Top FCNC

6th FCC Physics Workshop

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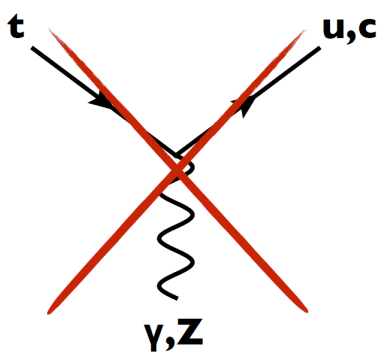
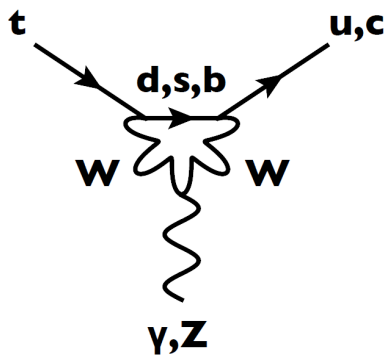
Table of Contents

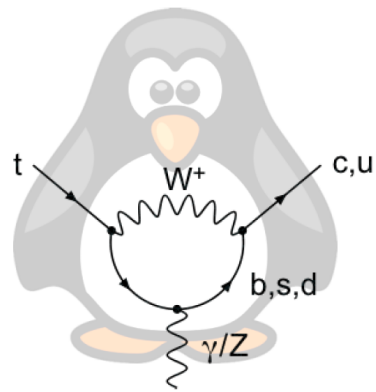
1. Motivation
2. Top-FCNC appearance at FCC-ee
3. Analysis strategy
   signal selection and Background estimation
4. Results
   Comparison with other experiments
5. Summary and Conclusion

Introduction and Motivation

- In the SM, top FCNC is forbidden at tree level and highly suppressed at one-loop corrections due to GIM.
- $\mathcal{B}r(t \to qV) < 10^{-12}$ ($V = H, \gamma, Z, g$) in the SM, but can be enhanced up to 10^{-5} in some BSMs.
- Any observation of top FCNC would be a clear signal of new physics beyond the SM.
- FCC-ee offers ideal environment to study FCNC due to reduction of QCD background as well as high luminosity.

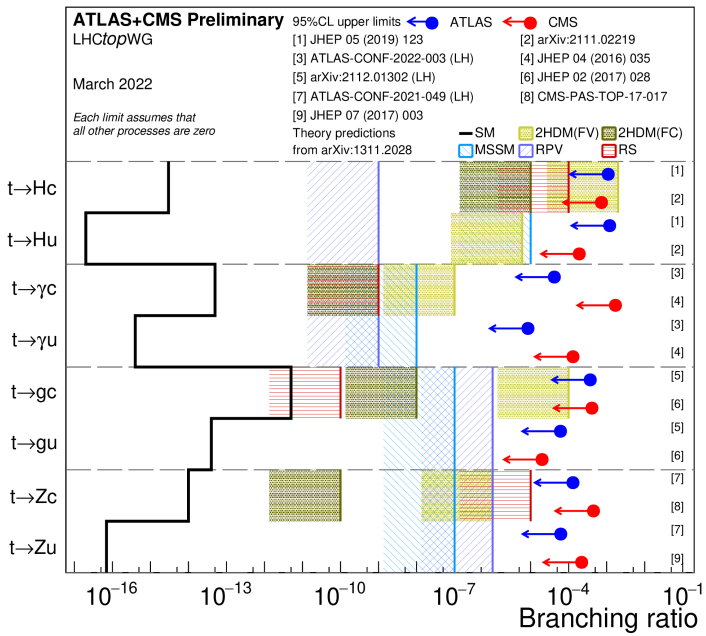


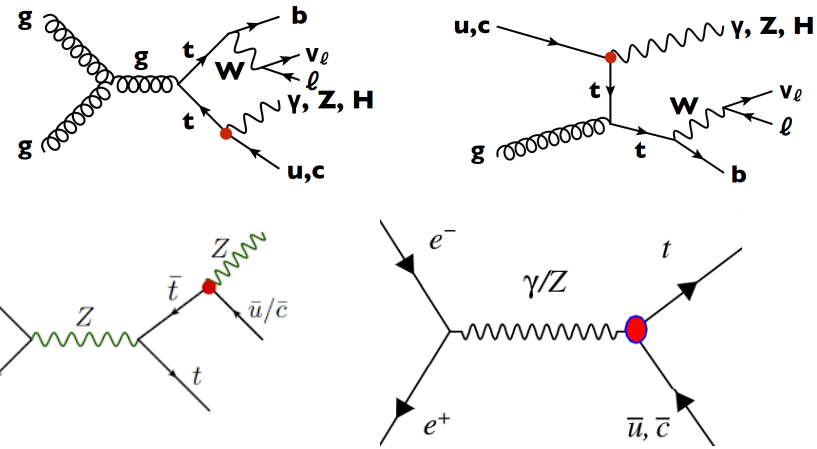




Experimental Limits

- LHC experiments have been searching for Top FCNC.
- So far, no clear evidence for the presence of top quark FCNC interactions has been observed and upper limits are set on the anomalous couplings and top quark branching.



