Search for the associated production of a single top quark with a Z boson in pp collisions at 8TeV

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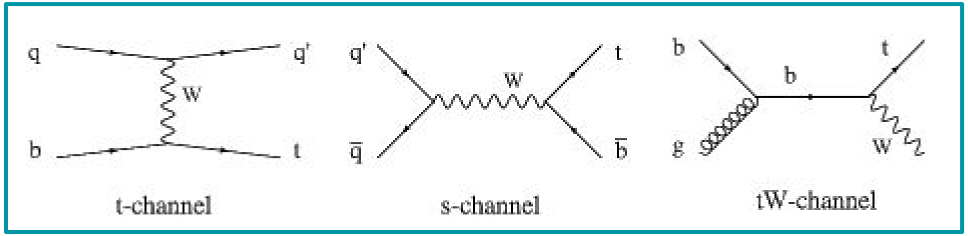
Introduction

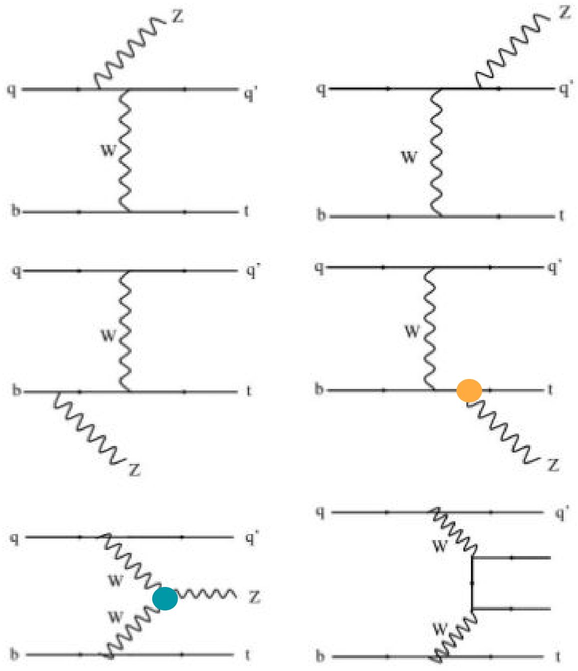
- Top quarks arise predominantly from top-antitop pair production (**ttbar production**) via strong interaction.
- They are also produced singly from EW processes (**single top production**) through three different production mechanisms, categorised by the virtuality of the W boson involved:
    - t-Channel
    - s-Channel
    - tW associated production



- Increasing luminosity and COM energy at LHC motivate the search for rare SM single top production, such as the production of a **single top in association with a Z boson**.
    - Standard Model tZq production (**tZq-SM**)
    - Flavour changing neutral current (FCNC) production (**tZ-FCNC**) subdivided into
        - single top FCNC
        - ttbar FCNC

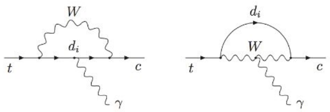
tZq production within the SM

- Predominantly occurs when the Z boson is radiated off one of the quark lines in the t-channel (sensitive to tZ-coupling).
- It is also related to the WZ production by crossing, therefore also sensitive to the WWZ coupling.
- The observation of tZq-SM production and the subsequent measurement of the production cross-section represent an important test of the SM.
- Search for tZq-SM using **two complementary approaches** that cross-check each other:
  - **Shape analysis** using a boosted decision tree (BDT).
  - Simple and robust **cut and count analysis**.



FCNC tZ production

- Flavour changing neutral currents are processes in which the flavour of the fermion changes while its electrical charge is not altered.
- Within the SM, the FCNC of the top quark to the Z boson is forbidden at tree level and is suppressed at higher orders because of the GIM mechanism.



- Some **extensions to the SM** predict enhancements of the FCNC branching fractions. tZ searches are sensitive to tZq and tgq anomalous couplings (tZq-SM irreducible background).

