Prospect for top quark FCNC searches at the FCC-hh

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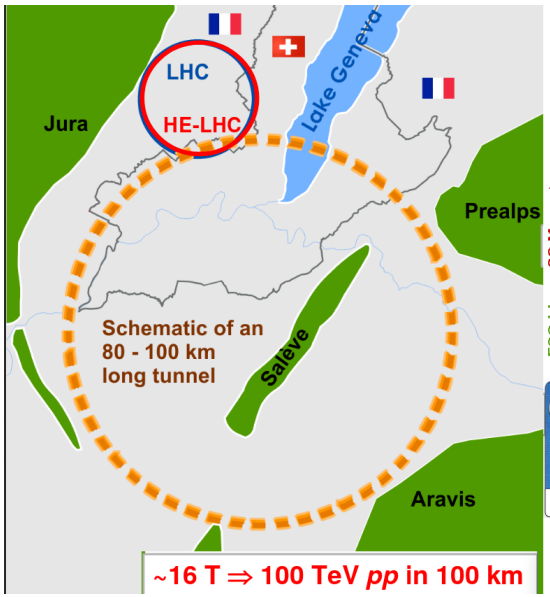
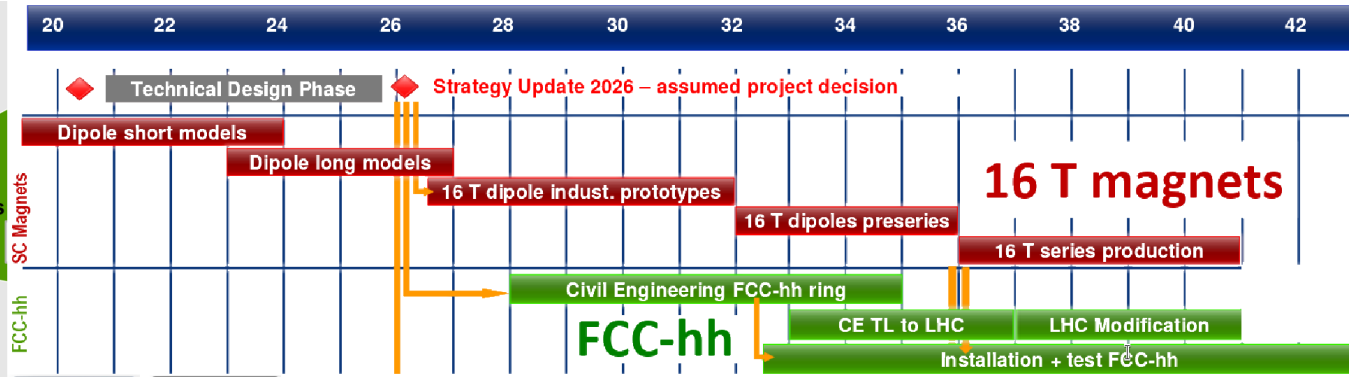
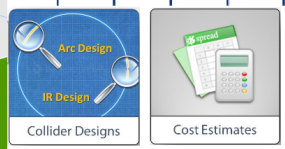
FCC-hh experiment

The Future Circular Collider - next generation hadron-hadron accelerator:

project	$\sqrt{s}$, TeV	$\mathcal{L}$, $\mathrm{sm}^{-2}\cdot\mathrm{c}^{-1}$	$\int \mathcal{L}$, ab^{-1}	$< \mu >$
LHC	7-13	$\approx 10^{34}$	0.3	10-40
HL-LHC	14	10^{35}	3	140-200
HE-LHC	27	2.5×10^{35}	12	800
SppC	75	1.2×10^{35}	15	400-500
FCC-hh	100	3×10^{35}	30	500-1000





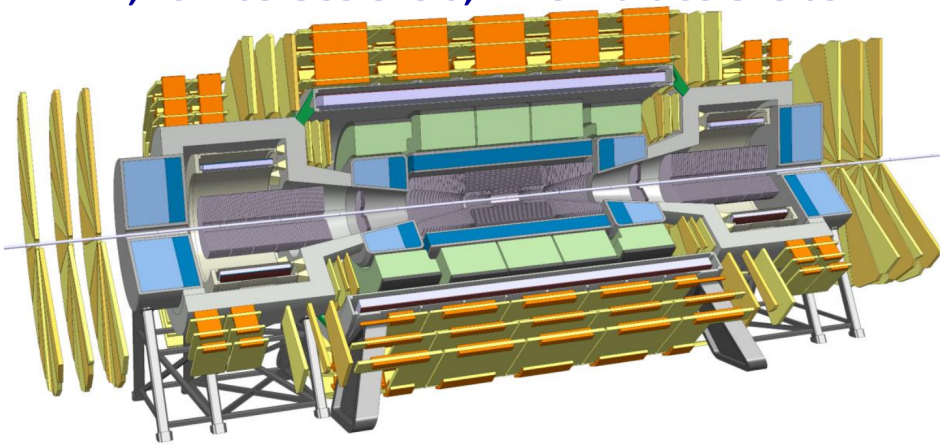


work in progress ...