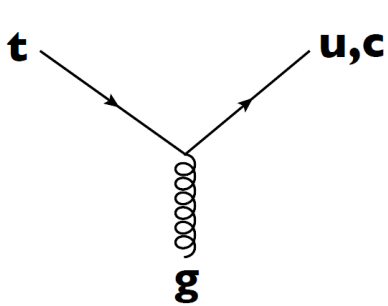


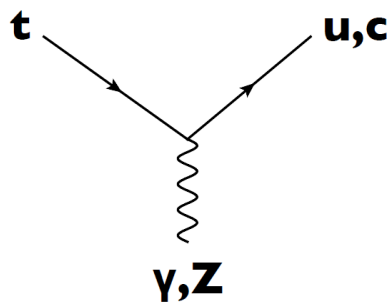
- OPAL & **600 pb^{-1}** data collected at **189-209 GeV** & leptonic and the hadronic decay modes of the W boson & the Durham algorithm [*Physics Letters B 521 (2001)* 181-194]($Br(t \to zq) = 13.7\%$).
- L3 & **the total integrated luminosity of 634 pb^{-1}** & $\sqrt{s}$ =**189 to 209 GeV** & Durham algorithm [*Physics Letters B 549 (2002) 290-300*] ($Br(t \to \gamma q) = 4.1\%$ and $Br(t \to Zq) = 13.7\%$).

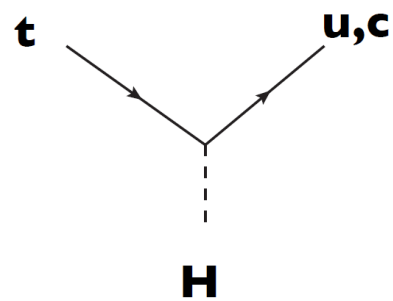
Effective Framework

The most general effective Lagrangian describing the FCNC interactions can be parameterized as:

$$\mathcal{L}_{FCNC} = \sum_{q=u,c} \frac{g_s}{2m_t}\bar{q}\lambda^a\sigma^{\mu\nu}(\zeta^L_{qt}P^L + \zeta^R_{qt}P^R)tG^a_{\mu\nu} - \frac{1}{\sqrt{2}}\bar{q}(\eta^L_{qt}P^L + \eta^R_{qt}P^R)tH -$$
$$-\frac{g_W}{2c_W}\bar{q}\gamma^\mu(X^L_{qt}P_L + X^R_{qt}P_R)tZ_\mu + \frac{g_W}{4c_W m_Z}\bar{q}\sigma^{\mu\nu}(K^L_{qt}P_L + K^R_{qt}P_R)tZ_{\mu\nu} +$$
$$+ \frac{e}{2m_t}\bar{q}\sigma^{\mu\nu}(\lambda^L_{qt}P_L + \lambda^R_{qt}P_R)tA_{\mu\nu} + H.c.$$



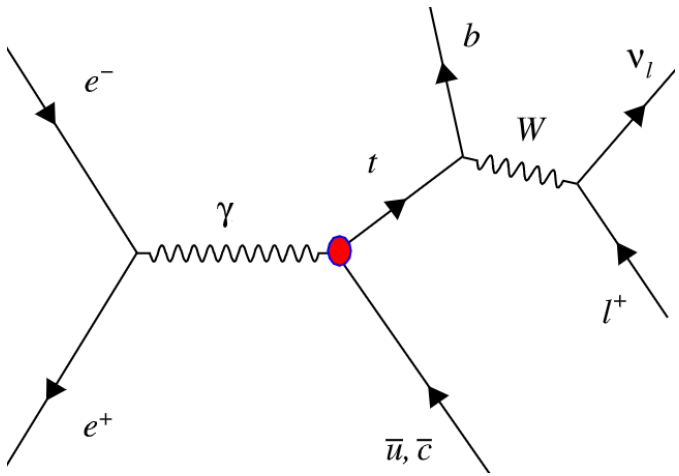




$\zeta^L_{qt} = \zeta^R_{qt}$ $\eta^L_{qt} = \eta^R_{qt}$ $\kappa^L_{qt} = \kappa^R_{qt}$ $X^L_{qt} = X^R_{qt}$ $\lambda^L_{qt} = \lambda^R_{qt}$

FCNC production at FCC-ee

- At the FCCee, FCNC tqV interaction can lead to single top production
- This analysis is performed at the center of mass energy 240 and 365 GeV.
- The distinctive signature of the signal is:
  - A top quark
  - A light energetic jet

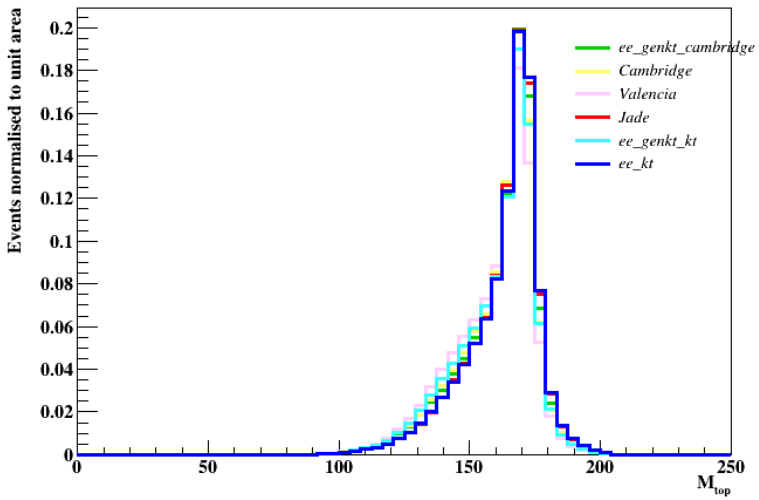


signal signature: One lepton, one neutrino, exactly 2exclusive jets which one of them are tagged as b-jet.