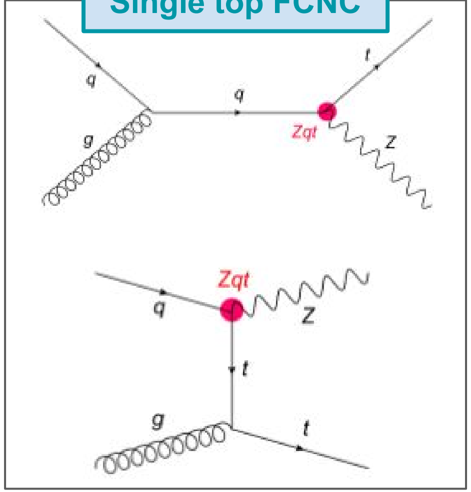
yaaaaaaayyyy new physics! (SM is so mainstream)

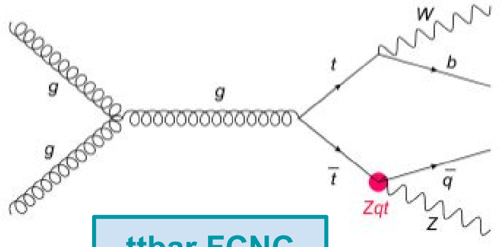
Production modes

- **Single top FCNC**: pp->tZ
- **ttbar-FCNC**: ttbar production via SM, but with one t->Zq

tZ-FCNC search consists on a **shape analysis** using a BDT (shared tools and strategy with tZq-SM shape analysis).

Single top FCNC





ttbar FCNC

CMS detector

skip this slide and say something like CMS is really cool and blah blah, but google has enough information

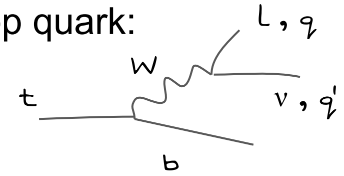
REMEMBER TO REMOVE THIS SLIDE

nooooooooooooo

Event topology and backgrounds

Two different channels, depending on the decay of the W boson coming from the top quark:

- Di-lepton channel: hadronic decay of the top quark (**t -> W(qq)b**)
- Tri-lepton channel: leptonic decay of the top quark (**t -> W(lnu)b**)



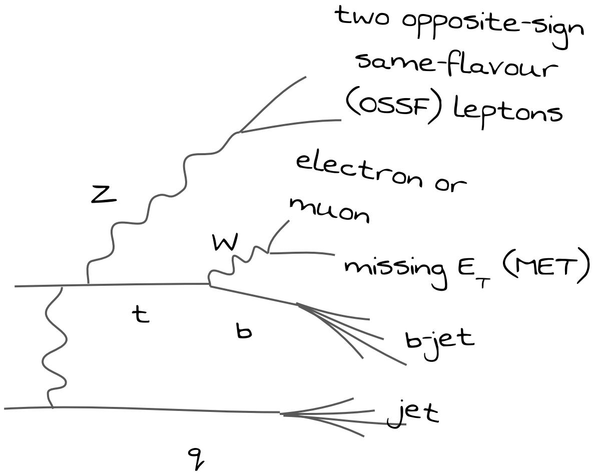
Analyses are conducted **only in the trilepton final state at 8TeV** (dilepton search addressed only at 13TeV)

- Smaller branching ratio, but **clearer signal**.

Event topology

4 channels: μμμ μμe μee eee

- Three isolated hight p_T leptons, two of them compatible with coming from a Z boson (OSSF)
- Two or three jets, at least one of them originating from a b-quark.
- Missing transverse energy.



