



A search for flavour changing neutral currents involving a top quark and a Z boson

using the data collected by CMS at a centre-of-mass energy of 13 TeV

Isis Van Parijs
VUB – IIHE
26 Januari 2018
Promotor Prof. J. D'Hondt

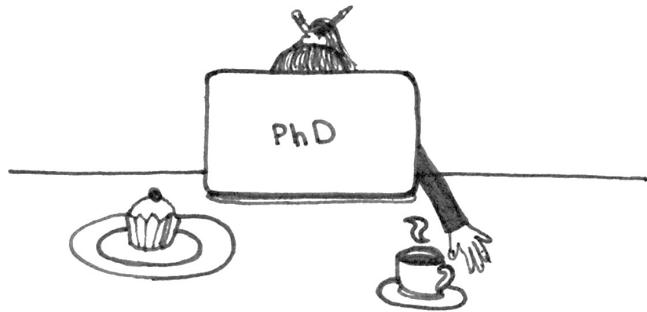


Een zoektocht naar smaakveranderende neutrale stromen gerelateerd met een top quark en een Z boson

gebruik makend van de data gecollecteerd
door het CMS experiment met een
massamiddelpuntsenergie van 13 TeV

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What have I been doing





MEETINGS



DATA TAKING



WEDDINGS



CONFERENCES



CMS Physics Analysis Summary

Available on the CERN CDS information server CMS PAS TOP-17-017

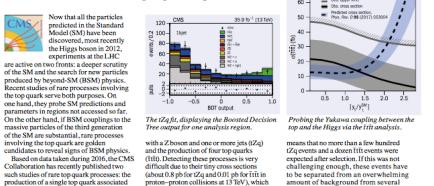
Contact: cms-pag-conveners-top@cern.ch 2017/11/07