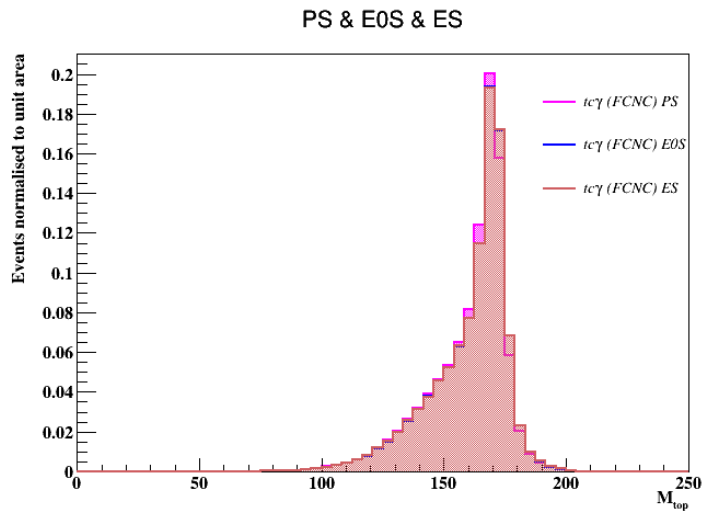
All MC files are generated in the FCCSW (https://github.com/HEP-FCC/FCCAnalyses) framework with $DelphesPythia8_E DM4HEP$ and IDEA Delphes Card

Jet clustering algorithms selection

Exactly two exclusive jet is required:

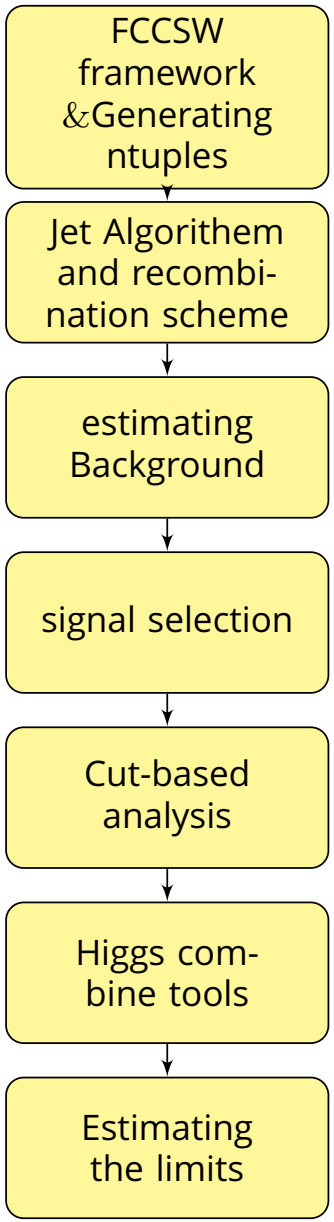


Reconstructed top mass distribution for three different schemes, for $tc\gamma$ coupling.



Jet Definition = Durham & E-scheme

MC simulation



Backgrounds:

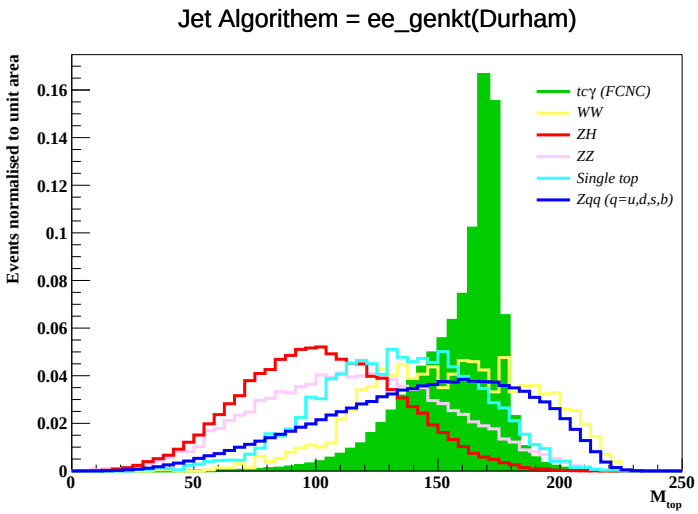
Process	σ[fb] $\sqrt{s} = 240$GeV	σ[fb] $\sqrt{s} = 365$GeV
ZH	202	117
WW	16439	10717
ZZ	1360	643
$e^-e^+q\bar{q}$	1637	620
single top	0.01	0.2
$tbjj$	-	6
$t\bar{t}$	-	800