Event topology and backgrounds

Backgrounds → (signal wannabes)

- Processes with prompt leptons originating from a W or a Z:
  - ttZ
  - WZ
  - (tZq-SM for FCNC search)
- Processes with non-prompt (fake) leptons that pass the tight selection criteria:
  - ttbar
  - DY(Z) + jets

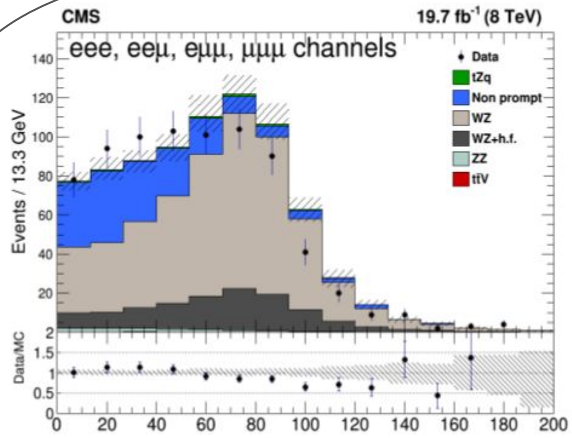
tight selection criteria → Set of cuts applied on selected leptons (kinematic requirements, isolation, etc).

Analysis strategy and background estimation

- **Baseline selection** is applied.
- A **fit** is then applied simultaneously to the **signal region** and the **WZ (background enriched) control region**, in order to extract the tZq cross section and calculate the significance of the measurement:
  - **BDT discriminant** in the signal region
  - **Transverse mass of the W boson** (**MTW**) in the control region (high sensitivity to fake lepton background)

$$m_{T,W} = \sqrt{2 \cdot E_{T,miss} \cdot p_{T,lepton} \left(1 - \cos(\varphi_{MET} - \varphi_{lepton})\right)}$$

- [ ] peaks at around W mass for leptons and MET from a W boson
- [ ] for non-prompt lepton backgrounds in maximum close to zero

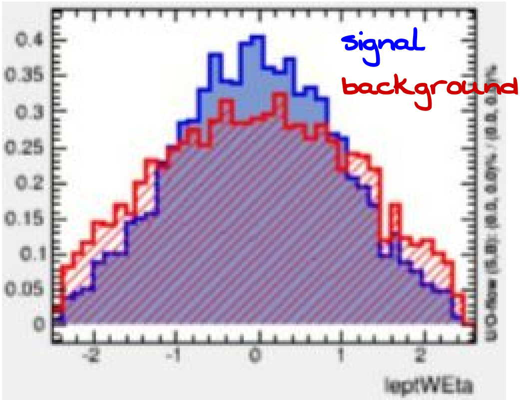


Signal extraction: boosted decision tree

- A **BDT is used in the signal region** to discriminate
  - **tZq-SM search**: tZq-SM events from the dominant main backgrounds (ttZ, WZ)
  - **tZ-FCNC search**: tZ-FCNC from tZq-SM
- A set of **input variables** is selected **based on their discriminating power**.

top and Z boson kinematic variables, jet properties...
more info in CMS TOP-12-039!

- The **output discriminant distribution** is then **fitted to determine whether there are any signal events** present in the data.
- Prior to the fitting, the templates for each background process are **scaled to the predicted SM cross section and integrated luminosity of the data sample** used for the analysis.



Systematic uncertainties

- **Luminosity measurement**: experimental uncertainty of ±2.6%
- **Pile-up estimation**: the uncertainty in the average number of additional interactions per bunch crossing is ±5%
- **Lepton trigger, reconstruction and identification efficiency**:
  - A set of data to MC scale factors (SF) are applied to ensure that the efficiencies observed in data are correctly reproduced in the simulation, these are varied by their corresponding uncertainties
  - 4% uncertainty for lepton trigger SFs
  - 2% uncertainty for lepton reconstruction and identification SFs

Uncertainties can either affect

- ☐ the number of events passing the selections
- ☐ shape of the BDT response
- ☐ both