RENOVATIONS



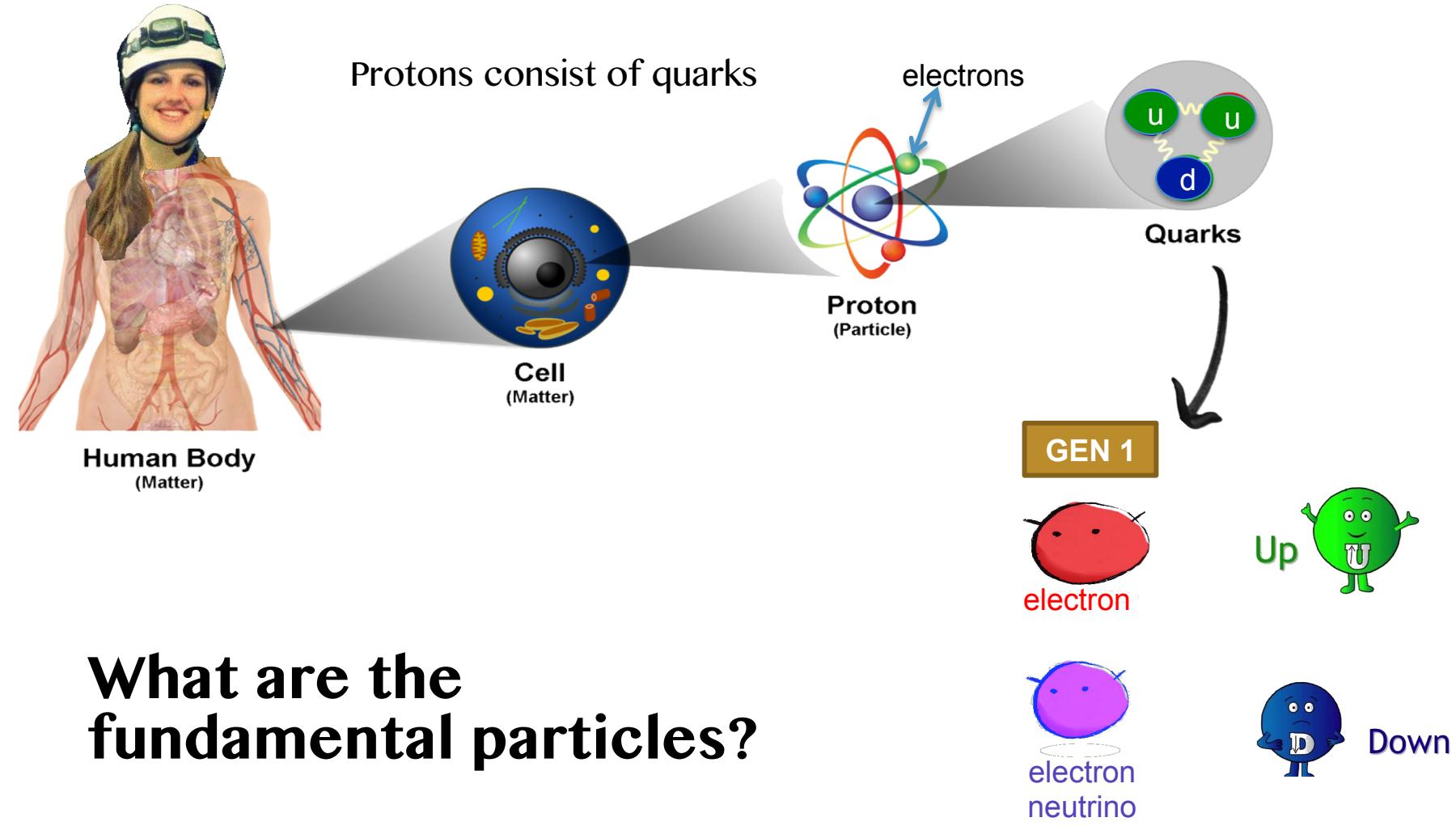
CMS studies rare top-quark processes



TRACKER SHIFTS

CERN COURIER

PARTICLES



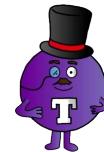
Q
U
A
R
K
S

FERMIONS

GEN 1

GEN 2

GEN 3



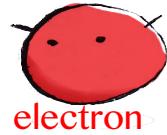
Down



Strange



Bottom



electron



muon



tau



electron
neutrino



muon
neutrino

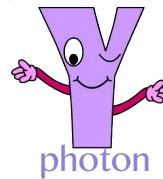


tau
neutrino

GAUGE
BOSONS



gluon



photon



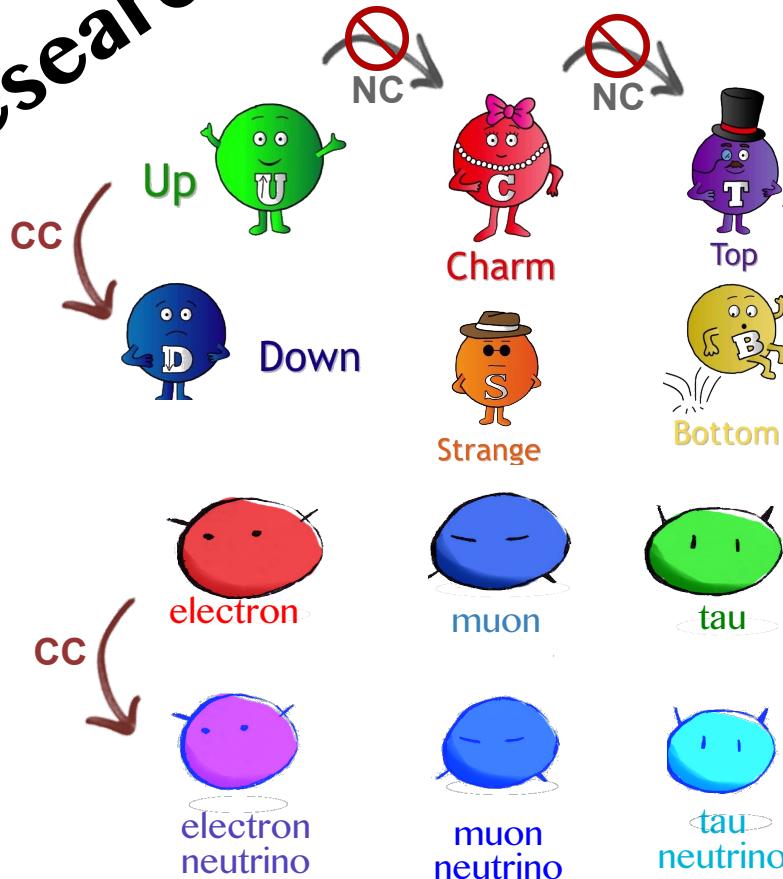
Z boson



W boson

The
Standard
Model of
particle
physics

Ph.D. My research



NC = neutral current

- Via exchange $g / \gamma / Z$
- forbidden at tree level
- Suppressed at higher order



