Measurements of the top-quark properties in the production and decays of $t\bar{t}$ events at CMS

Pieter David
on behalf of the CMS collaboration

DIS 2017
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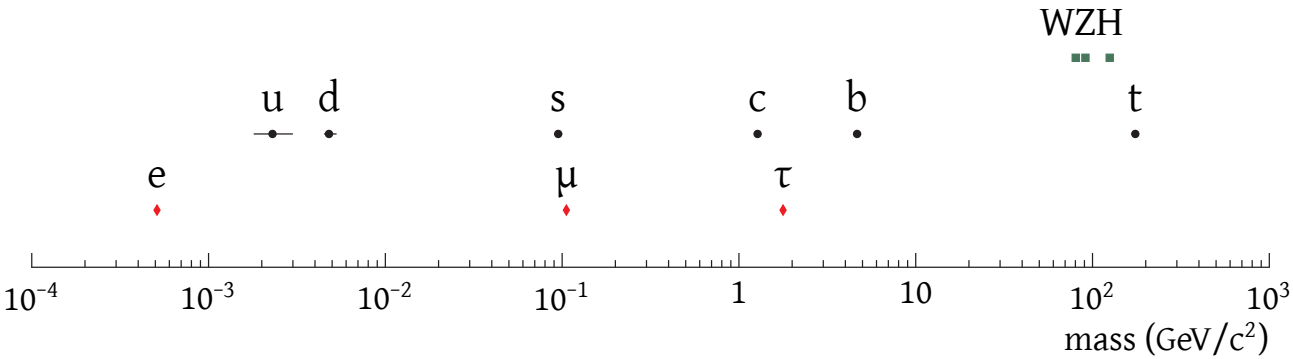
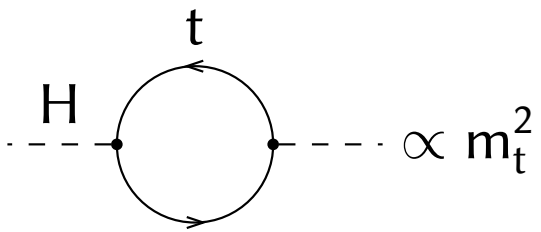
Why top quark properties?



- Only fermion with an electroweak-scale mass, more massive than W, Z, H
- $\tau_{\text{decay}} < \tau_{\text{hadronisation}}$: study a bare quark
- Interesting probe of EWSB
- Plays a prominent role in many proposed BSM theories
- The LHC is a top factory
  $\sigma(pp \to t\bar{t}) \approx 835\,\text{pb}$ at 13 TeV



$$(|V_{i_u j_d}^{CKM}|) = \begin{pmatrix} \bullet & \bullet & \cdot \\ \bullet & \bullet & \cdot \\ \cdot & \cdot & \bullet \end{pmatrix}$$

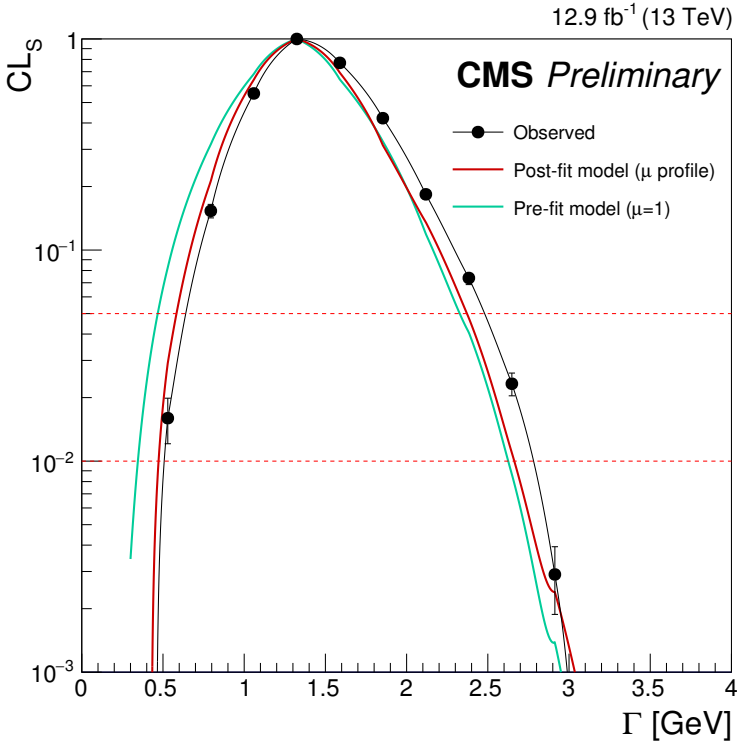
A variety of top quark properties measurements

