IN SUPREMÆ DIGNITATIS 1343

UNIVERSITÀ DI PISA

Top Quark Properties and EFT Interpretations(FCNC)

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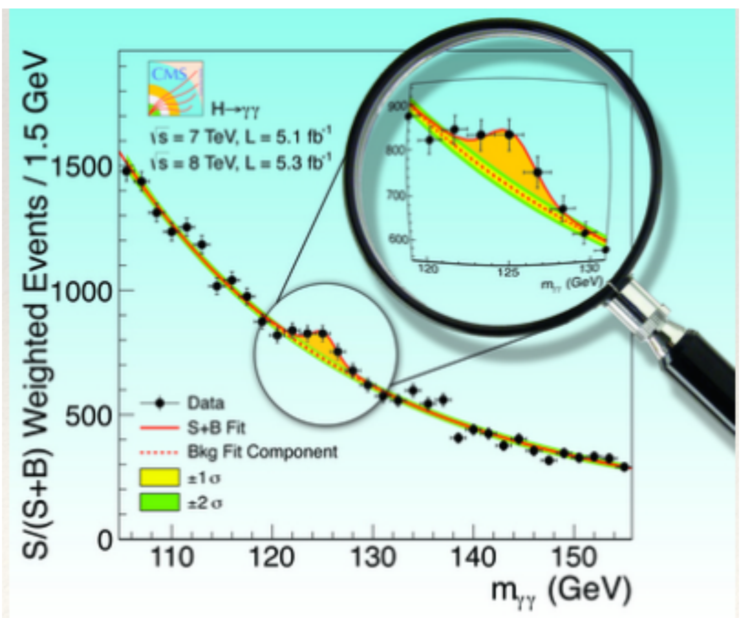
Outline

- Effective Field Theory.
- Why Top Quark.
- Flavor Changing Neutral Currents
- Top FCNC and Some example: tqg, tqγ, tqZ .
- Experimental searches for FCNC
- Some result of LHC and future collider
- Summary

New physics and Effective Field Theory

Model Dependent
SUSY, 2HDM, …

New Particles
resonances in spectra



Model InDependent

New Interactions among SM particles

$$\mathcal{L}_{eff} = \mathcal{L}^{(4)}_{SM} + \sum \frac{C_x}{\Lambda^2} O_{6,x} + h.c.$$

$O_{6,x}$ dimension-6 gauge-invariant operators

C_x Wilson coefficients (complex constants)

Λ Energy scale of new physics

Top quark Effective Field Theory

- There are **2 different approach**, depend On new physics energy scale :
- ✓ $\Lambda >> E_{exp}$ (indirect, EFT domain)
- ✓ $\Lambda \leq E_{exp}$ (direct searches domain)
- ✧ In the EFT framework, the degrees of freedom corresponding to heavy particles that cannot be directly produced are integrated out. Their effects are encoded into interactions among low energy SM particles.
- ✧ Under certain assumptions, EFT framework allows one to describe effects of new physics beyond SM in a model independent way.

Top quark vertices

General couplings (SM contribution)

- ➢ Wtb, ttg, ttZ, ttγ, ttH

Flavor Changing Neutral Current Couplings (FCNCs):

- ➢ tgq, tγq, tZq, tHq (q=u or c)

Why Top quark is interesting for us?

Top quark is the heaviest known fundamental particle.
-It has the largest coupling with the SM Higgs
$\lambda_{top} = \sqrt{2} m_{top}/v \approx 1$, so it may play a special role in EWSB.

-Very clean laboratory(environment) for strong and electroweak interactions.

Top quark is a short lived particle:

- Γ_{top} = 1.4 GeV corresponding to $\tau_{top} \approx 10^{-25}$s.
- Top has a distinctive event signature. It decays almost exclusively to W+b Small branching fraction for the other decay modes: B(t->Ws)=0.18%, B(t->Wd)= 0.02%.

The measurement of the top quark properties provides powerful tests of the SM.