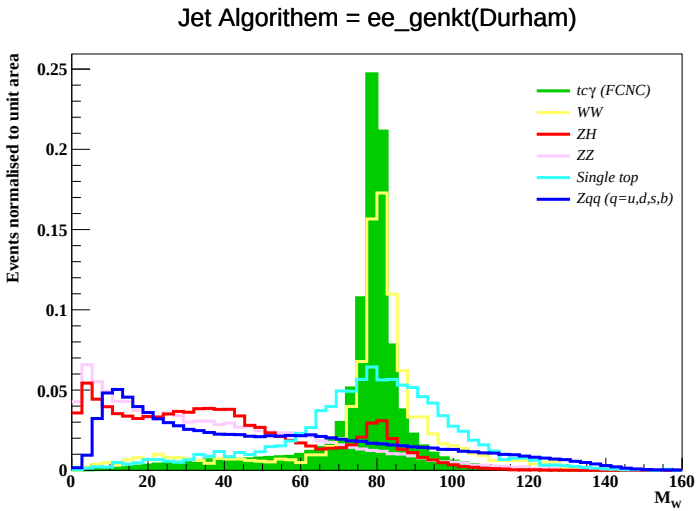
preselection cuts:

- Lepton and jets momentum are required to have: $p > 15$GeV
- Polar angle of lepton and jets are required to be: $\theta > 13$ degree
- The angular separation between lepton and jets are required to satisfy: $\Delta R > 0.5$
- Missing energy is grather than 15 GeV

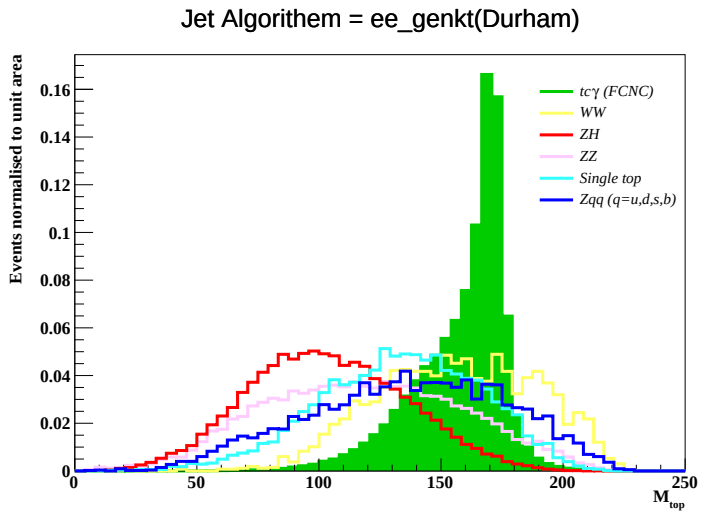
Mass reconstruction in electron and muon channels-240 GeV