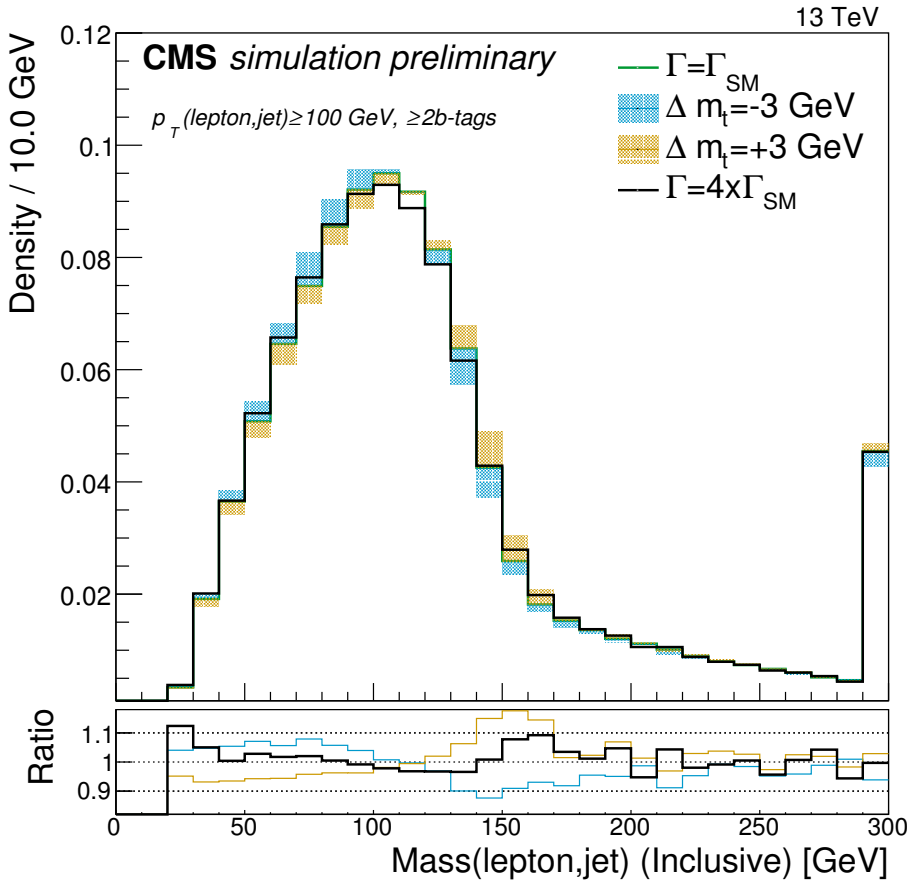
- $pp \to t\bar{t}$ production and modeling $\longrightarrow$ Juan Gonzalez, earlier today
- top properties in single top $\longrightarrow$ Ashfaq Ahmad, later in this session
- top quark mass, $m(t) - m(\bar{t})$ $\longrightarrow$ Nataliia Kovalchuk, this afternoon
- top quark width
- angular distributions of $pp \to t\bar{t}$ production and $t \to Wb$ decay
  - t polarization and spin correlations
  - W helicity fractions
  - charge asymmetry
- CP violation in $pp \to t\bar{t}$ production and $t \to Wb$ decay
- FCNC decays : $t \to Hu$, $t \to Hc$, $t \to Zq$, $t \to \gamma q$, $t \to ug$, $t \to cg$
- t-H coupling $pp \to t\bar{t}H$, $pp \to tHq$ $\longrightarrow$ Georgios Krintiras, WG3
- t-V couplings: $pp \to t\bar{t}V$ $(V = \gamma, Z, W)$

Bounding the top quark width using dilepton events

CMS-PAS-TOP-16-019

- $12.9\,\text{fb}^{-1}$ at $\sqrt{s} = 13\,\text{TeV}$
- Sensitive variable: $m(\ell b)$
- Distribution for various Γ_t obtained by reweighting between Γ_{SM} and $4\Gamma_{SM}$





- Likelihood test statistic to discriminate between Γ_{SM} and Γ_{alt}
- 95% CL bound of $0.6 \leq \Gamma_t \leq 2.5\,\text{GeV}$ expected: $[0.6, 2.4]$ ($m_t = 172.5\,\text{GeV}$)

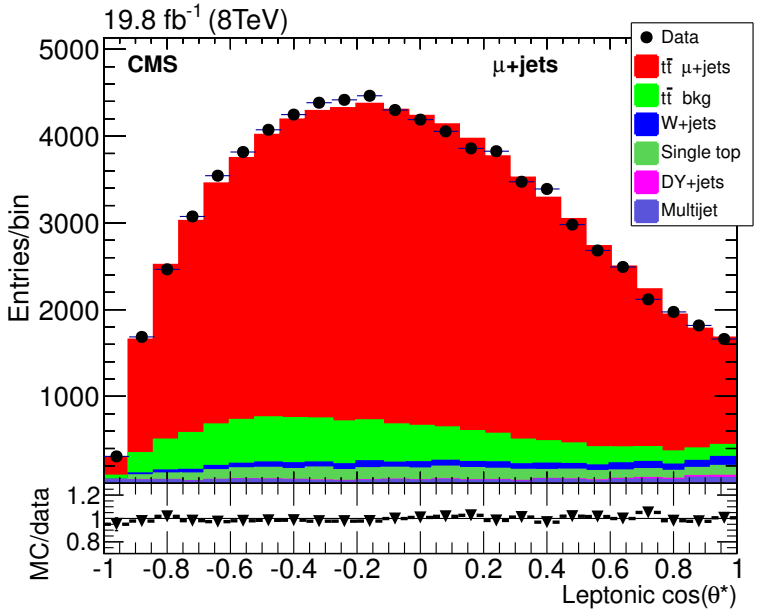
$W^{\pm}$ helicity fractions in $t\bar{t} \rightarrow$ lepton + jets

