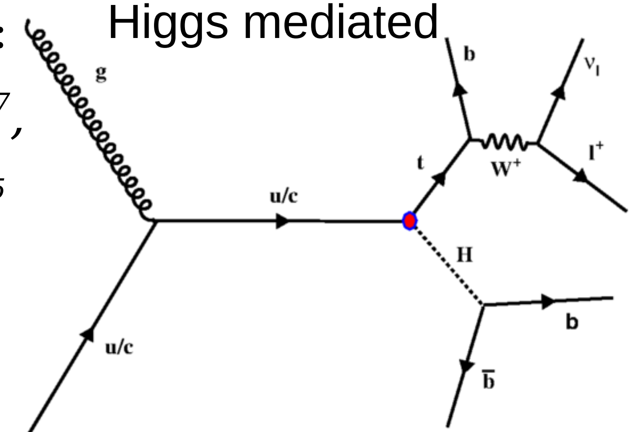


SM predictions:

$Br(t \to Hu) \sim 10^{-17}$,

$Br(t \to Hc) \sim 10^{-15}$

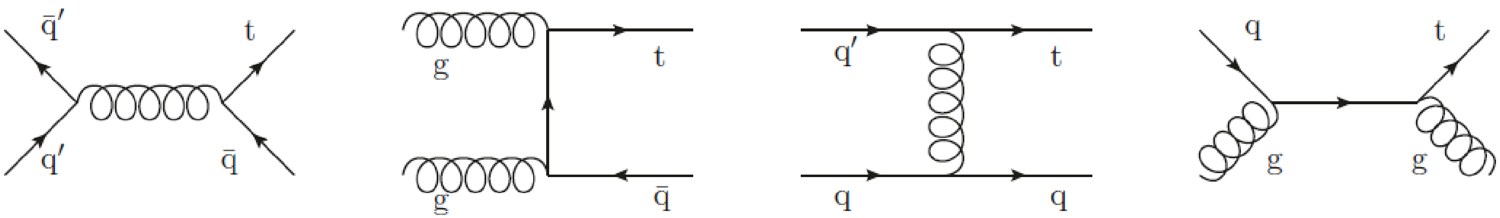
Higgs mediated



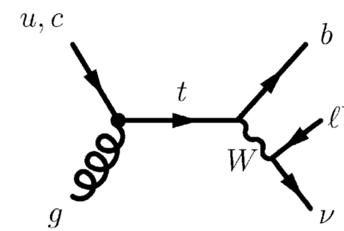
Gluon mediated FCNC top quark production

$$g_s \frac{\kappa_{tug}}{\Lambda} \, \bar{u} \, \sigma^{\mu\nu} \frac{\lambda^a}{2} t \, G^a_{\mu\nu} + g_s \frac{\kappa_{tcg}}{\Lambda} \, \bar{c} \, \sigma^{\mu\nu} \frac{\lambda^a}{2} t \, G^a_{\mu\nu} + \, h.c.$$

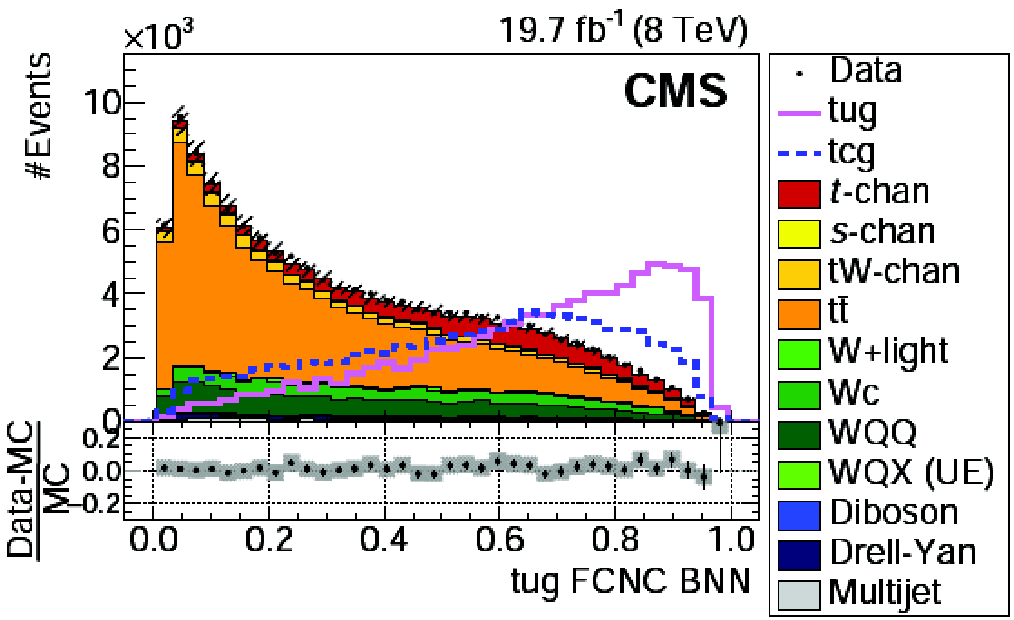
Representative diagrams of pp->tq->Wbj channel