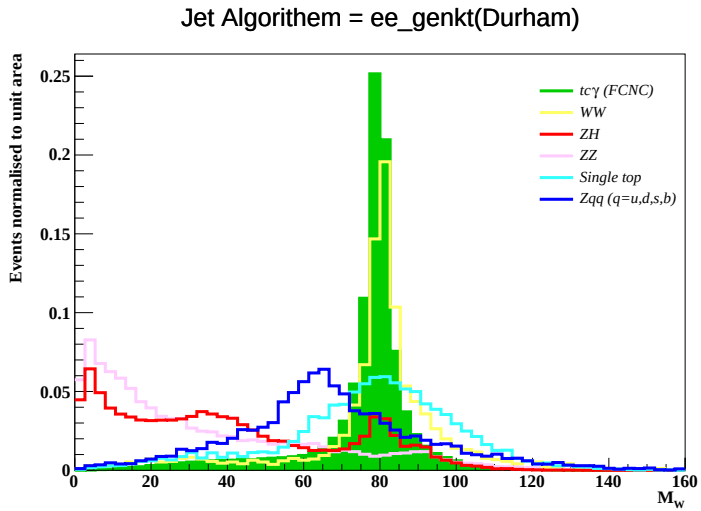
electron channel





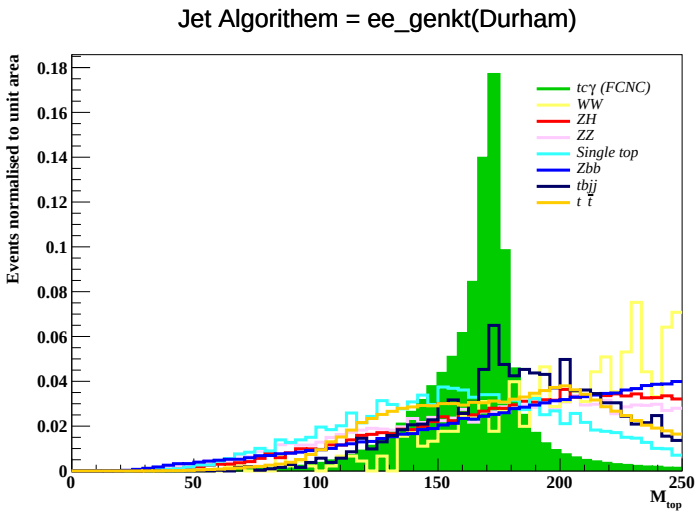
muon channel

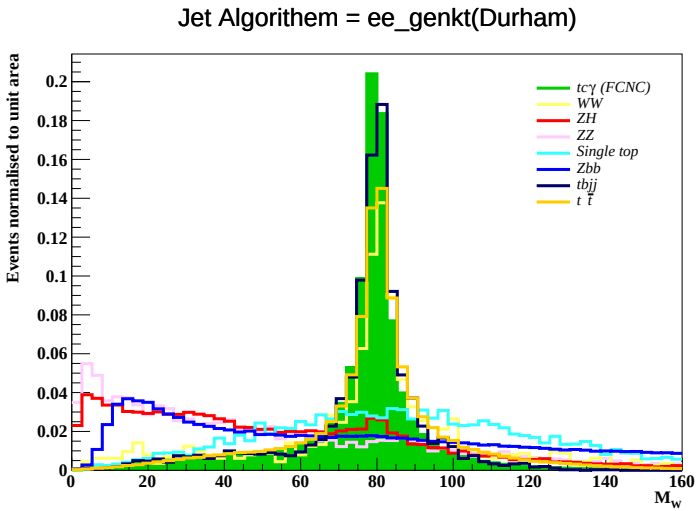




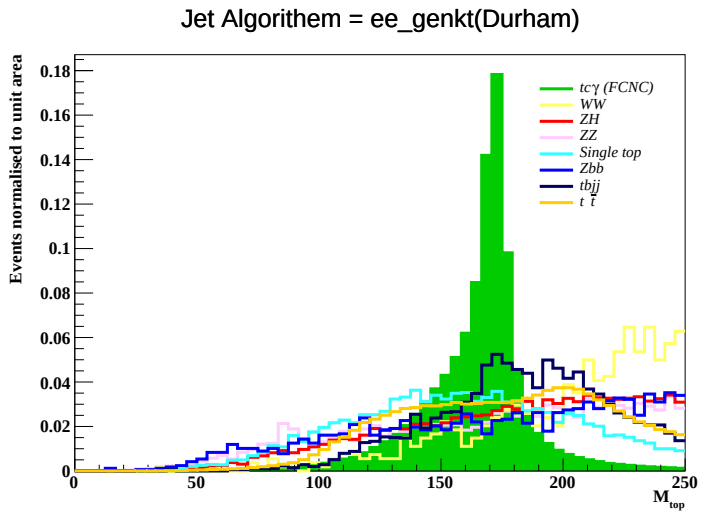
Mass reconstruction in electron and muon channels-365 GeV