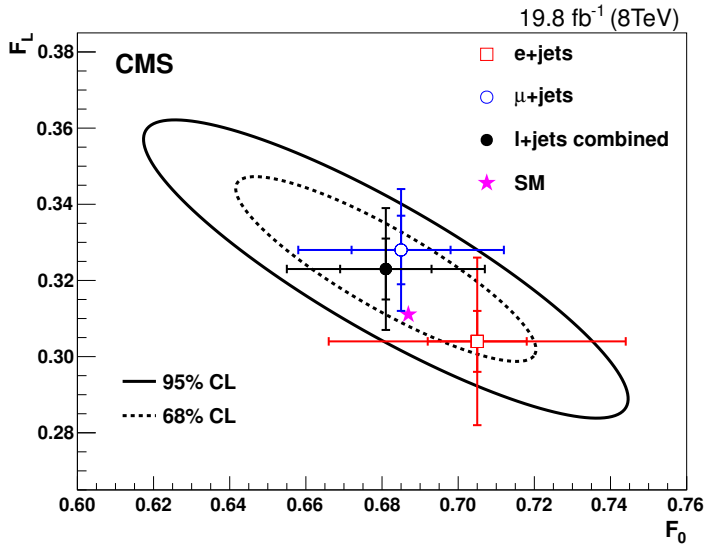
PhysLett**B762**(2016)512

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

- Kinematic fit (using t and W mass constraints) for the reconstruction of the complete $t\bar{t}$ system
- Maximum likelihood template fit to $\cos\theta^*_{\ell}$ and $|\cos\theta^*_{q}|$ distributions (parameterized as function of helicity fractions using simulation)

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{4}(\sin\theta^*)^2 F_0 + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

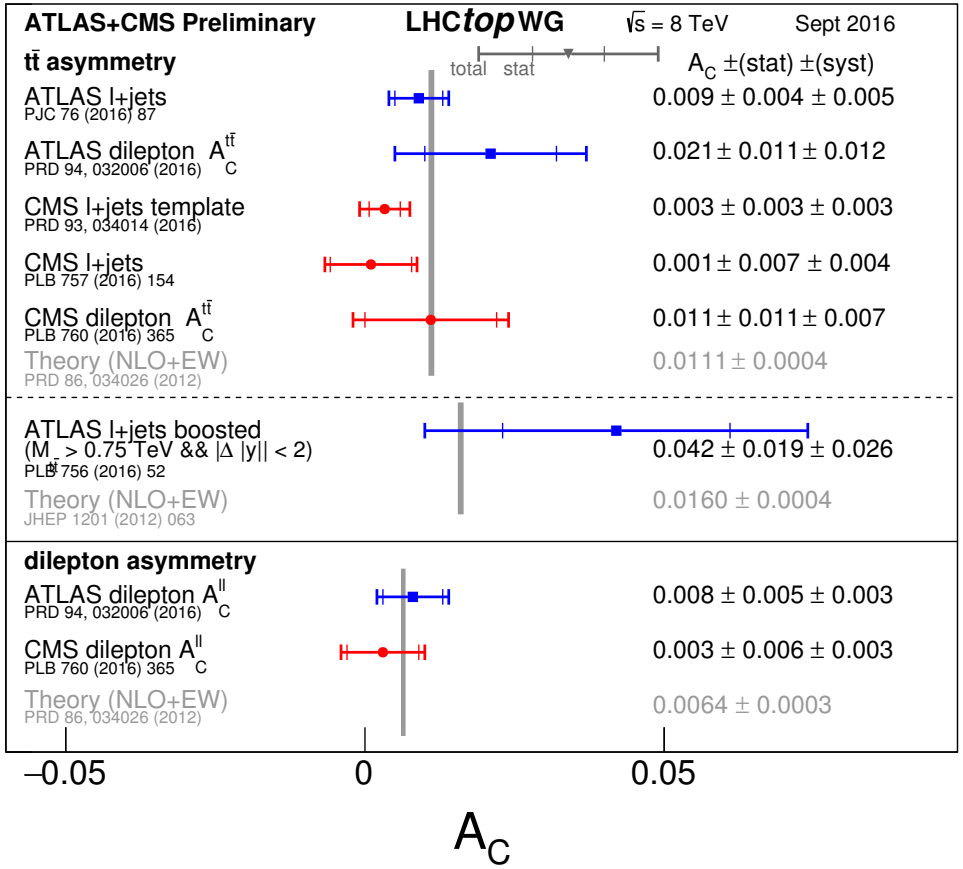




Charge asymmetry in $pp \to t\bar{t}$

→ full list of CMS results

- the $t\bar{t}$ charge asymmetry can be probed through the rapidity asymmetries $\frac{N(|\eta|_t > |\eta|_{\bar{t}}) - N(|\eta|_t < |\eta|_{\bar{t}})}{N(|\eta|_t > |\eta|_{\bar{t}}) + N(|\eta|_t < |\eta|_{\bar{t}})}$ and $\frac{N(|\eta|_{\ell+} > |\eta|_{\ell-}) - N(|\eta|_{\ell+} < |\eta|_{\ell-})}{N(|\eta|_{\ell+} > |\eta|_{\ell-}) + N(|\eta|_{\ell+} < |\eta|_{\ell-})}$ in pp collisions
- valence quark effect, so SM value smaller at 13 TeV ($pp \to t\bar{t}$ dominated by gg)
- enhanced sensitivity to SM asymmetry by studying kinematic dependence, specific phase space regions, or using optimised observables