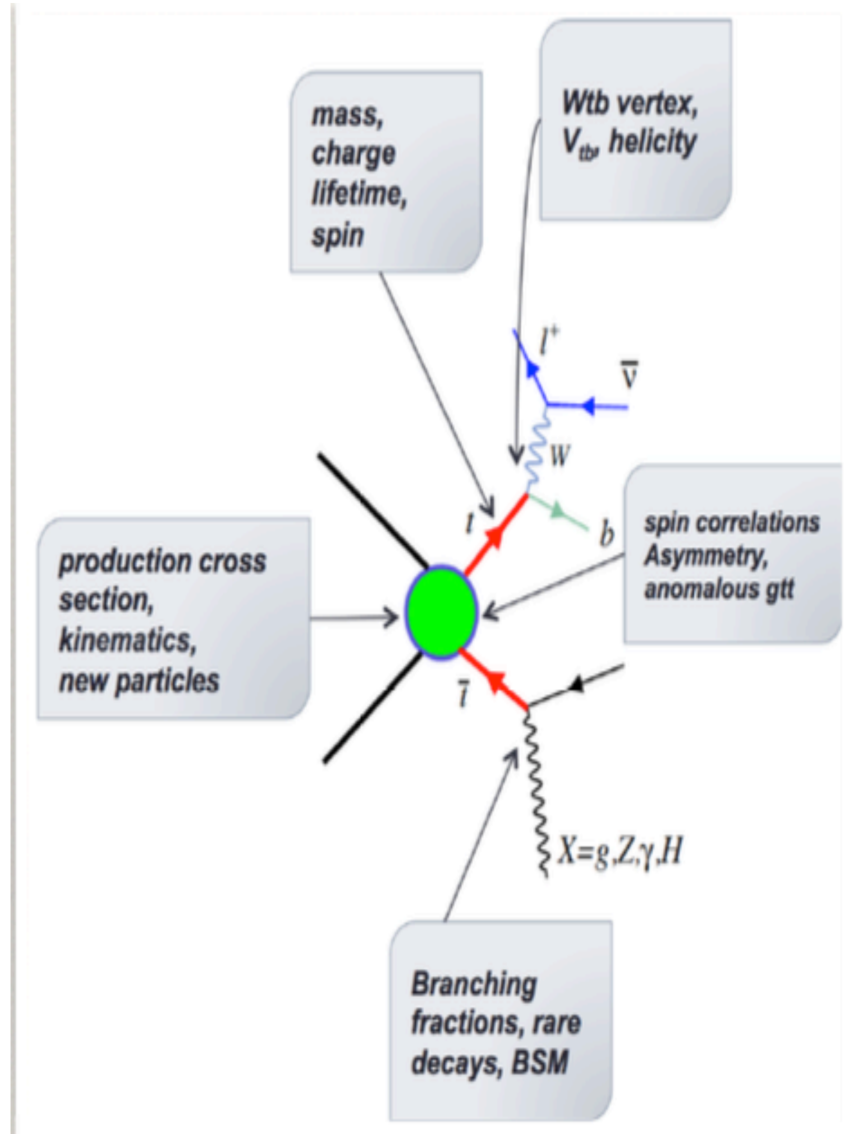
Hints of BSM: new particles W',Z' ... could decay preferentially to top quarks. Processes including top are of interest for new physics searches such as susy stop productions.

What can be measured at the LHC?

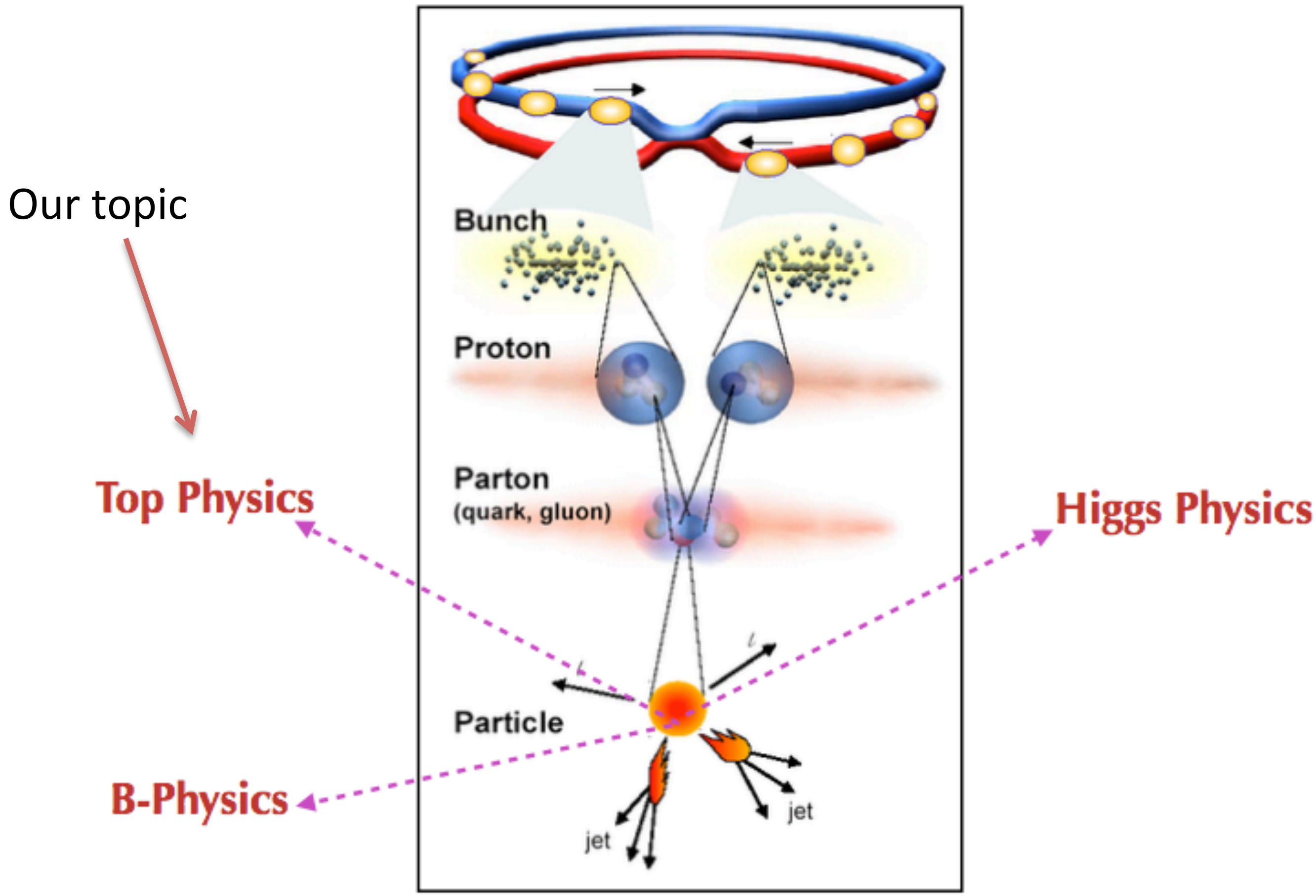
Observables:

Total and differential cross sections of

- top pair production
- single top quark production
- Top quark branching fractions and rare FCNC decays.
- (-Helicity of the W-boson in top quark decays. is not our topic for this seminars).
- Top quark couplings to photon, Z, W, and Higgs through studying associated productions tZj, tγj, tHj, ttZ,ttγ, ttW...



LHC as a Place to study SM&BSM

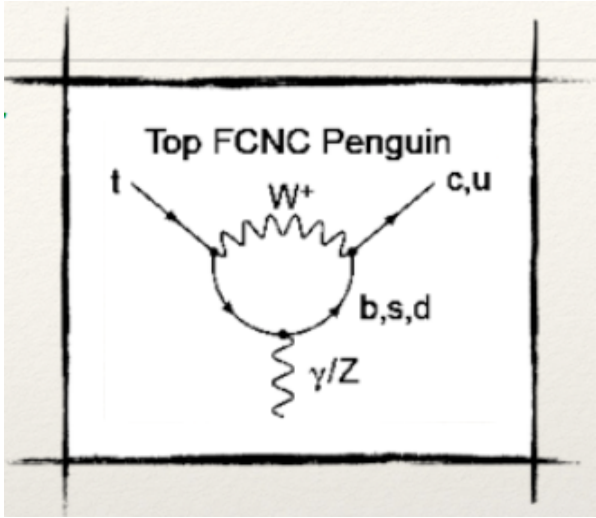


Flavor-changing neutral current (FCNC)

In SM FCNC is forbidden at tree level and only allowed via higher order corrections such as penguin diagrams and strongly suppressed: due to GIM mechanism and smallness of the related CKM matrix elements.

Any signal above SM expectations would indicate new physics.

EX:tqg,tqγ,tqz



$Br(t \to cg)$	$\mathcal{O}(10^{-11})$
$Br(t \to cZ)$	$\mathcal{O}(10^{-13})$
$Br(t \to c\gamma)$	$\mathcal{O}(10^{-13})$

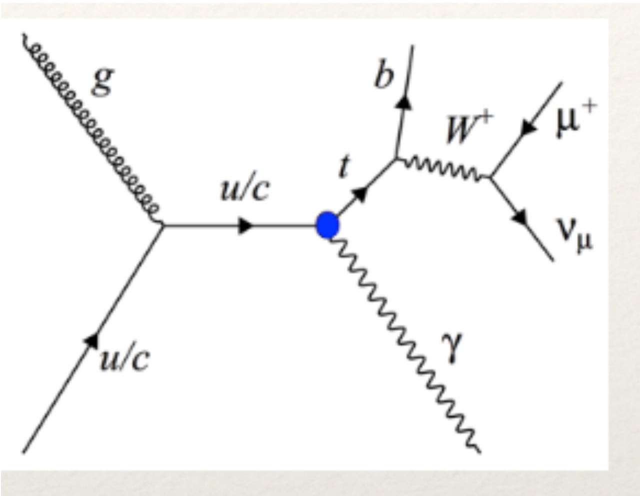
Phys. Rev. D 44, 1473 (1991); Phys. Lett. B 435, 401 (1998).

Model	BR($t \to Zq$)
Standard Model	$\mathcal{O}(10^{-14})$
$q = 2/3$ Quark Singlet	$\mathcal{O}(10^{-4})$
Two Higgs Doublets	$\mathcal{O}(10^{-7})$
MSSM	$\mathcal{O}(10^{-6})$
R-Parity violating SUSY	$\mathcal{O}(10^{-5})$