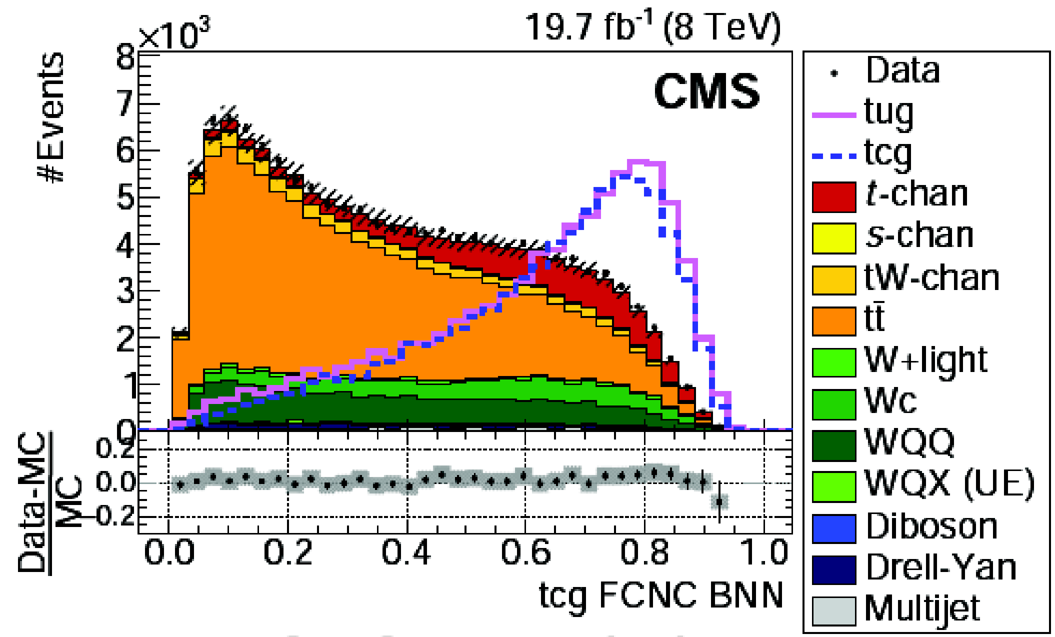


pp->t->Wb approach

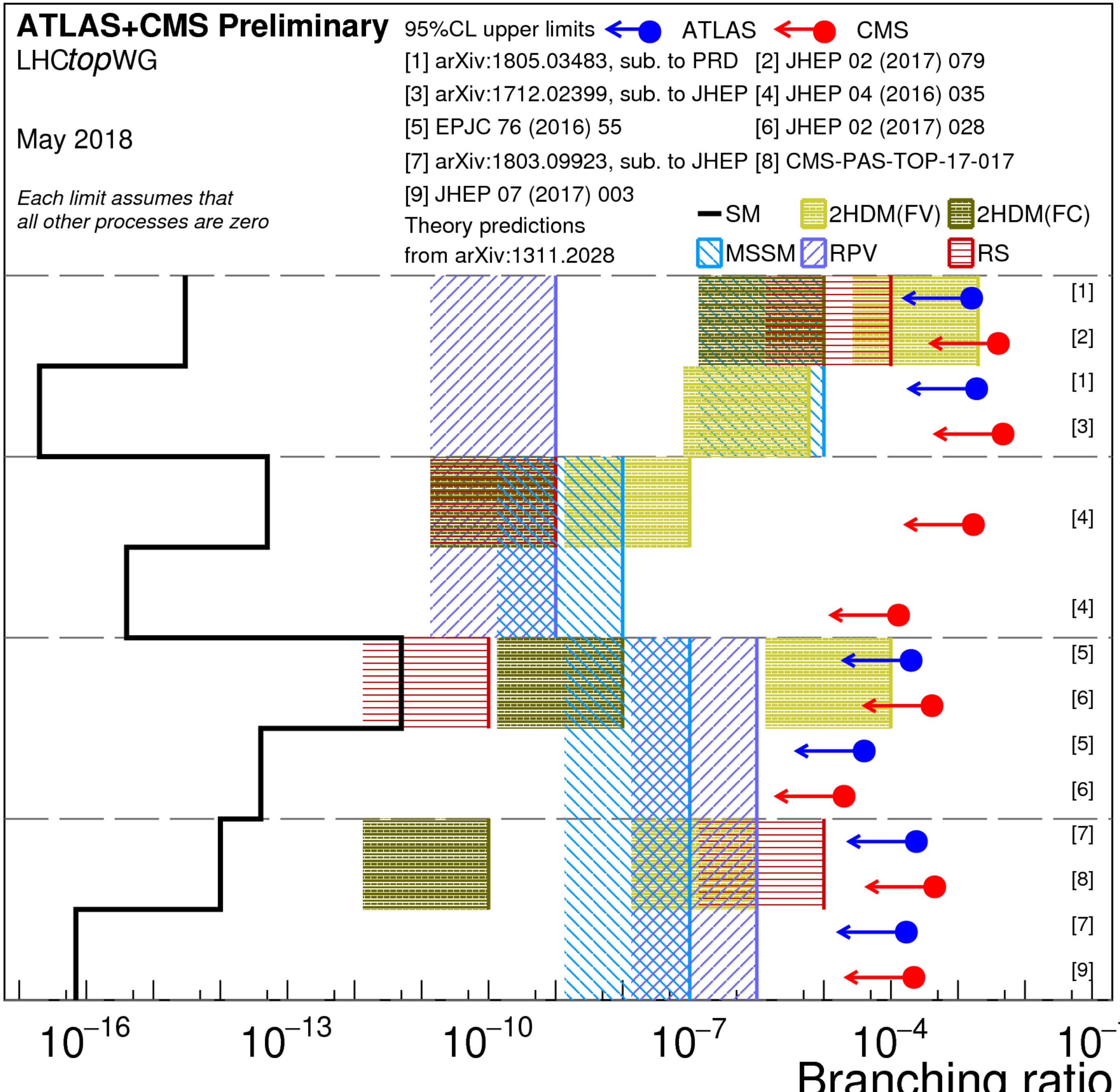


JHEP 02 (2017) 028





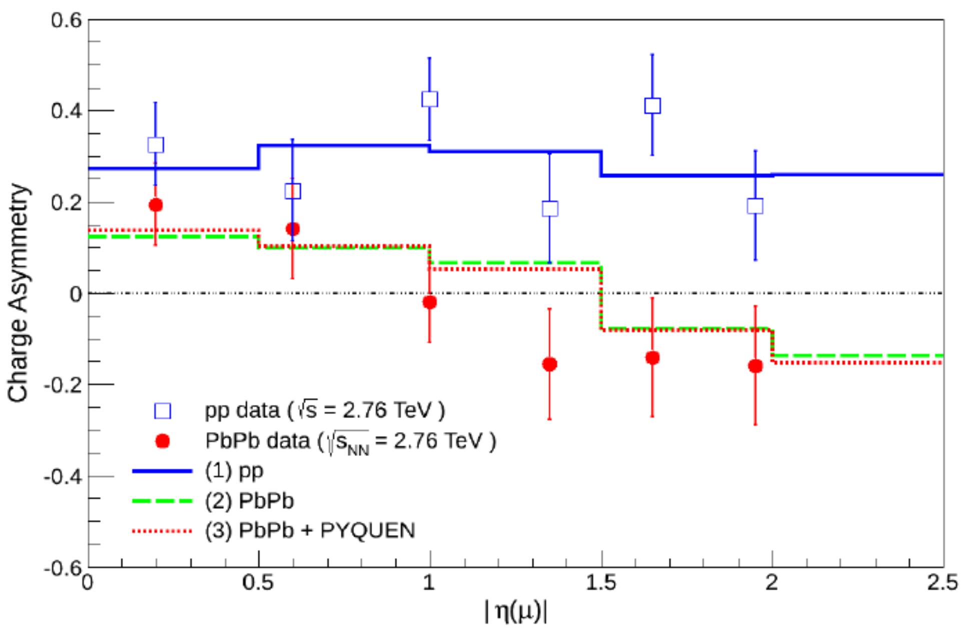