CP violation in $pp \to t\bar{t} \to$ lepton + jets at $\sqrt{s} = 8$ TeV

arχiv:1611.08931 submitted to JHEP

- asymmetry $\frac{N(O_i>0)-N(O_i<0)}{N(O_i>0)+N(O_i<0)}$ of T-odd triple products

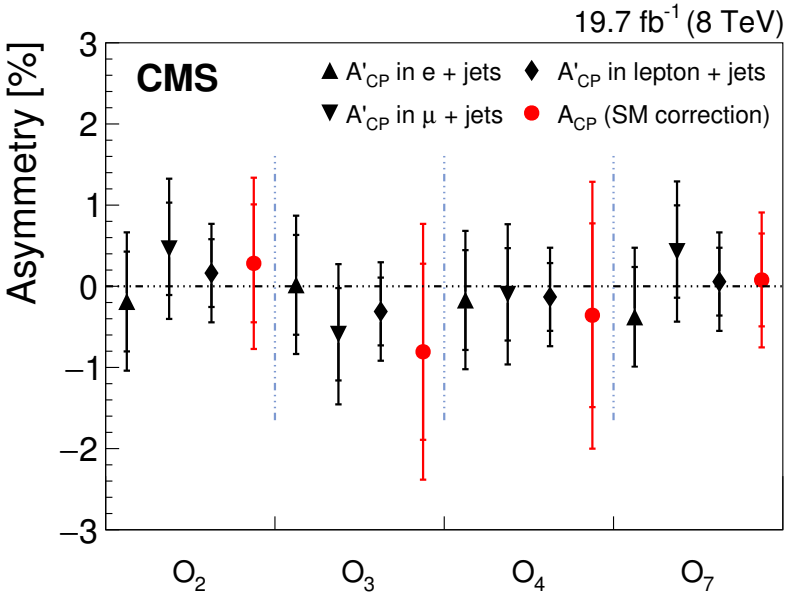
$$O_2 = \varepsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{\text{lab}} \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_3 = Q_\ell \varepsilon(p_b, p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{b\bar{b}\,\text{CM}} \propto Q_\ell \vec{p}_b \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_4 = Q_\ell \varepsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{\text{lab}} \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_7 = q \cdot (p_b - p_{\bar{b}}) \varepsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{\text{lab}} \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$

probes CP violation in $pp \to t\bar{t}$ production and decay to ℓ+jets



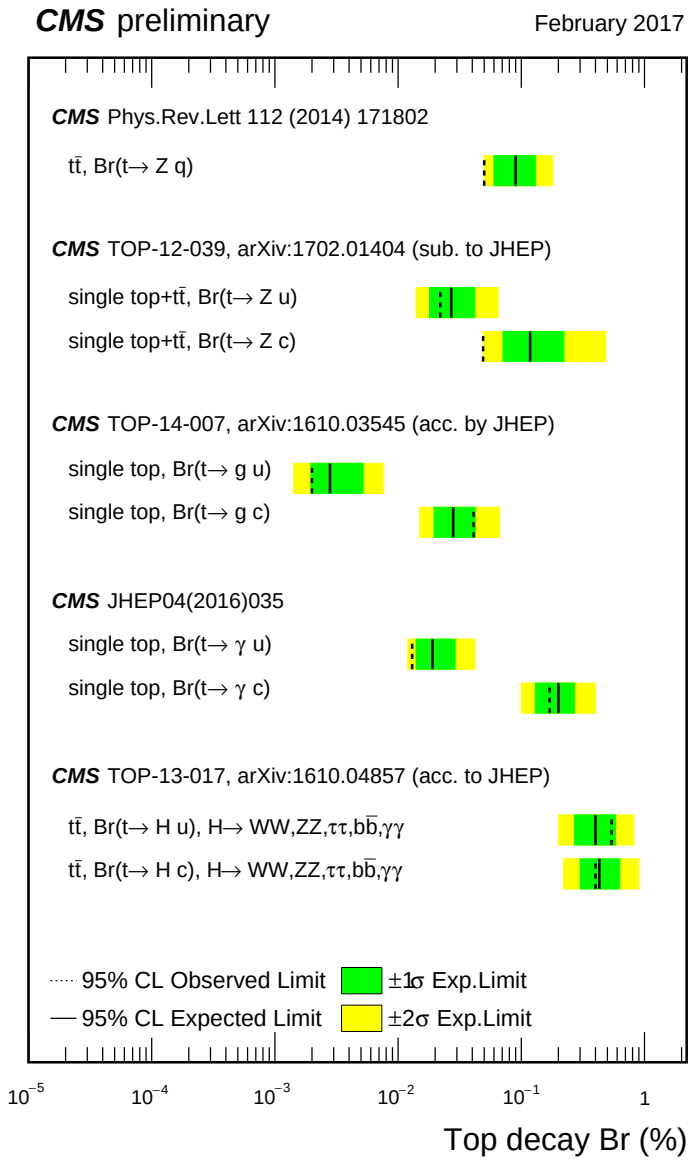
$$A'_{CP} = \mathcal{D} A_{CP} \qquad \mathcal{D} = 1 - 2k$$

