Triple top quark production in SM

~ SM processes

~ EW, QCD, Interference contributions

~ Uncertainties and Expectations

E. Boos, L. Dudko

SINP MSU, Moscow

Why triple top in SM

- The experimental sensitivity is close to observation of four top quark production (9 fb, 14 TeV) and it will be possible to check triple top quark production soon (1.9 fb, 14 TeV)

- Sensitivity for BSM physics (4 fermions EFT, additional resonances, …)

- Before we move to BSM need to understand SM contribution precisely

- The total cross sections has been calculated before [1001.0221], the main aim is to investigate the SM processes in details.

- The SM processes: tttW, tttq, tttb

- The details of this talk can be found in [2107.07629]

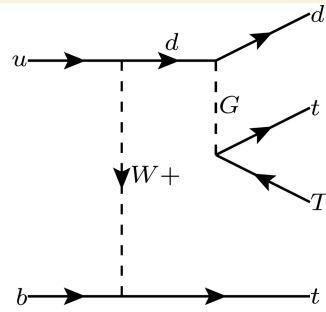# Gauge invariant subsets of Feynman diagrams
e.g. ub→d,t,t,t̄

Gluon mediated gauge invariant subset
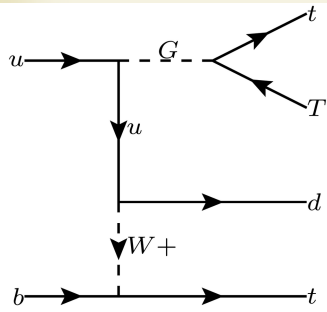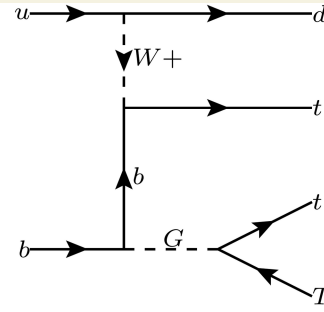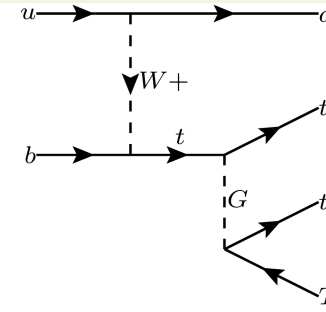
Electroweak boson mediated gauge invariant subset
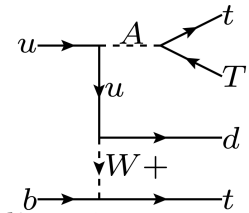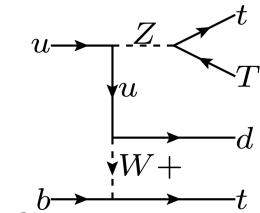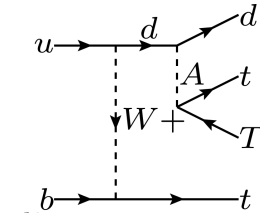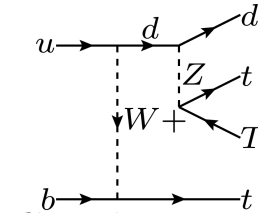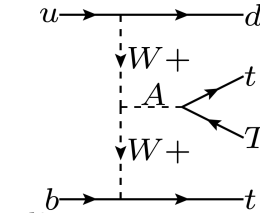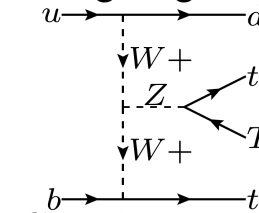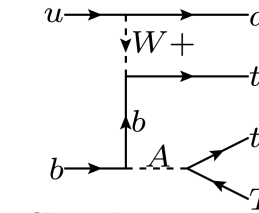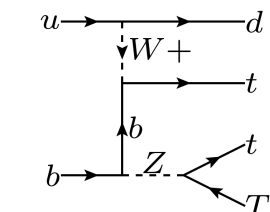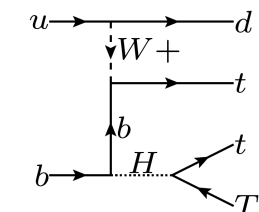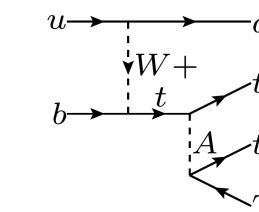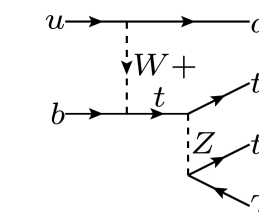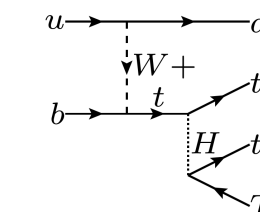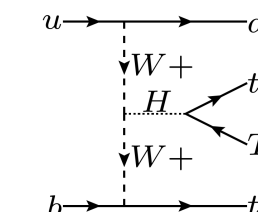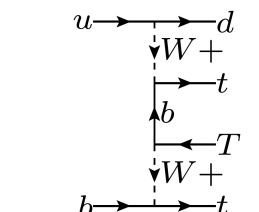
- Keeping gauge invariance is important, e.g. naive exclusion of Z, A, H rises the cross section to an order (1.4 fb, 14 TeV) in comparison with correct one (0.12 fb)
- The EW part is important contribution (0.12 fb, 14 TeV) in comparison with QCD part (0.10 fb)
- The interference between EW and QCD subsets is negative and important (-0.10 fb, 14 TeV)
- The calculations have been done in CompHEP package with NNPDF2.3 and scale 3Mtop/2