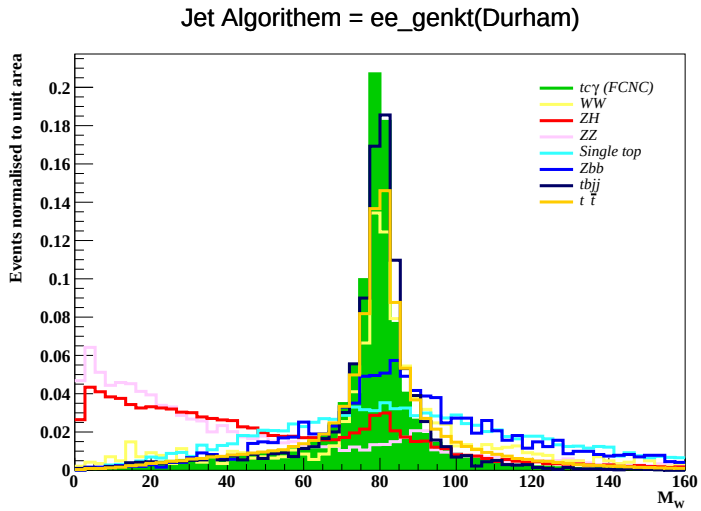
electron channel





muon channel

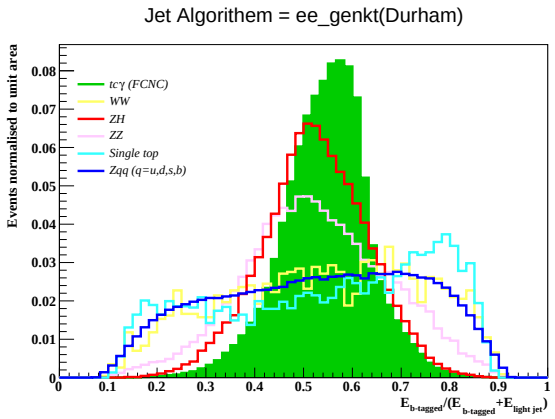


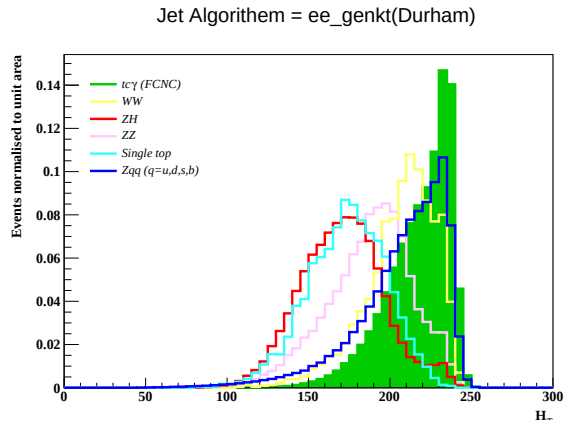


distinctive variables

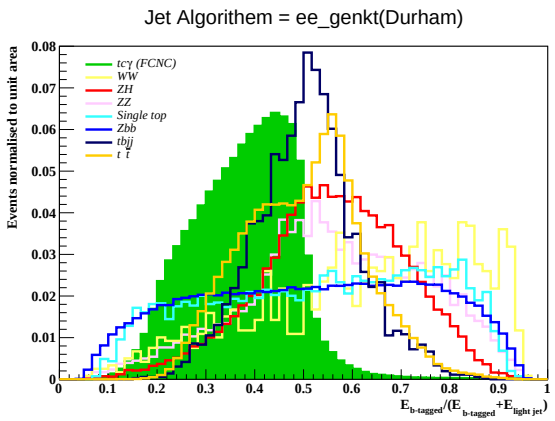
Optimal cuts on individual variables increase our sensitivity to the signal.

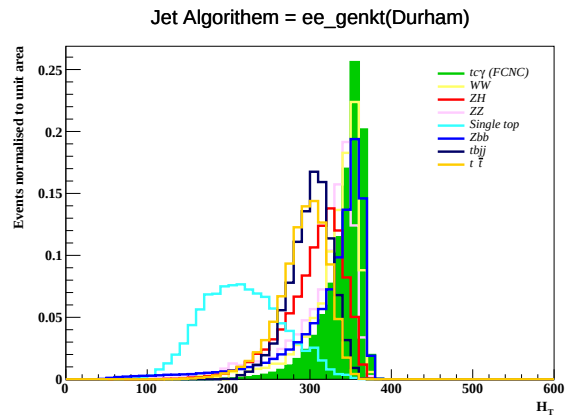
$\sqrt{s} = 240$ GeV





$\sqrt{s} = 365$ GeV



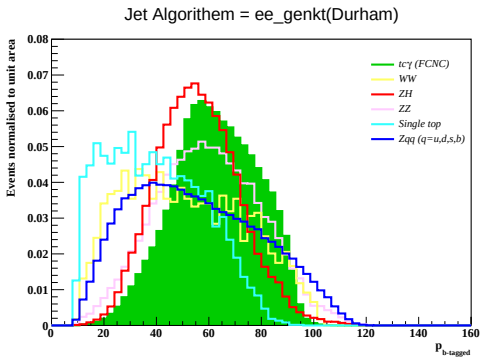


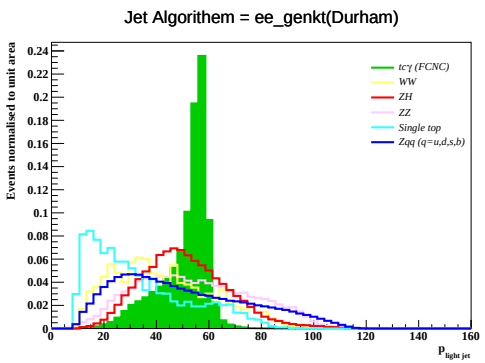
H_T is scalar sum of momentum of all outgoing particles.

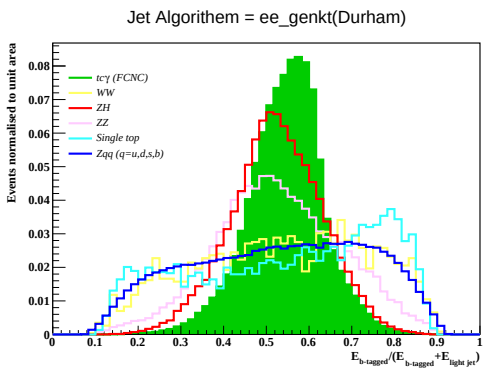
Selection cuts-240 GeV

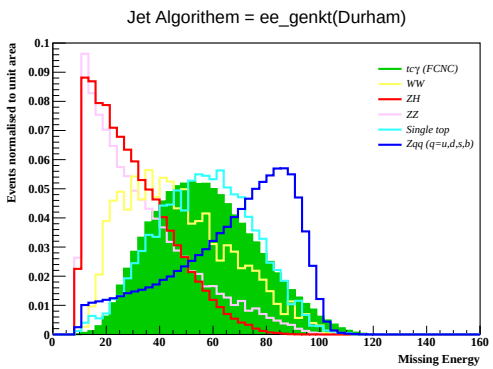
The variables which have the best possible discrimination power between the signal and background processes:

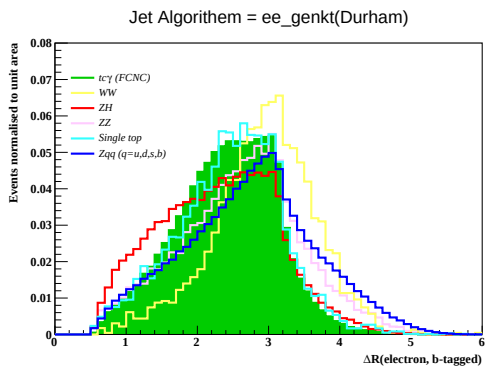
1. 140 GeV$< M_{\text{top}} <$ 190 GeV.
2. 70 GeV $< M_{\text{W}} <$ 90 GeV.
3. $p_{\text{bjet}} >$ 40 GeV.
4. $p_{\text{lightjet}} >$ 40 GeV.
5. $p_{\ell} >$ 20 GeV.
6. ME $>$ 30 GeV.
7. $\Delta R(\ell, b_{\text{jet}}) < 3.5$.
8. $0.35 < E_{\text{bjet}}/(E_{\text{bjet}} + E_{\text{lightjet}}) < 0.7$.
9. $H_T >$ 190 GeV.