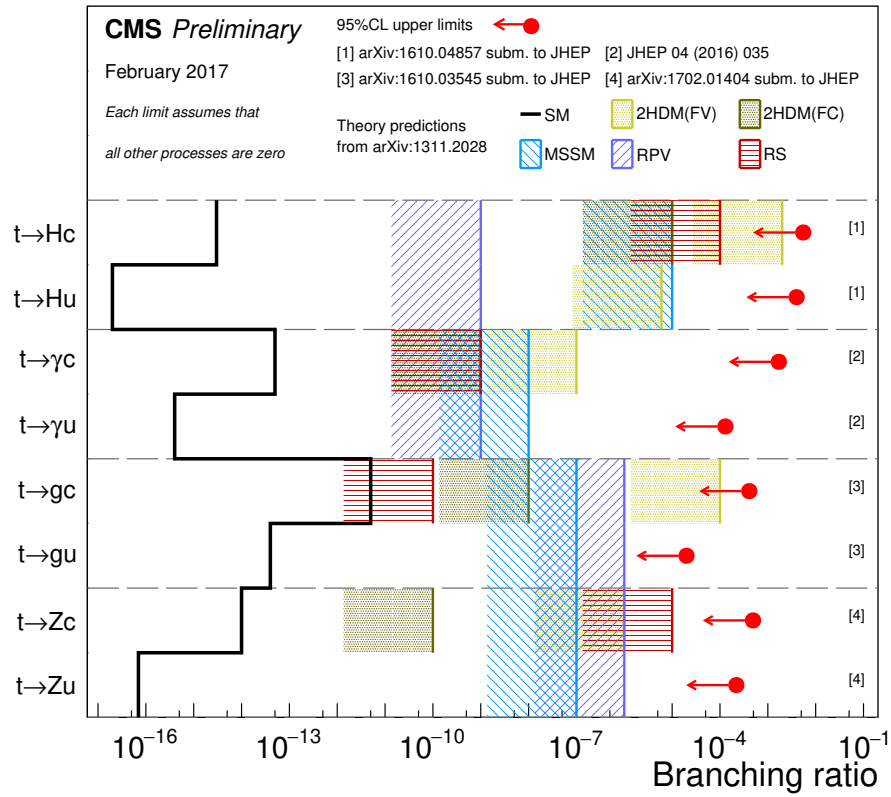
- bounds at the 1–2% level, SM values are extremely small

	k (%)	$\mathcal{D}$
O_2	$21.27 \pm 0.10 \pm 0.97$	$0.575 \pm 0.002 \pm 0.019$
O_3	$30.86 \pm 0.10 \pm 0.90$	$0.383 \pm 0.002 \pm 0.018$
O_4	$31.65 \pm 0.10 \pm 0.95$	$0.367 \pm 0.002 \pm 0.019$
O_7	$13.52 \pm 0.11 \pm 0.50$	$0.730 \pm 0.002 \pm 0.010$