Systematic uncertainties

- **Jet energy scale (JES), resolution (JER) and missing E_T**
  - jets 4-momenta are varied by the uncertainties associated to the jet energy scale and resolution (this also affects MET measurement)
  - contribution to MET that does not come from leptons, photons or jets is varied by ±10%
- **B-tagging**
  - b-tagging and misidentification efficiencies estimated using control samples
  - the SF thus obtained are varied by their corresponding uncertainties
- **Background normalisation**
  - non-prompt processes and WZ: estimated from data during final fit
  - backgrounds estimated from simulation: uncertainty taken to be ±30%

Uncertainties can either affect
- ☐ the number of events passing the selections
- ☐ shape of the BDT response
- ☐ both

Systematic uncertainties

- **Z boson p_T**
  - uncertainty coming from Z boson p_T reweighting
  - accounted by applying twice, or not applying, the reweighting

Uncertainties can either affect
- ☐ the number of events passing the selections
- ☐ shape of the BDT response
- ☐ both

- **Physics process modelling**
  - renormalisation and factorization scales are multiplied or divided by a factor 2

- **Parton Distribution Function (PDF) choice**
  - all simulated events are reweighted by each of the associated eigenvalues of the PDF set

- **Simulated event size**
  - statistical uncertainty arising from the limited size of the samples is taken as a source of systematic uncertainty using a "Barlow-Beeston light" method [R.Barlow and C.Beeston, "Fitting using finite Monte Carlo samples", *Comput. Phys. Commun.* 77 (1993) 219-228].

For each source of systematic (u), a nuisance parameter (θ_u) is introduced in the fit

Results

Yayy! I was already falling asleep...

Search for tZq-SM production

Shape analysis

Channel	Signal strength [1 sigma band]	Cross section (fb)
eee	0.0 [0.0 - 1.0]	$0.0^{+8.6}_{-0.7}$
eeμ	1.4 [0.2 - 2.8]	11^{+13}_{-10}
$\mu\mu$e	2.9 [1.4 - 4.5]	24^{+19}_{-16}
$\mu\mu\mu$	0.6 [0.0 - 1.6]	$5.0^{+8.5}_{-5.7}$
combination	1.2 [0.6 - 1.9]	$10^{+8.2}_{-7.0}$

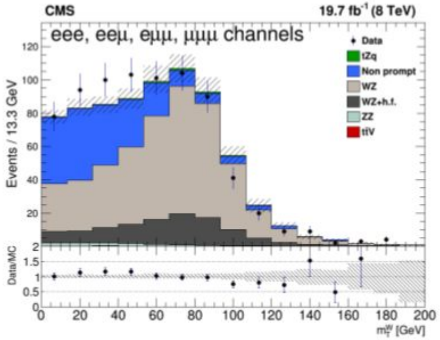
Combined cross section compatible with SM prediction

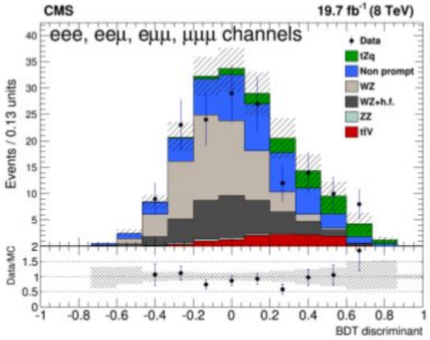
$\sigma(tllq)_{SM} = 8.2^{+0.59}_{-0.03}$ fb

Observed signal exclusion limit at 95%CL

$\sigma_{tZq} < 20.97$ fb

Observed (expected) significance: 2.4 (1.8).
Expected 1sigma band i: 0.4 - 2.7





Results

Search for tZq-SM production

Cut and count analysis

Channel	Cross section (fb)
eee	29^{+32}_{-24}(stat.)$^{+8}_{-7}$(syst.)
$ee\mu$	6^{+23}_{-6}(stat.)$^{+4}_{-0}$(syst.)
$\mu\mu e$	19^{+24}_{-18}(stat.)$^{+5}_{-5}$(syst.)
$\mu\mu\mu$	20^{+19}_{-15}(stat.)$^{+4}_{-3}$(syst.)
combination	18^{+11}_{-9}(stat.)$^{+4}_{-4}$(syst.)