Acta Phys. Polor B35 (2004) 2695

Feynman diagram

tqγ



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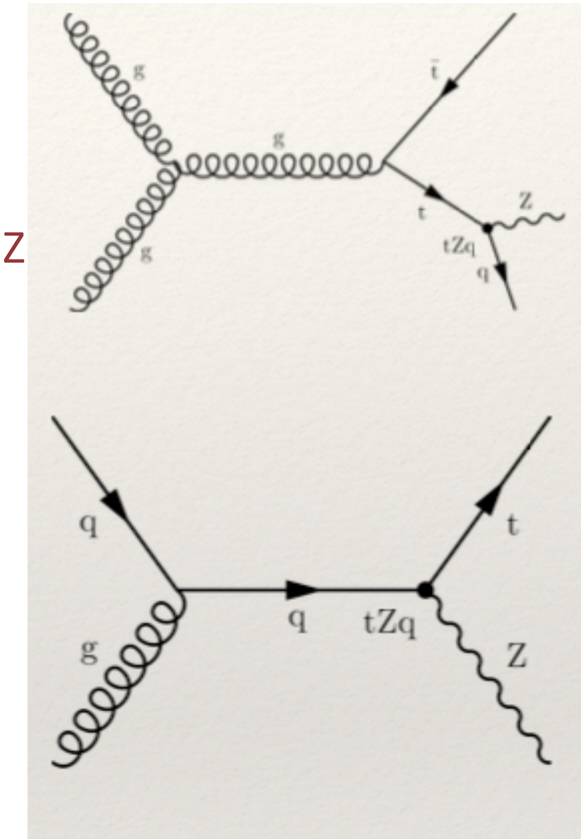
tqZ



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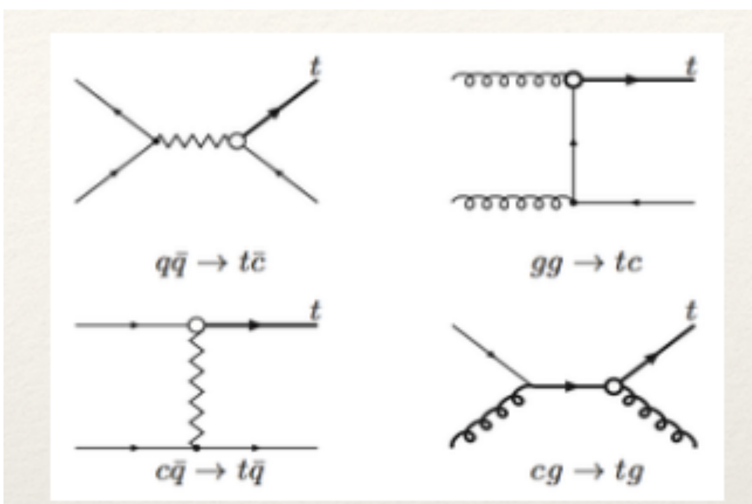
tqg



Experimental searches for FCNC

The searches for FCNC are performed either in decays of ttbar events or in single top production.

The results that are shown come from both ttbar and single top.

To search for FCNC effects in the top sector, a useful way is to adopt a model independent approach using an effective Lagrangian:

$$\begin{aligned}\mathcal{L} \;=\; & \sum_{q=u,c} \Big[\sqrt{2}\, g_s \frac{\kappa_{gqt}}{\Lambda}\, \bar{t}\, \sigma^{\mu\nu}\, T_a (f^L_{Gq} P_L + f^R_{Gq} P_R)\, q\, G^a_{\mu\nu} \\ & + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{zqt}}{\Lambda}\, \bar{t} \sigma^{\mu\nu} (f^L_{Zq} P_L + f^R_{Zq} P_R)\, q\, Z_{\mu\nu} \\ & - e \frac{\kappa_{\gamma qt}}{\Lambda}\, \bar{t}\, \sigma^{\mu\nu} (f^L_{\gamma q} P_L + f^R_{\gamma q} P_R)\, q\, A_{\mu\nu} \\ & + \frac{g}{\sqrt{2}} \bar{t}\, \kappa_{Hqt} (f^L_{Hq} P_L + f^R_{Hq} P_R)\, q\, H \Big] + \text{h.c.}\end{aligned}$$