Searches for FCNC top decays

→ full list of CMS results



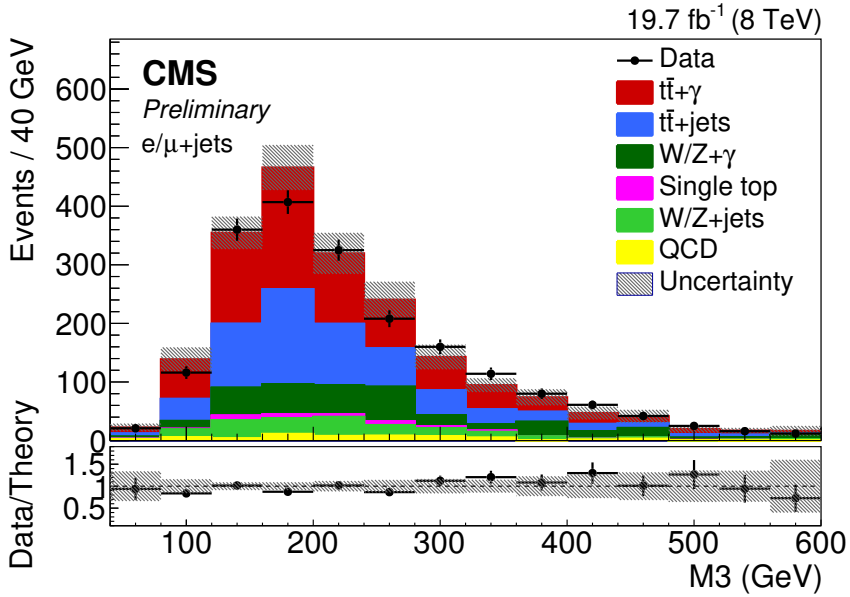


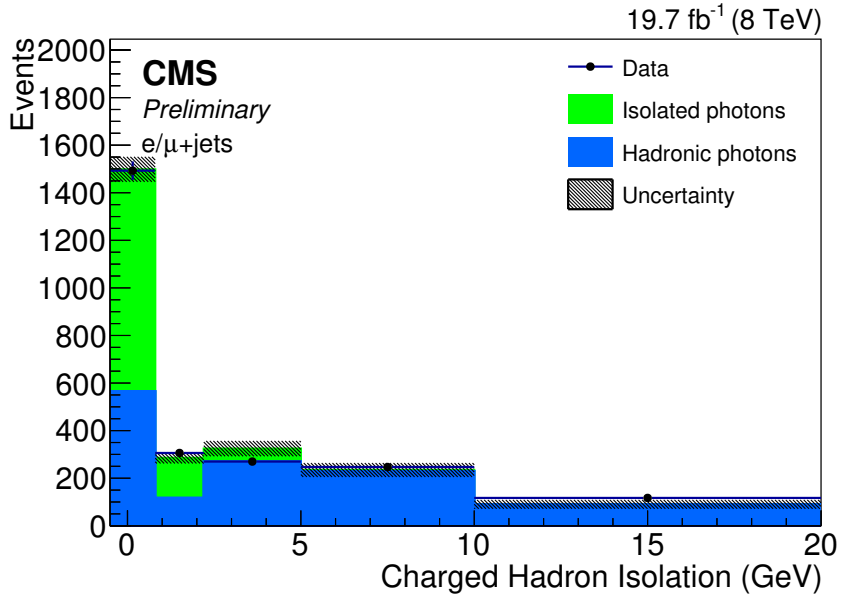
see the talk by Ashfaq Ahmad later in this session for more details on FCNC constraints in single top production

$pp \to t\bar{t} + \gamma$ cross-section at $\sqrt{s} = 8$ TeV

CMS-PAS-TOP-14-008

- Fiducial region: photon $E_T > 25$ GeV, $|\eta| < 1.44$
- $t\bar{t}$+jets and V+γ backgrounds determined from fits to M3 (hadronic top mass) and photon isolation (with templates from data: random cone (PU) for isolated, photon η spread sideband for photons from jets)
- $e \to \gamma$ mis-ID rate corrected with $Z \to e^+e^-$
- $\sigma^{fid}_{t\bar{t}+\gamma}/\sigma_{t\bar{t}} = 5.2 \pm 1.1 \times 10^{-4}$(stat+syst)
  $\sigma^{fid}_{t\bar{t}+\gamma} = 127 \pm 27$(stat+syst) fb
- photon E_T and η distributions in good agreement with simulation





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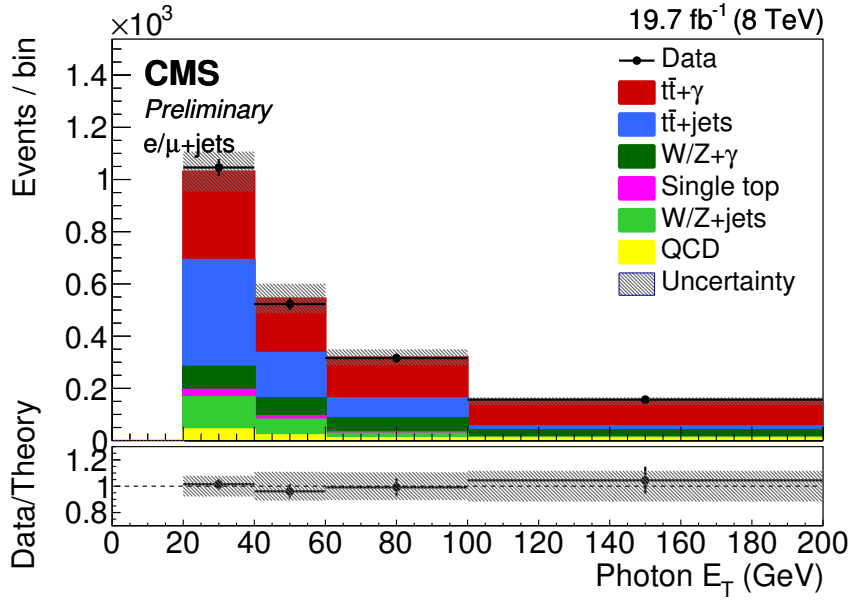
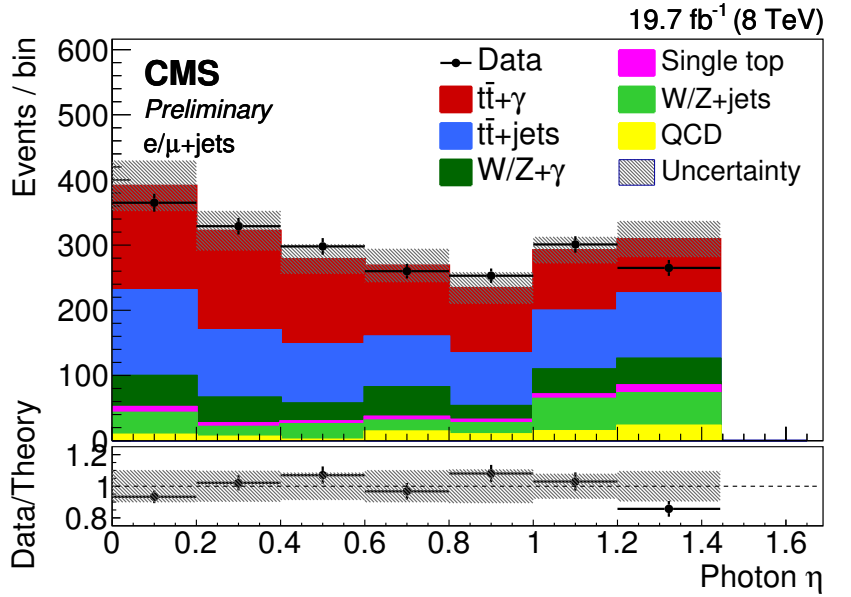
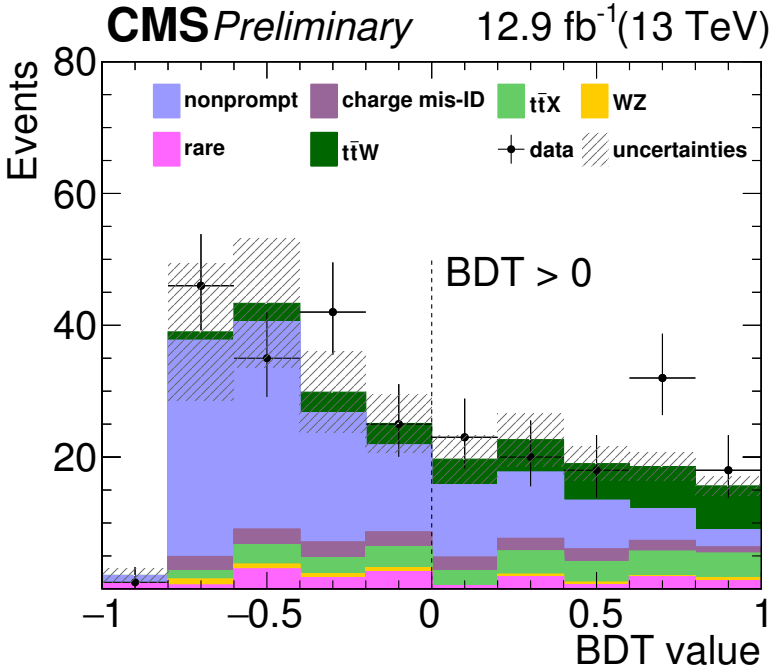