Limits on FCNC top quark decays



Single Top in Heavy Ion Collisions

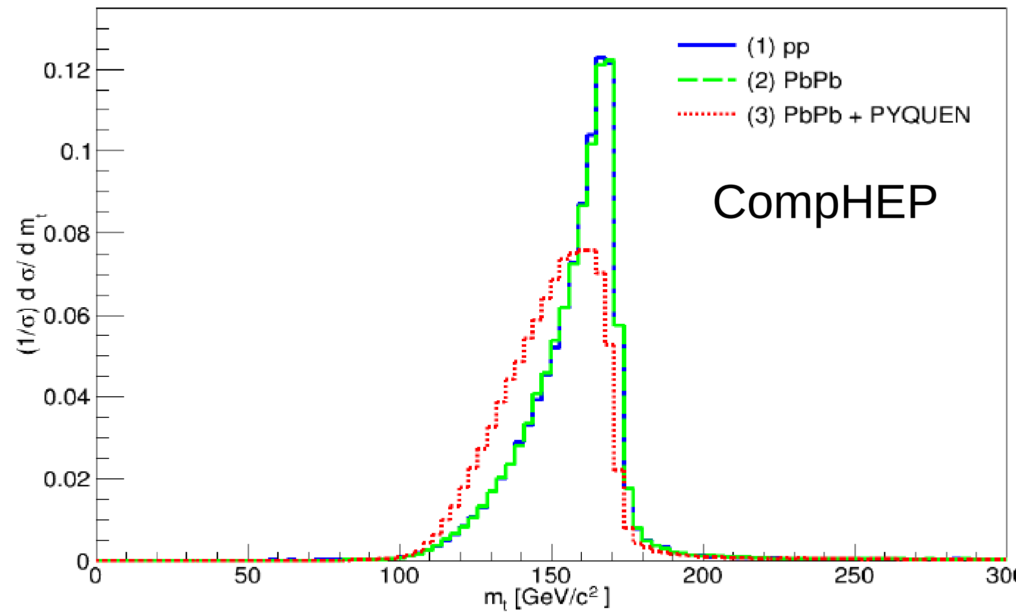
	EPS09	PYQUEN
(1) pp	-	-
(2) PbPb	+	-
(3) PbPb + PYQUEN	+	+