schedule constrained by 16 T magnets & CE
→ earliest possible physics starting dates
- **FCC-hh: 2043**

FCC-hh reference detector

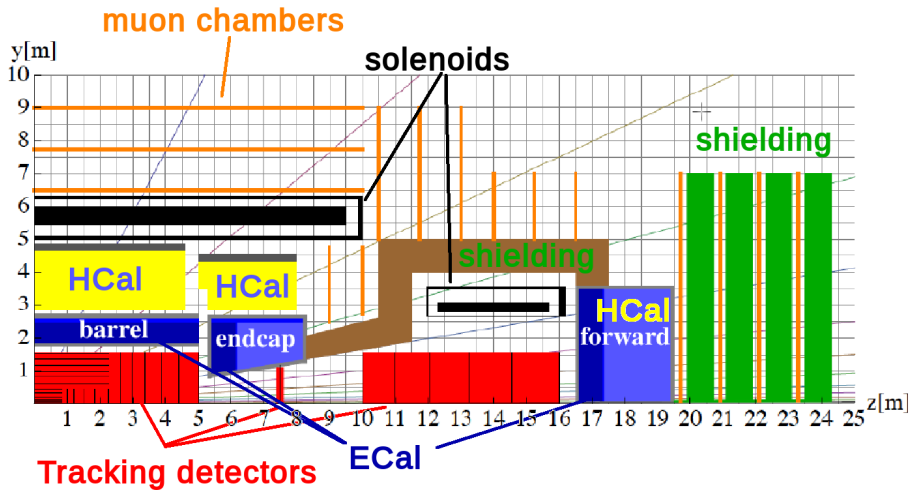
4T, 10m bore solenoid, 4T forward solenoids



→ 14 GJ Stored Energy **→ 15m shaft**

→ 20m Diameter (≈ ATLAS) **→ ≈ 1 Billion project**

→ Rotational symmetry for tracking and trigger !



Targets:

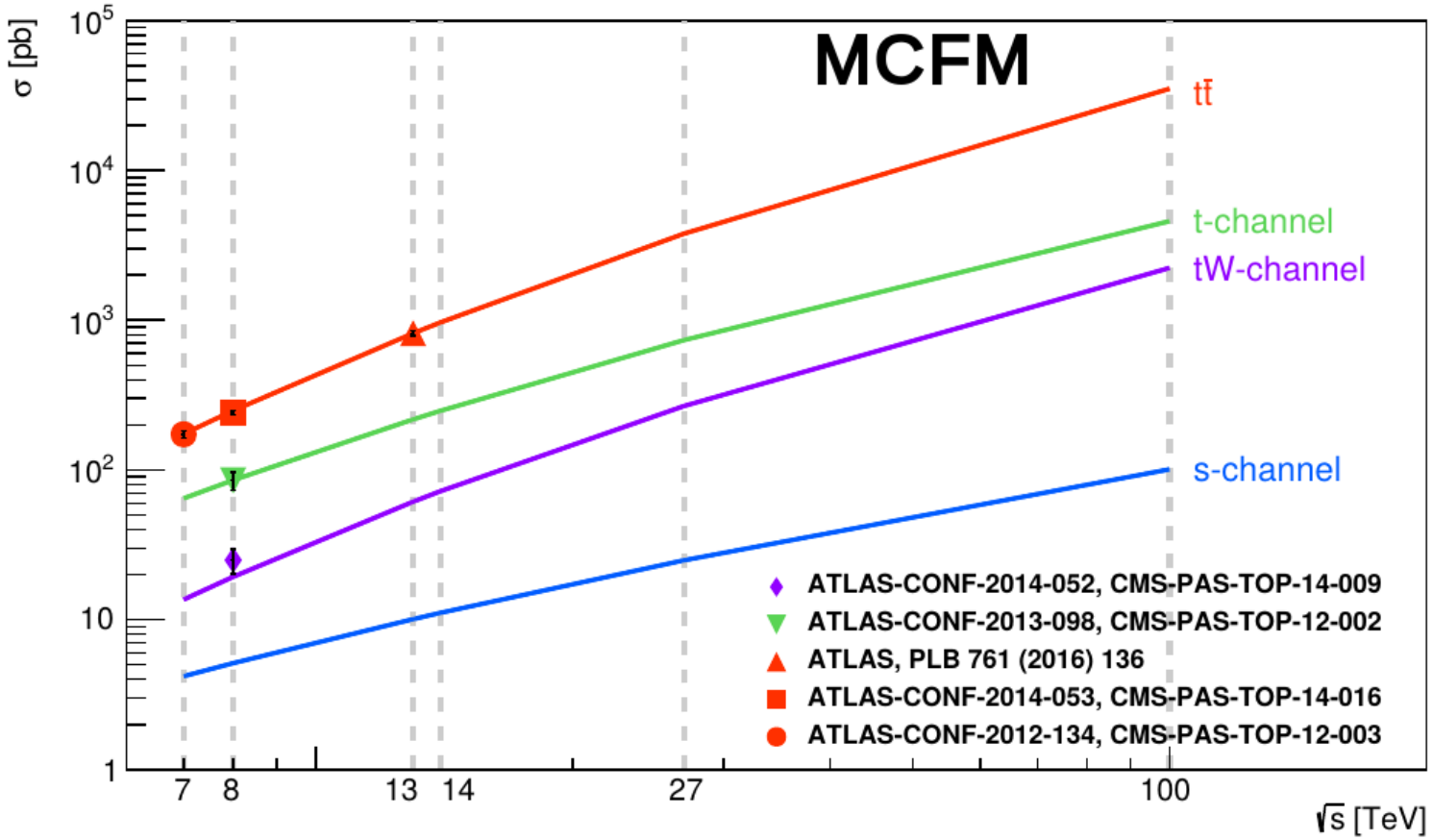
- Tracker - $\sigma_{p_T}/p_T < 20\%$ @ 10 TeV, $\sigma_{p_T}/p_T < 1\%$ @ low-p_T
- Muons system - $\sigma_{p_T}/p_T < 5\%$ @ 10 TeV (barrel)
- ECal - $\sigma_E/E < 10\%/\sqrt{E} \oplus 1\%$
- HCal - $\sigma_E/E < 60\%/\sqrt{E} \oplus 3\%$
- precision momentum spectroscopy up to $|\eta| < 4$

Clallenges:

- huge particle/data rates
- high pile-up rate $< \mu >= 500 - 1000$
- higher radiation level

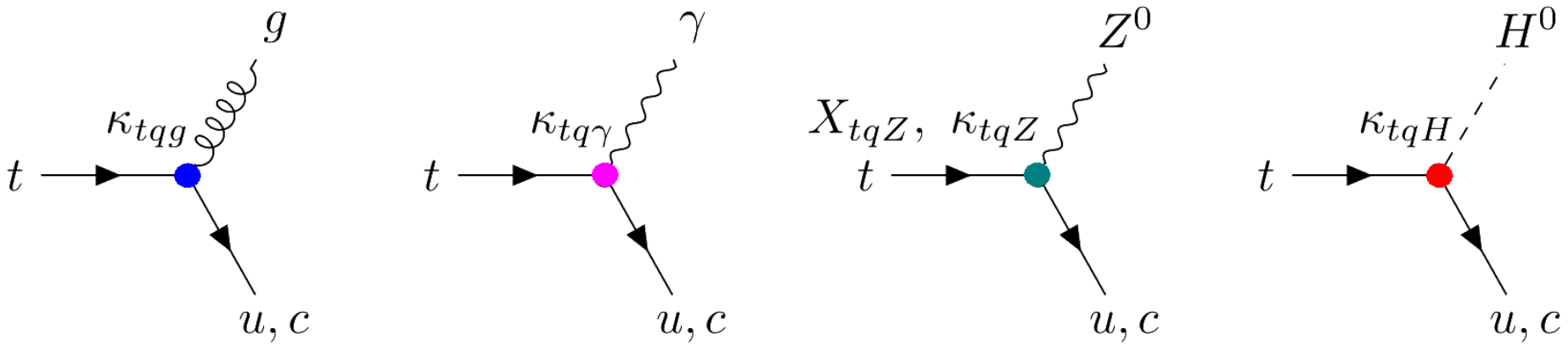
Large number of tops @ LHC $\Rightarrow$ 1000x more @ FCC-hh for:

- mass, width measurement
- kinematics, asymmetry study
- (anomalous) couplings measurement
- $\Rightarrow$ FCNC rare decays search $\Leftarrow$
- direct BSM search



Flavour changing neutral current in $t-$quark sector

- In the SM, FCNC decays are forbidden at tree level and have much smaller $\mathcal{B}$ at one loop level than the dominant decay mode $t \to bW$



- Model independent BSM physics searches via EFT; effective Lagrangian (up to dimension five):

$$-\mathcal{L} = g_s \kappa_{tqg} \bar{q}(g_L P_L + g_R P_R) \frac{i\sigma_{\mu\nu} q^\nu}{\Lambda} T^a t G^{a\mu} + e \kappa_{tq\gamma} \bar{q}(\gamma_L P_L + \gamma_R P_R) \frac{i\sigma_{\mu\nu} q^\nu}{\Lambda} t A^\mu +$$
$$+ \frac{g}{2c_W} X_{tqZ} \bar{q}(x_L P_L + x_R P_R) t Z^\mu + \frac{g}{2c_W} \kappa_{tqZ} \bar{q}(z_L P_L + z_R P_R) \frac{i\sigma_{\mu\nu} q^\nu}{\Lambda} t Z^\mu +$$
$$+ \frac{g}{2\sqrt{2}} \kappa_{tqH} \bar{q}(h_L P_L + h_R P_R) t H^\mu + h.c.,$$

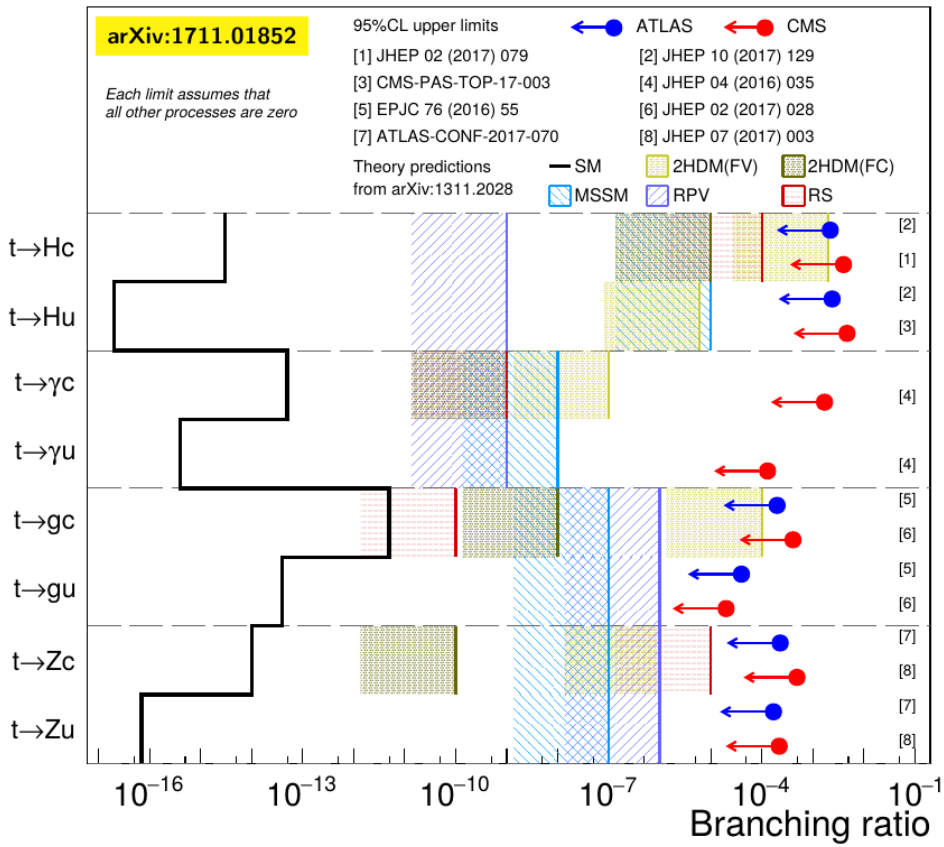
- BSM models predict higher $\mathcal{B}$ for top FCNC decays:

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

arXiv:1311.2028

- Hot topic at LHC during Run-I/-II era $\Rightarrow$
- Prospects for top quark FCNC searches at the HL/HE-LHC
- Powerful probe for new physics