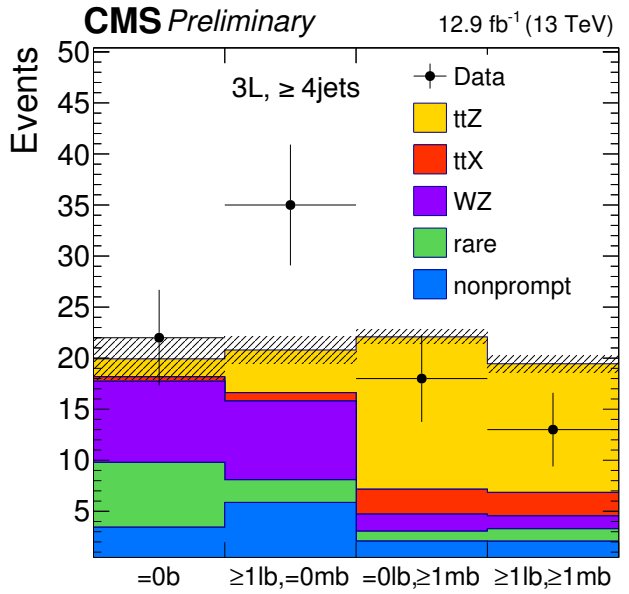


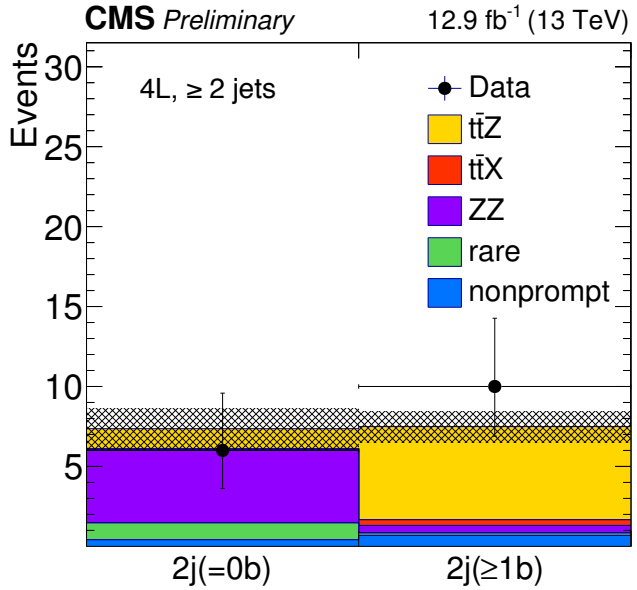
$pp \to t\bar{t} + W/Z$ cross-sections at $\sqrt{s} = 13$ TeV

CMS-PAS-TOP-16-017

- $12.9\ fb^{-1}$ of 2016 data
- (same-sign) dilepton, three-lepton and four-lepton categories
- Data-driven non-prompt lepton background, WZ from control region