Total p,p→t,t,t,q cross section

CompHEP calculations at 14 TeV, NNPDF2.3-nlo-as-0118, Scale=3Mtop/2
$P_T(q) > 10$ GeV cut has applied

R(ttTq/tTTq) ~ 2.6 due to PDF, similar to t-channel single top

Some of the processes are CKM and/or PDF suppressed
(13% left, 29% right of the total)

$tt\bar{t}q$	subprocess	Cross section [pb]
1	$u, b \to d, t, t, \bar{t}$	1.19e-04
2	$\bar{d}, b \to \bar{u}, t, t, \bar{t}$	6.45e-06
3	$u, b \to s, t, t, \bar{t}$	6.22e-06
4	$\bar{s}, b \to \bar{c}, t, t, \bar{t}$	2.69e-06
5	$c, b \to s, t, t, \bar{t}$	2.60e-06
6	$\bar{d}, b \to \bar{c}, t, t, \bar{t}$	3.37e-07
7	$\bar{s}, b \to \bar{u}, t, t, \bar{t}$	1.41e-07
8	$c, b \to d, t, t, \bar{t}$	1.36e-07
G	Sum of gluon diags.	2.28e-04
EW	Sum of EW diags.	2.88e-04
Int	Interference	-2.41e-04
	Total cross section	2.75e-04

$t\bar{t}\bar{t}q$	subprocess	Cross section [pb]
1	$d, \bar{b} \to u, t, \bar{t}, \bar{t}$	3.92e-05
2	$\bar{u}, b \to \bar{d}, t, \bar{t}, \bar{t}$	7.33e-06
3	$s, \bar{b} \to c, t, \bar{t}, \bar{t}$	3.20e-06
4	$\bar{c}, b \to \bar{s}, t, \bar{t}, \bar{t}$	2.60e-06
5	$d, \bar{b} \to c, t, \bar{t}, \bar{t}$	2.05e-06
6	$\bar{u}, b \to \bar{s}, t, \bar{t}, \bar{t}$	3.83e-07
7	$s, \bar{b} \to u, t, \bar{t}, \bar{t}$	1.67e-07
8	$\bar{c}, b \to \bar{d}, t, \bar{t}, \bar{t}$	1.36e-07
G	Sum of gluon diags.	1.05e-04
EW	Sum of EW diags.	1.20e-04
Int	Interference	-1.15e-04
	Total cross section	1.10e-04

Total p,p→t,t,t,W cross section

- CompHEP calculations at 14 TeV, NNPDF2.3-nlo-as-0118, Scale=3Mtop/2

- 59 2→4 Feynman diagrams (in backup), the topology is similar to tW single top, leading triple top quark production process

- This process interferes with four top quark production at NLO (t,t,t,W,b), like tWb to tt

- Such significant EW/QCD interference can be exploited for something, e.g. check the sign of Wtb vertex (unfortunately, all of the diagrams have 1 or 3 Wtb vertexes and even power in interference)

$tt(\bar{t})\bar{t}W$	subprocess	Cross section [pb]
1	$\bar{b}, g \rightarrow W^+, t, \bar{t}, \bar{t}$	3.40e-04
2	$b, g \rightarrow W^-, t, t, \bar{t}$	3.40e-04
G	Sum of gluon diags.	1.01e-03
EW	Sum of EW diags.	0.962e-03
Int	Interference	-0.612e-03
	Total cross section	1.36e-03

Total p,p→t,t,t,b cross section

- CompHEP calculations at 14 TeV, NNPDF2.3-nlo-as-0118, Scale=3Mtop/2
  $P_T(b) > 10$ GeV cut has applied

- 18 2→4 Feynman diagrams (in backup), lowest rate 3-top process

- EW contribution is about 3% of the total

- EW/QCD interference is positive and about EW contribution

$tt\bar{t}b$	subprocess	Cross section [pb]
1	$u, \bar{d} \rightarrow t, t, \bar{t}, \bar{b}$	5.35e-05
2	$u, \bar{s} \rightarrow t, t, \bar{t}, \bar{b}$	1.57e-06
3	$c, \bar{s} \rightarrow t, t, \bar{t}, \bar{b}$	9.91e-07
4	$c, \bar{d} \rightarrow t, t, \bar{t}, \bar{b}$	1.14e-07
G	Sum of gluon diags.	1.06e-04
EW	Sum of EW diags.	3.43e-06
Int	Interference	2.57e-06
	Total cross section	1.12e-04