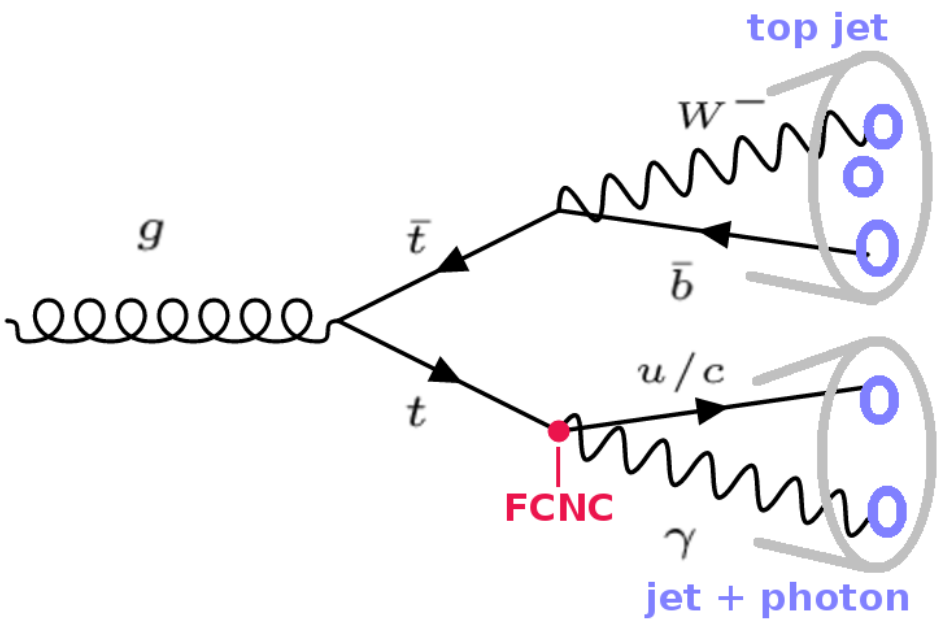
- No indication of FCNC transitions in $t-$quark sector so far:



$tq\gamma$ coupling

the most stringent upper limits are set by the CMS through single-top quark production in association with a photon

this analysis focusses on the boosted regime of $pp \to t\bar{t} \to q\gamma\bar{t}$



Final state signature:

- two fat ($R = 0.8$) highly energetic jets ($p_T > 400$ GeV)
- one highly energetic photon ($p_T > 200$ GeV) within one of the fat jets
- one b-tagged jet within another fat jet
- 0 or 1 highly energetic leptons (e or μ, $p_T > 25$)

Signals:

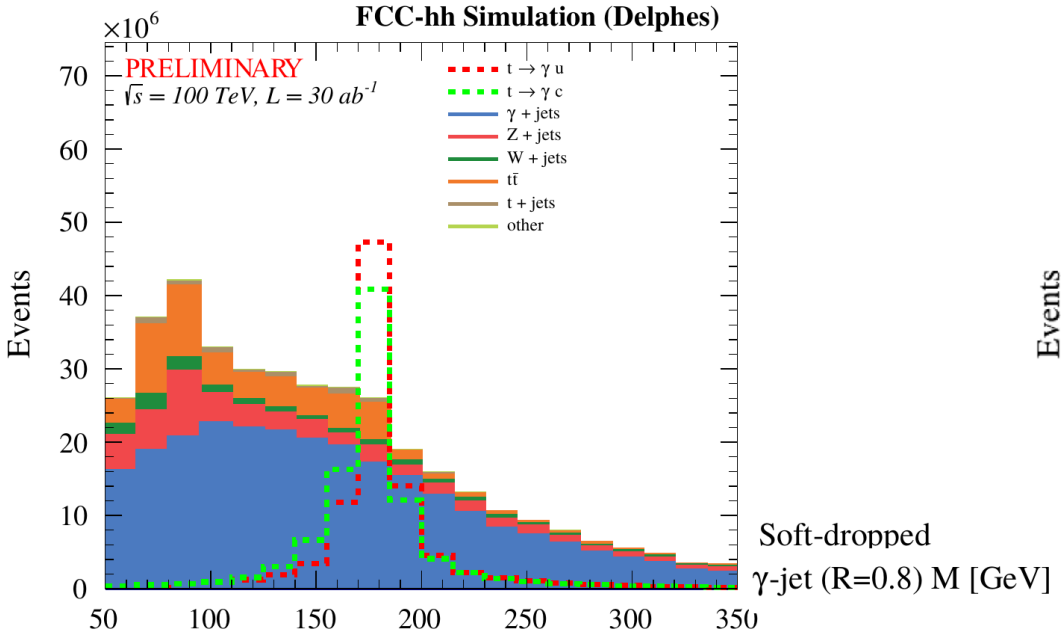
- $t \to c\gamma$, $t \to u\gamma$, $p_T(t) > 500$ GeV