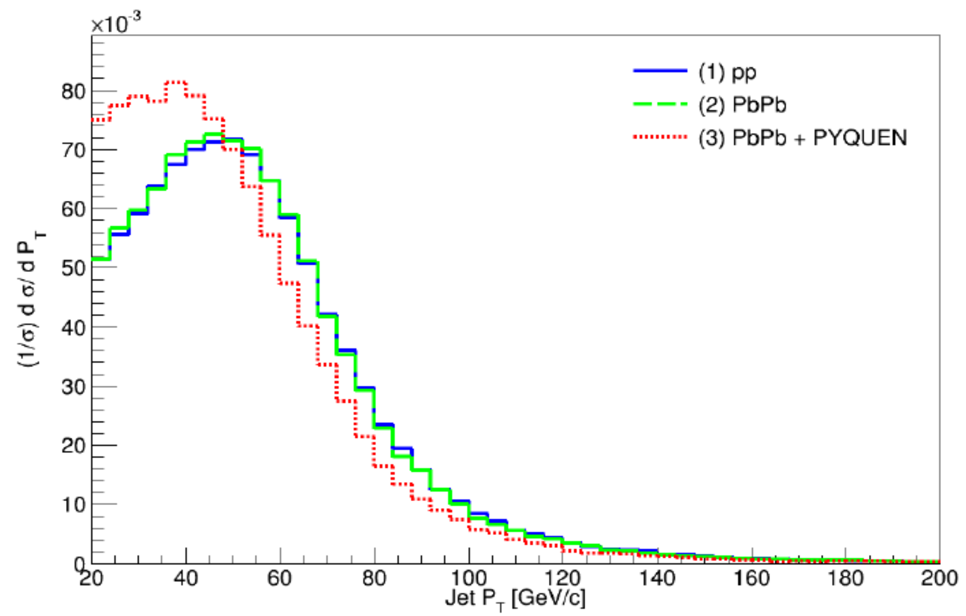
Test of MC simulation (W+/W- production)



Phys.Rev. C92 (2015) no.4, 044901

Single top simulation:



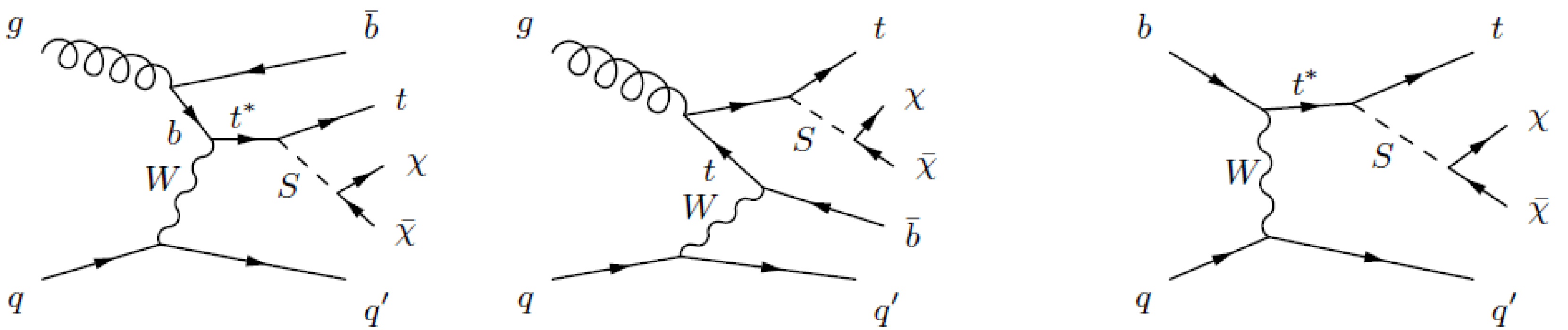


Search for Dark Matter production in association with top quark

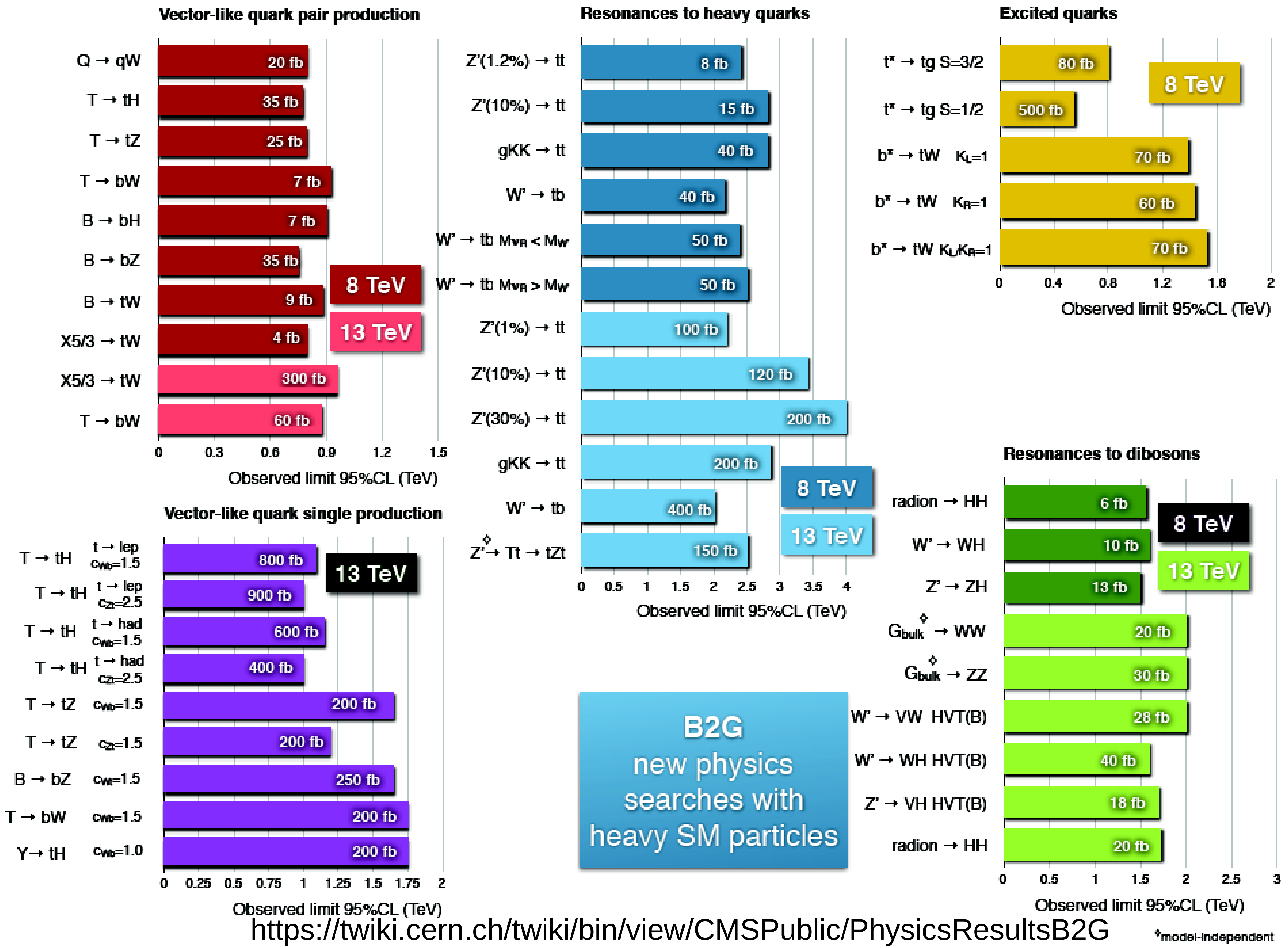
Phys.Rev. D98 (2018) no.1, 015012

$$\mathcal{L}_S \supset g_S^{\chi}\,(\bar{\chi}\chi)\,S + g_S^t \frac{m_t}{v}\,(\bar{t}t)\,S,$$

$$\mathcal{L}_P \supset i g_P^{\chi}\,(\bar{\chi}\gamma_5\chi)\,P + i g_P^t \frac{m_t}{v}\,(\bar{t}\gamma_5 t)\,P$$



Standard Model	σ_{tot} [pb]	dark matter signal	σ_{tot} [fb]
$pp \to t\bar{t}$	832 [27]	$pp \to t\bar{t}\,\chi\bar{\chi}$	30
$pp \to tj$ (t-channel)	217 [28]	$pp \to tj\,\chi\bar{\chi}$	26
$pp \to tW$	72 [29]	$pp \to tW\,\chi\bar{\chi}$	9
$pp \to tj_b$ (s-channel)	10 [28]	$pp \to tj_b\,\chi\bar{\chi}$	0.01



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Summary

- There are no experimental observation of deviation from SM in top quark sector
- Main search directions:

  - all possible modifications of top quark interactions

  - additional charged vector or scalar bosons

  - additional top quark interactions:

    tgu(c), tZu(c), tγu(c)
- With a new LHC data it will be possible to test in details tHq interactions