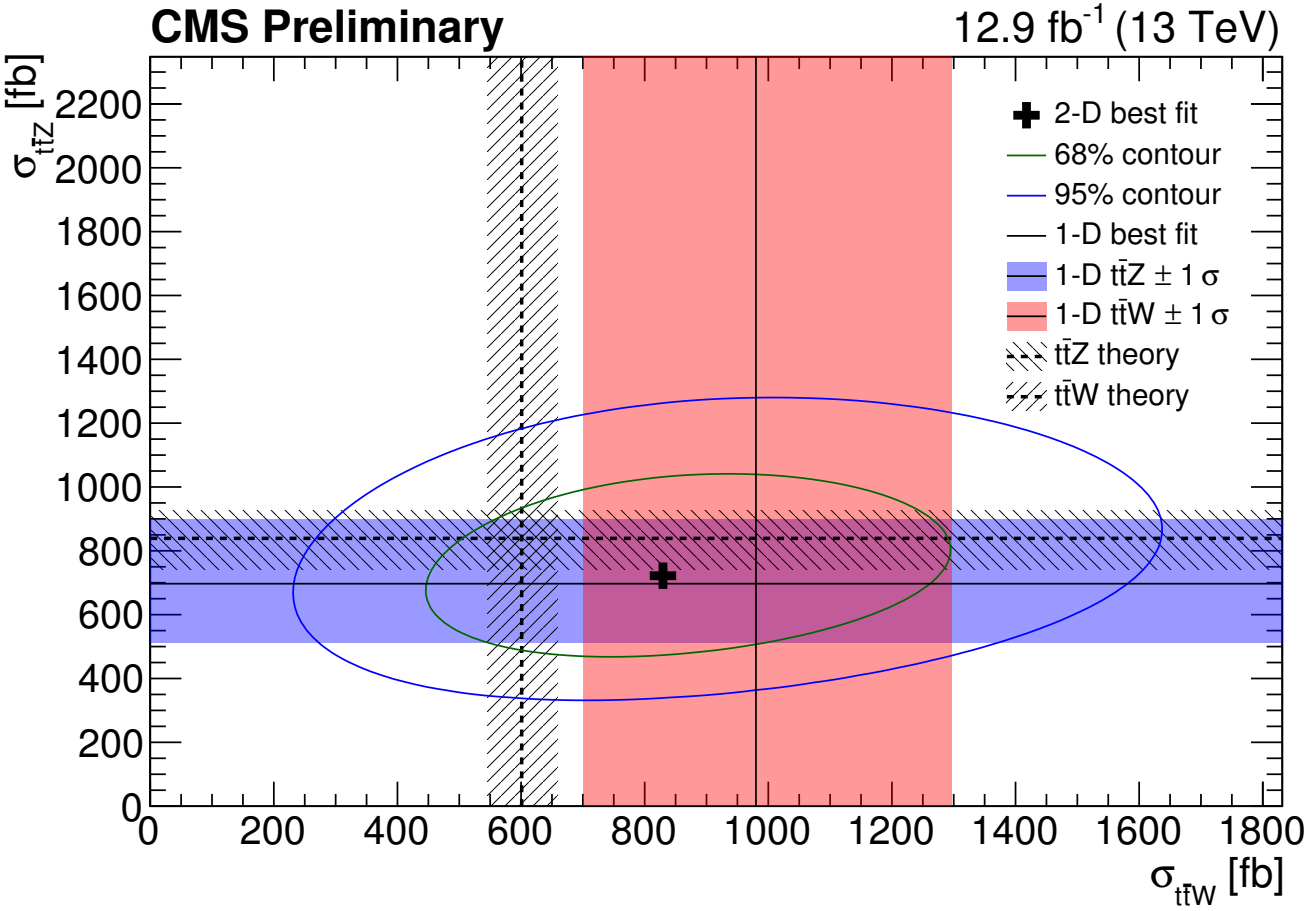




$pp \to t\bar{t} + W/Z$ cross-sections at $\sqrt{s} = 13$ TeV

CMS-PAS-TOP-16-017

$$\sigma(pp \to t\bar{t}Z) = 0.70^{+0.16}_{-0.15}\,(\text{stat.})\,^{+0.14}_{-0.12}\,(\text{sys.})\ \text{pb}$$
$$\sigma(pp \to t\bar{t}W) = 0.98^{+0.23}_{-0.22}\,(\text{stat.})\,^{+0.22}_{-0.18}\,(\text{sys.})\ \text{pb}$$



Conclusions

- Top properties analyses allow to constrain BSM physics in various ways
- Many measurements performed by CMS with run 1 data
- $\sqrt{s} = 13\,\text{TeV}$: boost in cross-section, especially interesting for rare decay modes and production processes, *e.g.* $t\bar{t}$+X
- 2016 dataset: $36\,\text{fb}^{-1}$, many more $t\bar{t}$ pairs than run 1
- many improved and new top properties measurements are in preparation

Additional material

References

- CMS collaboration, Bounding the top quark width using final states with two charged leptons and two jets at $\sqrt{s} = 13$ TeV, CMS-PAS-TOP-16-019, 2016.
- CMS collaboration, Measurement of the W boson helicity fractions in the decays of top quark pairs to lepton + jets final states produced in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Lett. **B762** (2016) 512, arχiv:1605.09047.
- CMS collaboration, Search for CP violation in top quark-antiquark production and decay in proton-proton collisions at $\sqrt{s}$ = 8 TeV, CMS-TOP-16-001, CERN-EP-2016-266, arχiv:1611.08931, submitted to JHEP.
- CMS collaboration, Measurement of the $t\bar{t}+\gamma$ production cross-section in pp collisions at $\sqrt{s} = 8$ TeV, CMS-PAS-TOP-14-008, 2016.
- CMS collaboration, Measurement of the top pair-production in association with a W or Z boson in pp collisions at 13 TeV, CMS-PAS-TOP-16-017, 2016.