$t\bar{t}\bar{t}b$	subprocess	Cross section [pb]
1	$d, \bar{u} \rightarrow t, \bar{t}, \bar{t}, b$	2.25e-05
2	$s, \bar{c} \rightarrow t, \bar{t}, \bar{t}, b$	1.13e-06
3	$d, \bar{c} \rightarrow t, \bar{t}, \bar{t}, b$	5.51e-07
4	$\bar{u}, s \rightarrow t, \bar{t}, \bar{t}, b$	1.47e-07
G	Sum of gluon diags.	4.60e-05
EW	Sum of EW diags.	1.44e-06
Int	Interference	1.16e-06
	Total cross section	4.86e-05

Uncertainties and expectations for 14 TeV (HL-LHC)

- The factorisation and renormalisation scales (Q) uncertainty is estimated as a variation from 3Mtop/4 up to 3Mtop

- rough estimation of PDF uncertainty comes from comparison of NNPDF2.3-nlo-as-0118 and CTEQ6l1

Process	Cross sec. [pb]	$\delta\sigma_Q$, %	$\delta\sigma_{PDF}$, %
$p, p \rightarrow W^-, t, t, \bar{t}$	6.8e-04	13	6
$p, p \rightarrow W^+, t, \bar{t}, \bar{t}$	6.8e-04	13	6
$p, p \rightarrow q', t, t, \bar{t}$	2.7e-04	12	14
$p, p \rightarrow q', t, \bar{t}, \bar{t}$	1.1e-04	13	4
$p, p \rightarrow \bar{b}, t, t, \bar{t}$	1.1e-04	35	13
$p, p \rightarrow b, t, \bar{t}, \bar{t}$	4.9e-05	35	4
Total $p, p \rightarrow X, t, t\,(\bar{t}), \bar{t}$	1.9e-03	15	7

- The total rate 1.9 fb and possible integrated luminosity 3 ab^{-1} (HL-LHC) give about 5700 events. If one exclude all-hadronic and tau+jets channels (BR~0.6) and estimate total experimental accceptance as 10%, one can expect about 300 detected events of triple top quark production at HL-LHC.

Total cross sections for 100 TeV (FCC)

- The uncertainties are estimated in a same way as for HL-LHC
- The $P_T(b,q) > 10$ GeV cut has applied
- The significant enhancement of the cross section is mainly due to rapid growing of the gluon parton density g(x) in protons with a decrease of momentum fraction x.

Process	Cross sec. [pb]	$\delta\sigma_Q$, %	$\delta\sigma_{\mathrm{PDF}}$, %
$p, p \to W^-, t, t, \bar{t}$	2.4e-01	15	4
$p, p \to W^+, t, \bar{t}, \bar{t}$	2.4e-01	15	4
$p, p \to q', t, t, \bar{t}$	3.1e-02	4	7
$p, p \to q', t, \bar{t}, \bar{t}$	1.8e-02	4	4
$p, p \to \bar{b}, t, t, \bar{t}$	2.6e-03	12	4
$p, p \to b, t, \bar{t}, \bar{t}$	1.7e-03	12	4
Total $p, p \to X, t, t\,(\bar{t}), \bar{t}$	5.3e-01	14	4

Conclusion

- The triple top quark production processes in SM: tttW, tttq, tttb

    - it is important to keep gauge invariance for these processes (sometimes neglected, e.g. DR scheme for tWb)

    - EW boson mediated contribution is of the same order as gluon mediated contribution

    - EW/QCD interference is negative and of the same order as EW contribution, this unusual cancellation can be exploited, also it could be important for the BSM calculations

    - the uncertainties are at the level of 15% (scale) and 7% (PDF)
    - the interference with four top quark production at NLO can be important

- At HL-LHC with 3 ab^{-1} integrated luminosity and total SM rate 1.9 fb one can expect about 300 detected events. The distinguishing from the backgrounds is strongly depends on the analysis methods.

- The FCC is able to investigate precisely the triple top quark production with the total rate of 530 fb.

Back Up

diagr.1 diagr.2 diagr.3 diagr.4 diagr.5 diagr.6 diagr.7
diagr.8 diagr.9 diagr.10 diagr.11 diagr.12 diagr.13 diagr.14
diagr.15 diagr.16 diagr.17 diagr.18 diagr.19 diagr.20 diagr.21
diagr.22 diagr.23 diagr.24 diagr.25 diagr.26 diagr.27 diagr.28
diagr.29 diagr.30 diagr.31 diagr.32 diagr.33 diagr.34 diagr.35
diagr.36 diagr.37 diagr.38 diagr.39 diagr.40 diagr.41 diagr.42
diagr.43 diagr.44 diagr.45 diagr.46 diagr.47 diagr.48 diagr.49
diagr.50 diagr.51 diagr.52 diagr.53 diagr.54 diagr.55 diagr.56
diagr.57 diagr.58 diagr.59

diagr.1 diagr.2 diagr.3 diagr.4 diagr.5 diagr.6 diagr.7

diagr.8 diagr.9 diagr.10 diagr.11 diagr.12 diagr.13 diagr.14

diagr.15 diagr.16 diagr.17 diagr.18