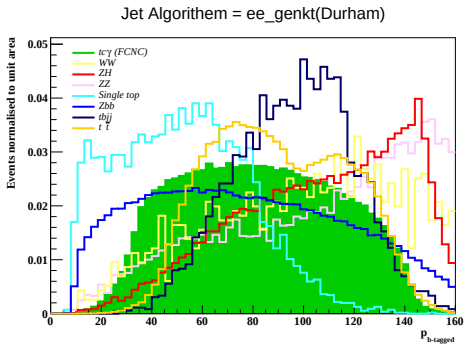


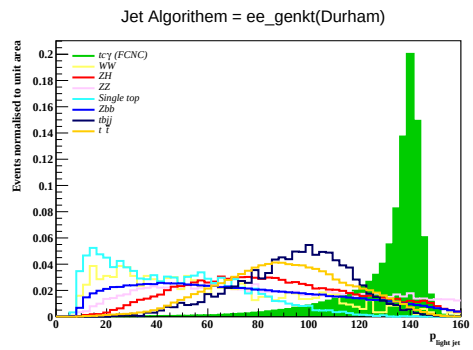




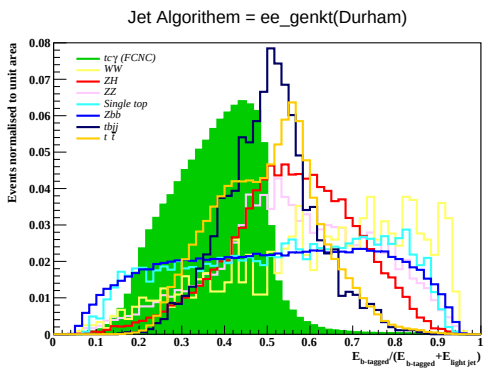


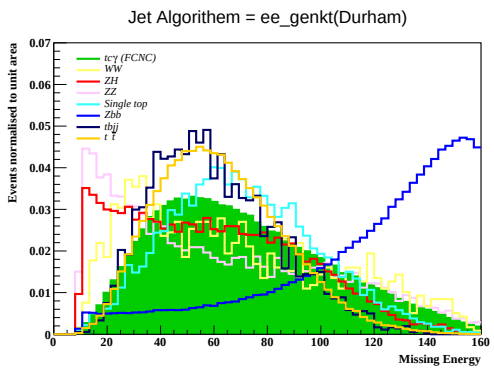
Selection cuts-365 GeV

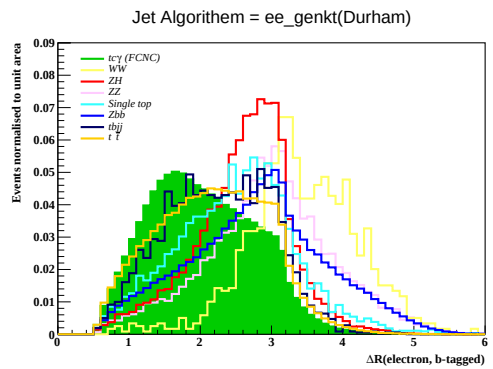




1. 140 GeV$< M_{\text{top}} <$ 190 GeV.
2. 70 GeV $< M_{\text{W}} <$ 90 GeV.
3. $p_{\text{bjet}} >$ 30 GeV.
4. $p_{\text{lightjet}} >$ 120 GeV.
5. $p_{\ell} >$ 20 GeV.
6. ME $>$ 30 GeV.
7. $\Delta R(\ell, b_{\text{jet}}) < 3.5$.
8. $0.2 < E_{\text{bjet}}/(E_{\text{bjet}} + E_{\text{lightjet}}) < 0.5$.
9. $H_T >$ 300 GeV.







Cut Flow table

cut flow table for 240 GeV

$\sqrt{s}$ = 240 GeV	$tc\gamma$	tcZ	ZH	WW	ZZ	eebb	eeqq (q=uds)	single top
Cross section	14.327	34.132	201.868	16438.5	1358.99	455.7	1635.9	0.010753
Preselection	3.1542	7.5154	1.1953	3.75948	2.76677	19.251	0.155146	0.0003208
Final selection	1.3686	3.2622	0.00847	0.254797	0.01127	0.1807	0.001439	3.2259×10^{-7}

cut flow table for 365 GeV

$\sqrt{s}$ = 365 GeV	$tc\gamma$	tcZ	ZH	WW	ZZ	$t\bar{t}$	eebb	single top	single top ($tbjj$)
Cross section	25.958	50.9517	117.3	10716.5	642.8	800.0	615.2	0.227	5.98
Preselection	5.2107	10.2299	0.6240	2.55696	1.21039	39.7574	25.0175	0.006297	0.2159
Final selection	1.9599	4.3406	0.00410	0.00857	0.00809	1.10752	0.004332	2.276×10^{-6}	0.006947