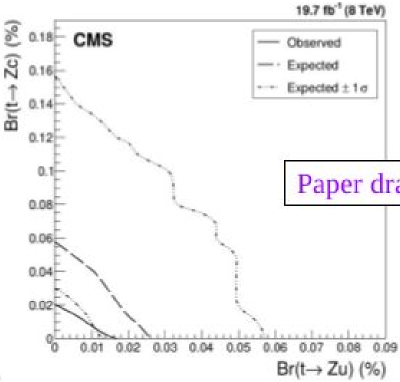
Combined cross section **compatible with SM prediction** and **with shape analysis results**.

	Total Data	Total MC	tqZ	$t\bar{t}Z$	WZ	$t\bar{t}W$	ZZ	fake leptons
eee	5.00	3.30	0.63	1.19	0.52	0.09	0.02	0.86
$\mu\mu\mu$	7.00	5.16	1.22	1.71	1.41	0.12	0.06	0.64
$\mu\mu e$	5.00	3.79	0.85	1.19	0.93	0.16	0.03	0.64
$ee\mu$	3.00	3.16	0.70	1.15	0.74	0.12	0.03	0.43
Total	20.00	15.42±0.54	3.39±0.13	5.24±0.35	3.59±0.20	0.49±0.02	0.13±0.01	2.57±0.30

Results

Search for tZ-FCNC production

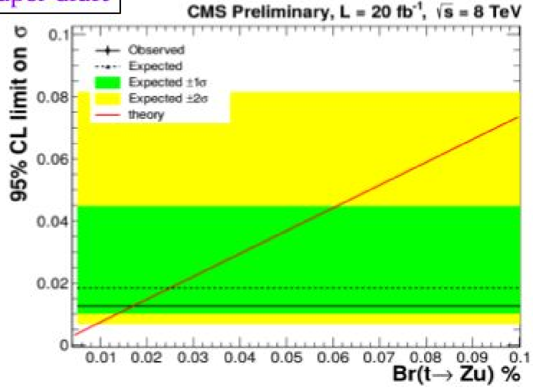
- No excess over background is observed
- Exclusion limits on top FCNC calculated using theta with a Bayesian method
- Calculated for different values of couplings, but shown as a function of Br(t->Zq)

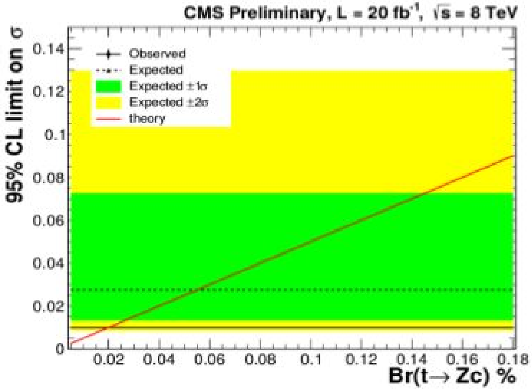


Paper draft

Branching ratio	Expected	1σ range	2 σ range	Observed
$\mathcal{BR}$(t→ Zu) (%)	0.025	0.014-0.061	0.010-0.111	0.017
$\mathcal{BR}$(t→ Zc) (%)	0.055	0.027-0.145	0.016-0.258	0.020

Paper draft





Conclusions

- The search for a single top quark produced in association with a Z boson, in both SM and FCNC events, has been presented.
- The tZq SM cross section has been measured for the first time by a shape analysis and a cut and count cross check. Both methods agree well with each other and the SM prediction.
  - The tri-lepton tZq cross section was measure to be $\sigma_{tZq} = 10^{+8}_{-7}$ fb
- No evidence for new physics has been found. The limits on FCNC tZq coupling are set to Br(t->Zu) < 0.017% and Br(t->Zc) < 0.020%. These are the best current limits.

Ongoing analysis at 13TeV...Stay tuned!