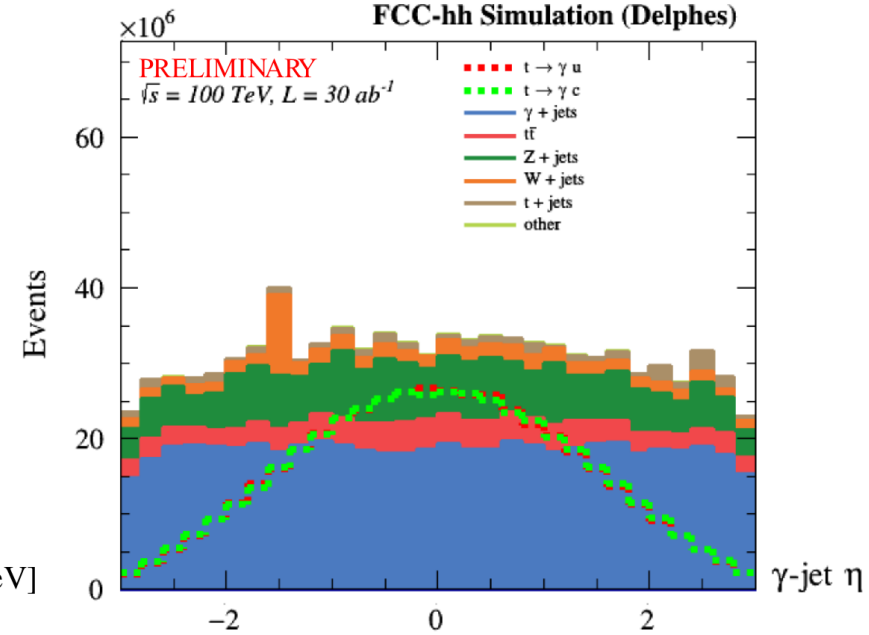
Backgrounds:

- $t\bar{t}$, $t\bar{t} + jets$, $t\bar{t} + \gamma$
- $t + jets$, $t + \gamma$
- $Z + jets$, $W + jets$, $W + \gamma$
- $\gamma + jets$ (Multijet QCD)

Generations:

- $MadGraph5\_aMC@NLO$ 2.5.5 (+ K-factors for signals and background samples).
- Showered and hadronized with Pythia 8.230.
- Detector effects with the fast simulation in Delphes 3.4.2.
- No pile-up simulation.



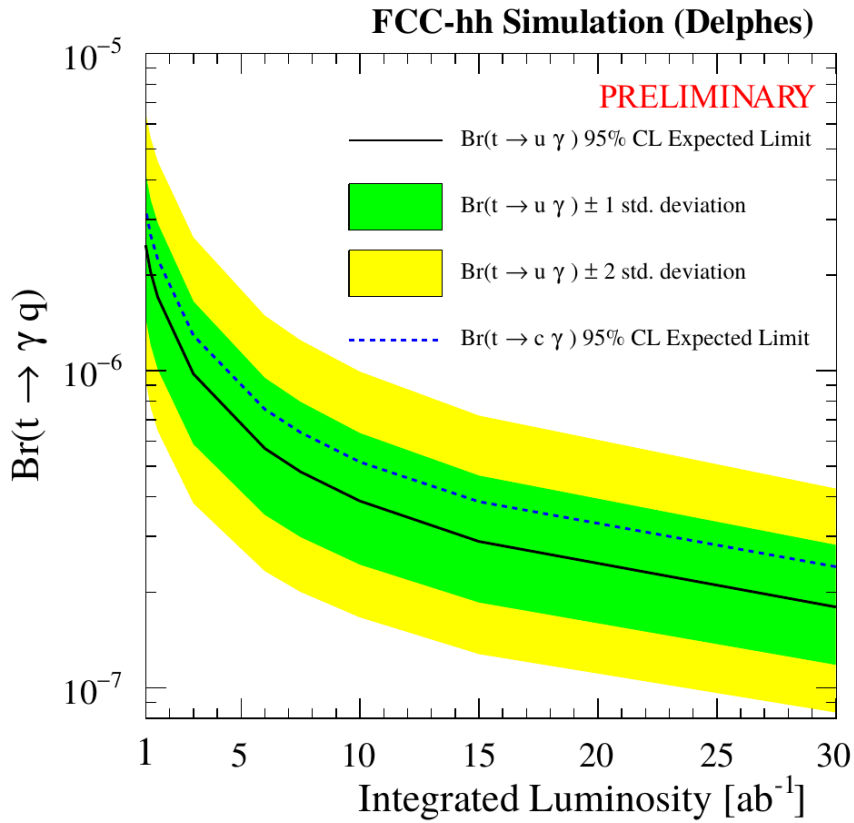


MVA analysis:

- TMVA BDT: τ_{21}, τ_{31}, SD masses of the fat jets, p_T of γ, fat jets, scalar product of γ and fat jets four-vectors, SD masses of fat jets most corresponds to the mass of top quark.

Statistical analysis:

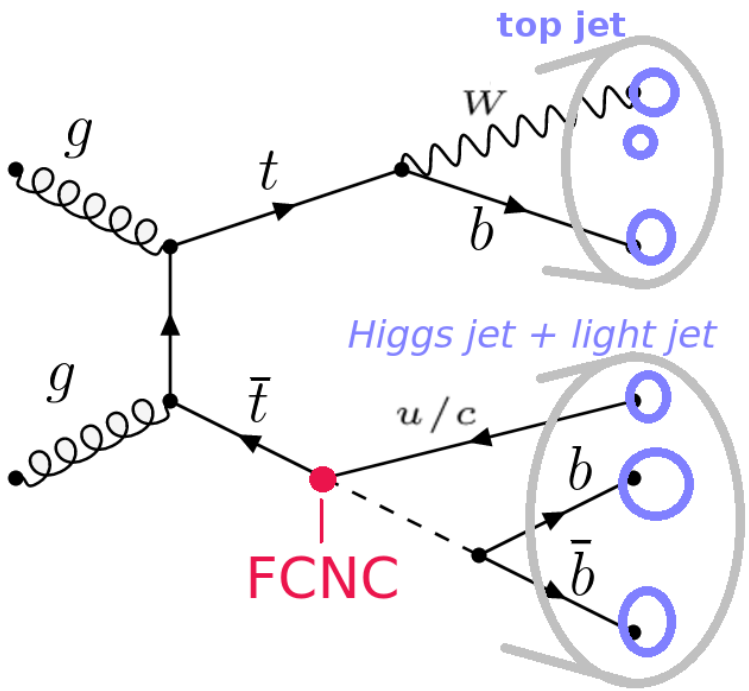
- for each background - 30% normalisation uncertainty
- asymptotic frequentist formulae



Detector	$\mathcal{B}(t \to u\gamma)$	$\mathcal{B}(t \to c\gamma)$	Ref.
CMS (19.8 fb^{-1}, 8 TeV)	13×10^{-5}	170×10^{-5}	arxiv:1511.03951
CMS Phase-2 (300 fb^{-1}, 14 TeV)	2.1×10^{-5}	15×10^{-5}	arxiv:1808.09915
CMS Phase-2 (3 ab^{-1}, 14 TeV)	0.9×10^{-5}	7.4×10^{-5}	arxiv:1808.09915
FCC-hh (3 ab^{-1}, 100 TeV)	9.8×10^{-7}	12.9×10^{-7}	preliminary
FCC-hh (30 ab^{-1}, 100 TeV)	1.8×10^{-7}	2.4×10^{-7}	preliminary

tqH coupling

boosted regime of $pp \to t\bar{t} \to qH\bar{t}$, $H \to b\bar{b}$



Final state signature:

- two fat ($R = 0.8$) highly energetic jets (leading with $p_T > 500$ GeV, second - $p_T > 300$ GeV)
- one b-tagged jet within one of the fat jets
- two b-tagged jets within another fat jet
- $\Delta\phi(\text{fat jets}) < 1.0$

Signals:

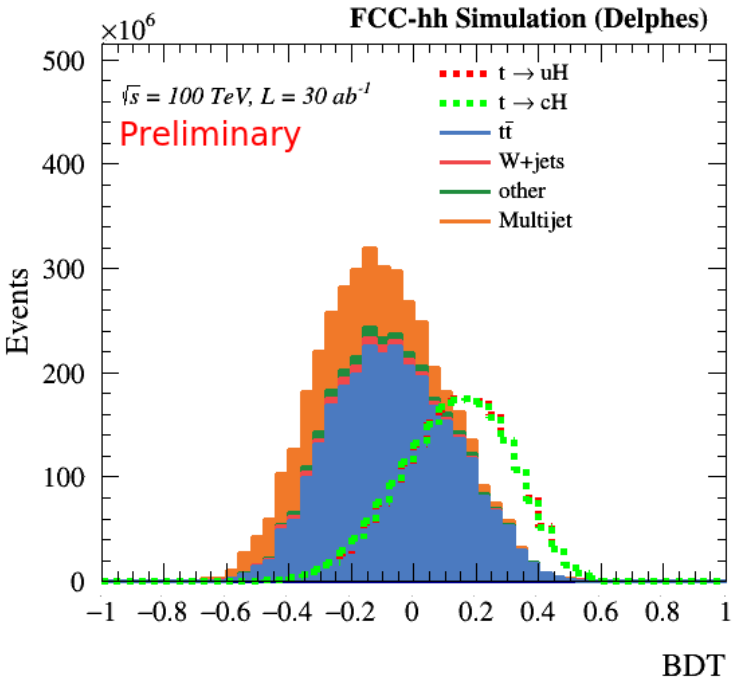
- $t \to cH \to cb\bar{b}$, $t \to uH \to ub\bar{b}$, $p_T(t) > 500$ GeV

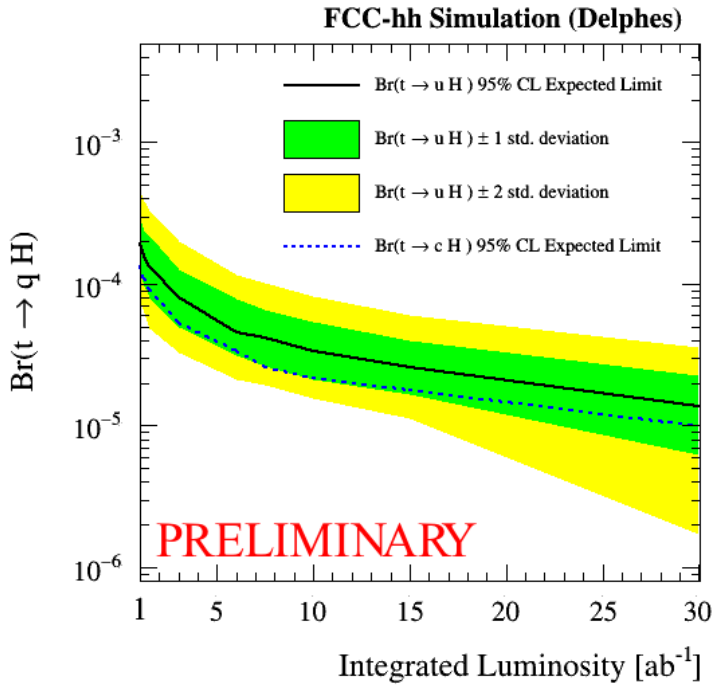
Backgrounds:

- $t\bar{t}$, $t\bar{t} + jets$, $t\bar{t} + H$, $W + jets$, $t + Z$, $t + W$, multijet QCD

MC generation and statistical analyses workflow is the same as for $tq\gamma$.

MVA analysis with TMVA BDT: τ variables, SD masses of the fat jets, p_T and masses of the H and W candidates combined from subjets, mass disbalance.





Detector	$\mathcal{B}(t \to u\gamma)$	$\mathcal{B}(t \to c\gamma)$	Ref.
CMS (36.1 fb^{-1}, 13 TeV)	4.7×10^{-3}	4.7×10^{-3}	arXiv:1712.02399
ATLAS (36.1 fb^{-1}, 13 TeV)	1.9×10^{-3}	1.6×10^{-3}	arXiv:1805.03483
FCC-hh (3 ab^{-1}, 100 TeV)	8.1×10^{-5}	5.3×10^{-5}	preliminary
FCC-hh (30 ab^{-1}, 100 TeV)	1.4×10^{-5}	1.0×10^{-5}	preliminary

Conclusions

The FCC-hh will be able to deliver up to trillion of tops $\Rightarrow$ great opportunity to challenge the SM by searching for FCNC;
Searches for FCNC in $t \to q\gamma$ and $t \to qH$ events are projected into the FCC-hh conditions and showed the possibility of improving existing constraints on the branchings by about two order of magnitude.
Further improvements can be obtained from the combinations with different analysis strategy (resolved analysis, single top production, ...)
The workflow for the physical analysis based on fast MC simulation of the FCC-hh is established $\Rightarrow$ great possibility to participate in short-term physical analysis for masters and PhD students