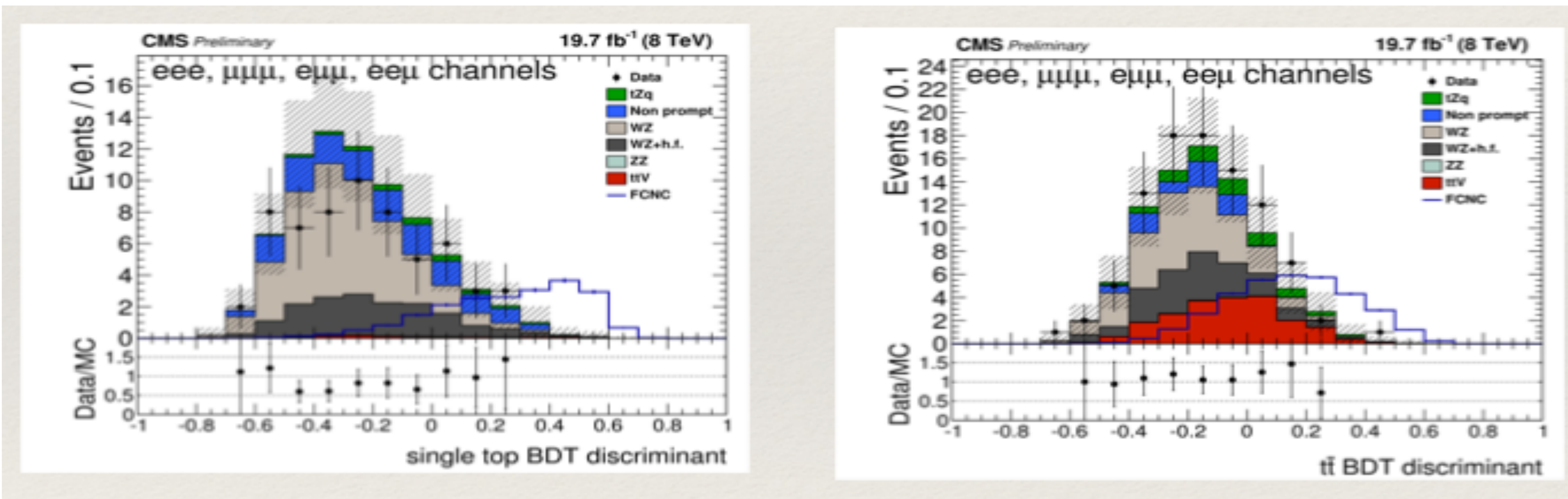
Hep-ph/0409342 Aguilar-saavedra

FCNC: tqZ

-For tt: Three leptons, 2 lepton (Z) and 1 lepton (W)

- missing transverse energy > 40 GeV and M_T > 10 GeV

-For single top:1b-jet and for the ttbar: ≥2jets (≥ 1b-jet)



Upper limit

Branching fraction	Expected	68% CL range	95% CL range	Observed
$\mathcal{B}(t \rightarrow Zu)$ (%)	0.027	0.018 – 0.042	0.014 – 0.065	0.022
$\mathcal{B}(t \rightarrow Zc)$ (%)	0.118	0.071 – 0.222	0.049 – 0.484	0.049

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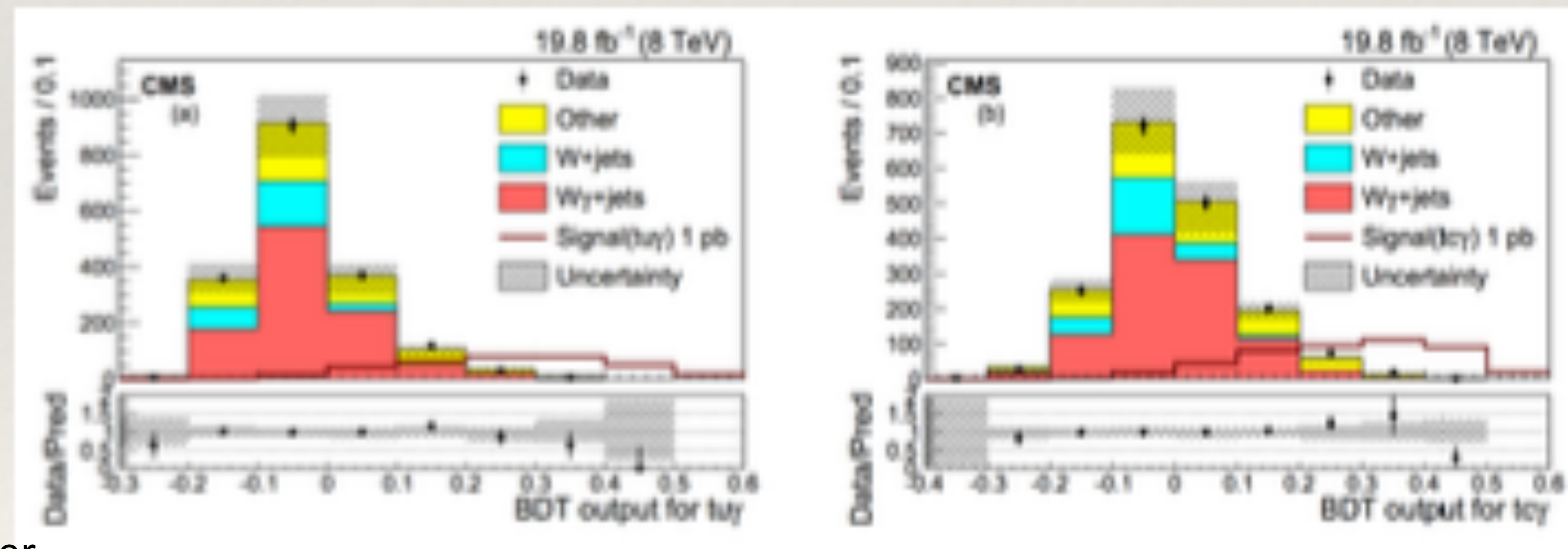
tqγ

- Search for FCNC interactions in tuγ and tcγ vertices.
  - High pT isolated photon due to recoil with the top quark.
  - No electrons are allowed.
  - At least one jet (at most one can be tagged as a b-jet).
  - Events with more than one b-jet are vetoed to suppress tt+γ.