Results

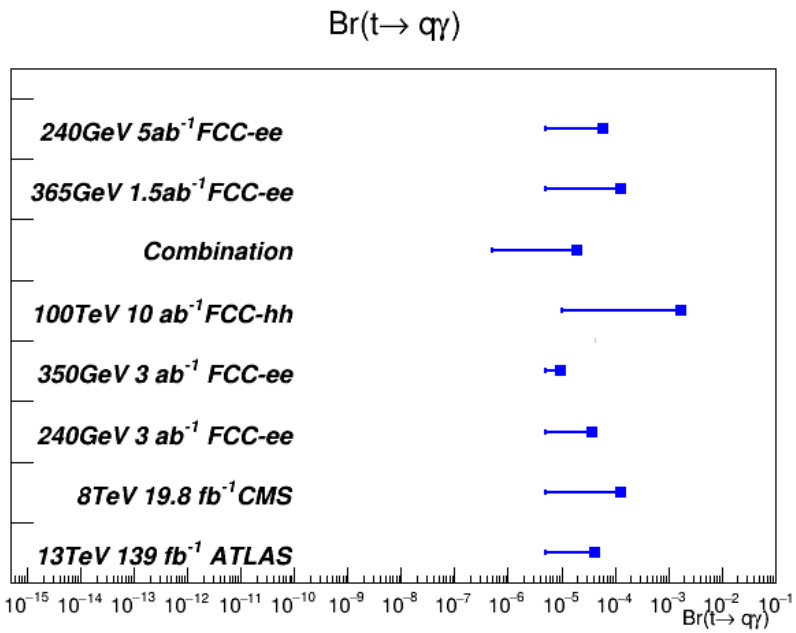
95% CL upper limts on the anomalous FCNC couplings and consequently on the branching ratios are estimated by using Higgs Combine tools.

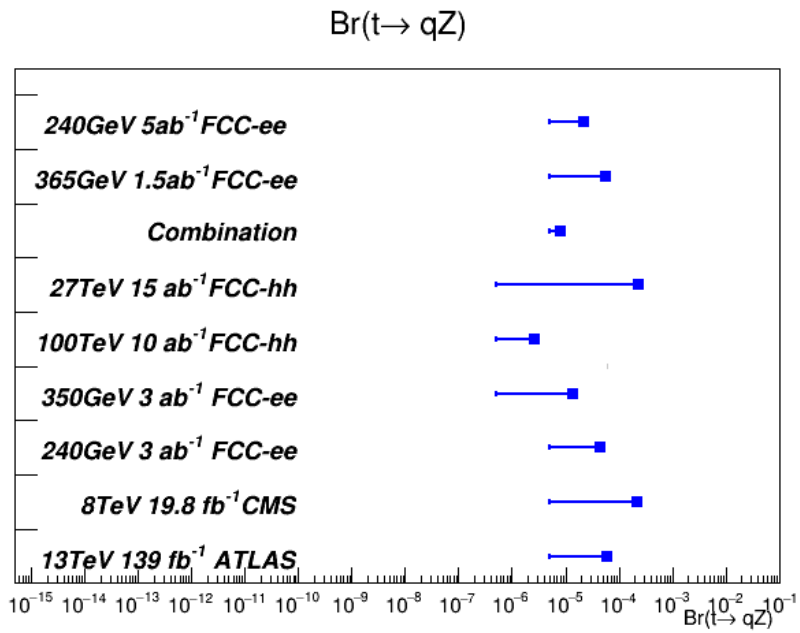
$\sqrt{s} = 240$ GeV $\&\mathcal{L} = 5$ ab^{-1}	$Br(t \to c\gamma)$	$Br(t \to cZ)$
Electron channel	9.60×10^{-5}	3.53×10^{-5}
Muon channel	6.29×10^{-5}	2.31×10^{-5}

$\sqrt{s} = 365$ GeV $\&\mathcal{L} = 1.5$ ab^{-1}	$Br(t \to c\gamma)$	$Br(t \to cZ)$
Electron channel	1.65×10^{-4}	6.96×10^{-5}
Muon channel	1.47×10^{-4}	6.19×10^{-5}

	$Br(t \to c\gamma)$	$Br(t \to cZ)$
Energy $\&$ channel statistical combination	1.99×10^{-5}	8.19×10^{-6}

Comparison with current and future experiments





Summary and to do next

Summary

1. The sensitivity of the FCC-ee to top FCNC interaction is probed by searching tq production.
2. This study has been done in the official FCCAnalysis framework.
3. leptonic decay of the top qurak is considered.
4. We presented the upper limits on the branching ration for the leptonic (electron $\&$ muon) channel of single-top quark production via FCNC at two FCC-ee benchmarks ($\sqrt{s} = 240$ GeV at 5 ab^{-1} and $\sqrt{s} = 365$ GeV at 1.5 ab^{-1}).
5. We show the statistical conbination will improve the sensitivity to $tq\gamma$ and $tc\gamma$ couplings.

To do next

1. Applying the mis-tagging efficiency for b-quark.
2. Including hadronic decay channel of top quark.
3. Statistical combination of leptonic and hadronic decay channel to increase the sensitivity to FCNC interactions.
4. Applying systematic and statistical uncertainties.
5. Using Multivariate analysis to extract the limits.


Thank
you