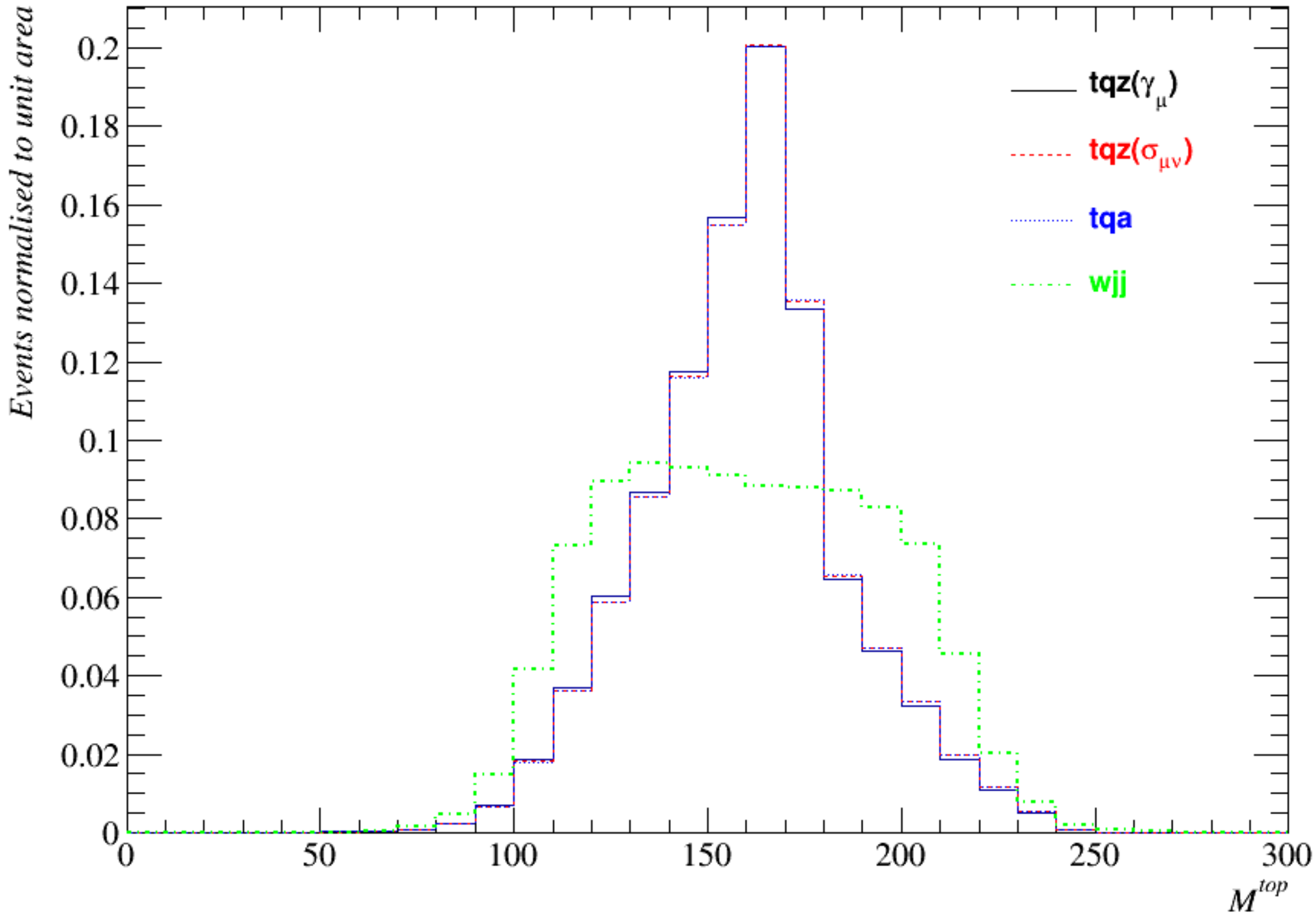
Upper limit

$$BR(t \rightarrow u+\gamma) < 1.3 \times 10^{-4} \; ; \; BR(t \rightarrow c+\gamma) < 1.7 \times 10^{-3}$$

Searches in FCC-ee

- The FCNC interaction $tq\gamma$ and tqZ lead to production of a top quark in association with a light quark in electron- positron collisions.
- MadGraph5 is used to generate the signal & background events. The signal and background events are generated in the center-of-mass energies of 240 GeV.
- The detector simulation is obtained using a preliminary Delphes card. The parameters used are:
- ◆ Magnetic field: 3.5 Tesla.
- ◆ ECAL CMS inspired.
- ◆ HCAL ILD inspired.
- ◆ B-tagging efficiency of 70% (pt>10 and |eta|<2.5) and Mis-tagging efficiency of 10% for c-jets.
- ◆ Mis-tagging efficiency of 1% for light quarks.
  ◆ Jets are reconstructed with Fast-Jet with a cone size of R=0.4.

Event reconstruction



Reconstructed top mass distribution for signal and background at 240 GeV

summary

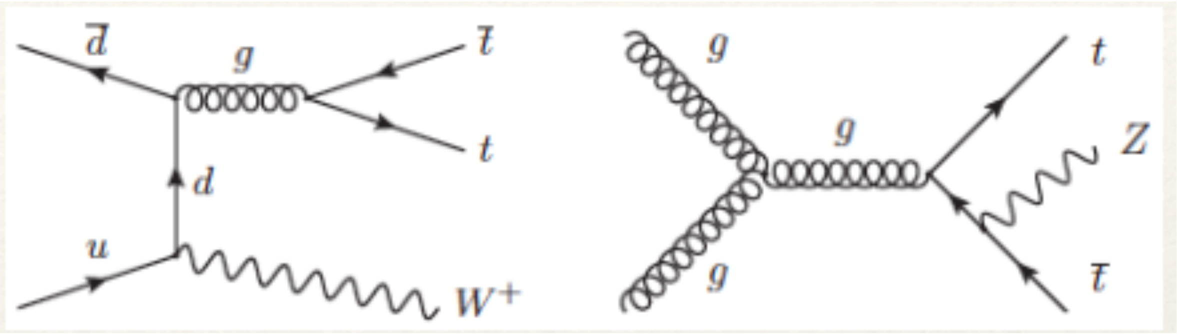
- Precise measurements of top quark properties and its couplings provide the possibility for accurate tests of the SM, being at the same time sensitive to new physics.
- With the LHC data the top quark physics has entered in a precision era.
- Limits on the effective couplings will be strengthened with the whole 13 TeV data.

Back up

Top quark couplings with Z,W-boson

Studying ttbar+V (V=Z,W) is very important as:

- ttZ and ttW backgrounds to new physics searches and ttH.
- Both σ(ttW) and σ(ttZ) would be altered in a variety of new physics models that can be parameterized by dimension-six operators added to the SM Lagrangian.



Anomalous Wtb couplings

- The most general, lowest-dimension, CP-conserving Lagrangian for the Wtb vertex has the following form:

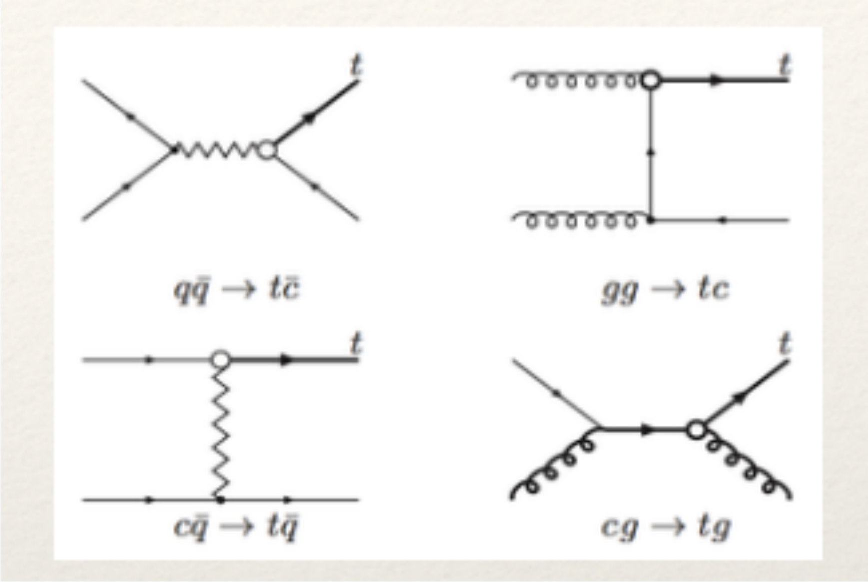
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\, t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)\, t\, W_{\mu}^{-}$$

- $V_L = V_{tb}$ and Vector (VR) and Tensor like couplings (g_L, g_R) zero @ tree level in SM.
- -Deviations from zero would provide hints of new physics.
- -Complex values could imply top quark decay has a CP-violating component.
- **New effective Wtb coupling can affect:**
- -The t-channel single top quark production.

$$\sigma = \sigma_{SM}\left(V_L^2 + \kappa^{V_R} V_R^2 + \kappa^{V_L V_R} V_L V_R + \kappa^{g_L} g_L^2 + \kappa^{g_R} g_R^2 + \kappa^{g_L g_R} g_L g_R + \ldots\right)$$

- Focused on a singly produced top quark with leptonic decay of the W boson:
- - Request exactly on isolated muon (rejection is applied on extra leptons passing quality criteria).
- - Either 2 or 3 jets with at least one tagged as b-jet.

tqg



tqH

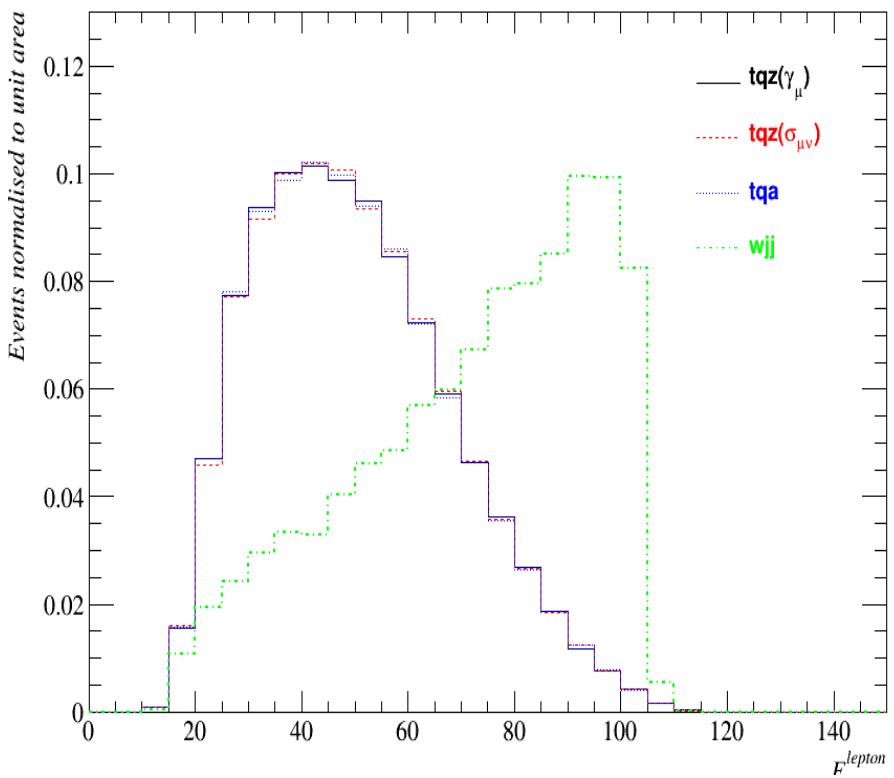
- Both tH and tHj channels are combined and H→bb is chosen as it has largest branching ratio.
- Final state consists of:

-One isolated lepton

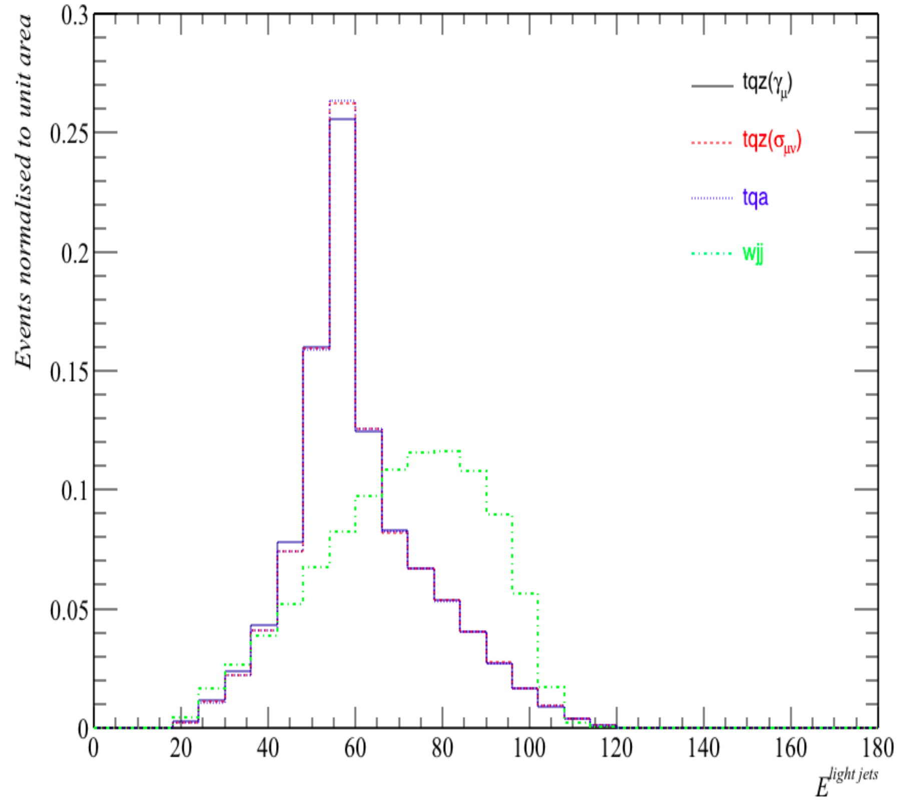
-At least three reconstructed jets, among which at least two are identified as b quark jets. -Exactly one lepton (electron, muon)

$$\mathcal{L} = \sum_{q=u,c} \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} \left(f^L_{Hq} P_L + f^R_{Hq} P_R \right) q H + \text{h.c.},$$

Secondary cuts



$E^{lepton} < 70$



$E^{light\ jets} < 70$