CC = charged current

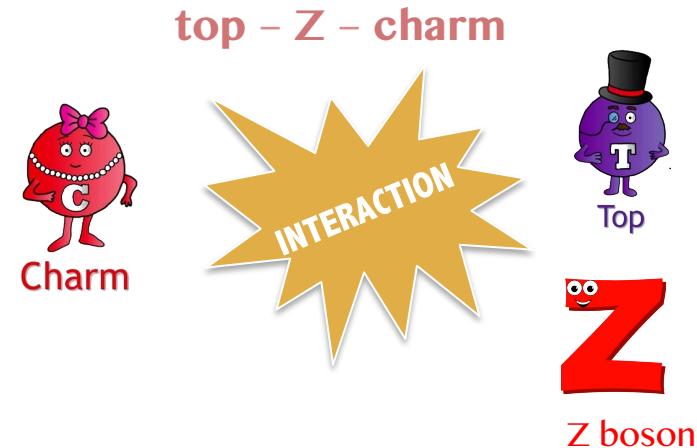
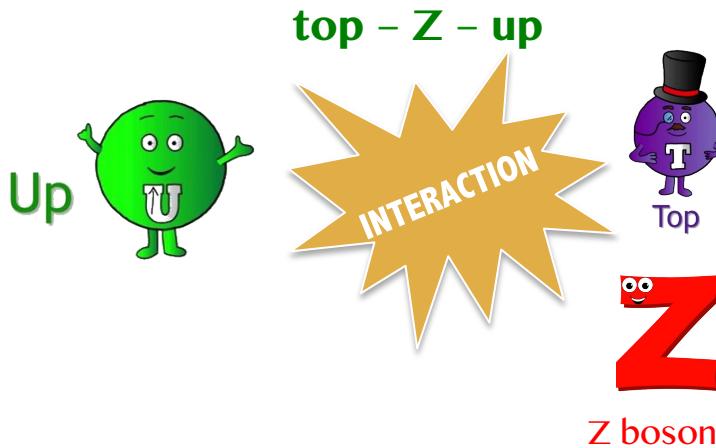
- Via exchange W boson
- Described by CKM- and PMNS matrix



My research

Ph.D.

I am looking at two “kinds” of flavour changing neutral current couplings



$$\mathcal{L}_{\text{EFT}}^t = \frac{\sqrt{2}}{2} \sum_{q=u,c} \left[\frac{g}{2\cos\theta_W} \frac{\kappa_{tZq}}{\Lambda} Z_{\mu\nu} \bar{t} \sigma^{\mu\nu} \left(f_{Zq}^L P_L + f_{Zq}^R P_R \right) q + \text{h.c.} \right]$$

The Large Hadron Collider

Home to e.g. CMS and ATLAS.

Experiments that study proton collisions

CMS

ALICE

LHCb

ATLAS

- Billions of protons travelling at 99.999991% of the speed of light
- More than 11000 tours of 27km per second!



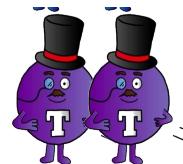
The LHC collides proton collisions at 7 TeV, 8 TeV, 13 TeV

Approx. nb. Of top quark pair events:

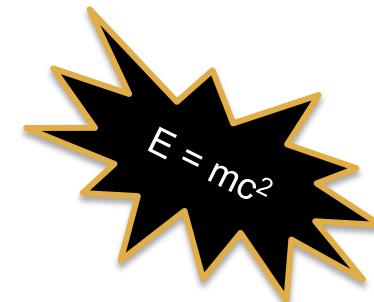
7 TeV: 868 000

8 TeV: 4 854 920

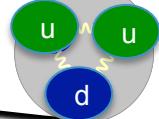
13 TeV: 29 294 400



events:



7.5 TeV

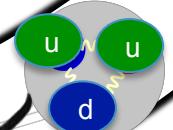


LARGE HADRON COLLIDER

13 TeV



7.5 TeV

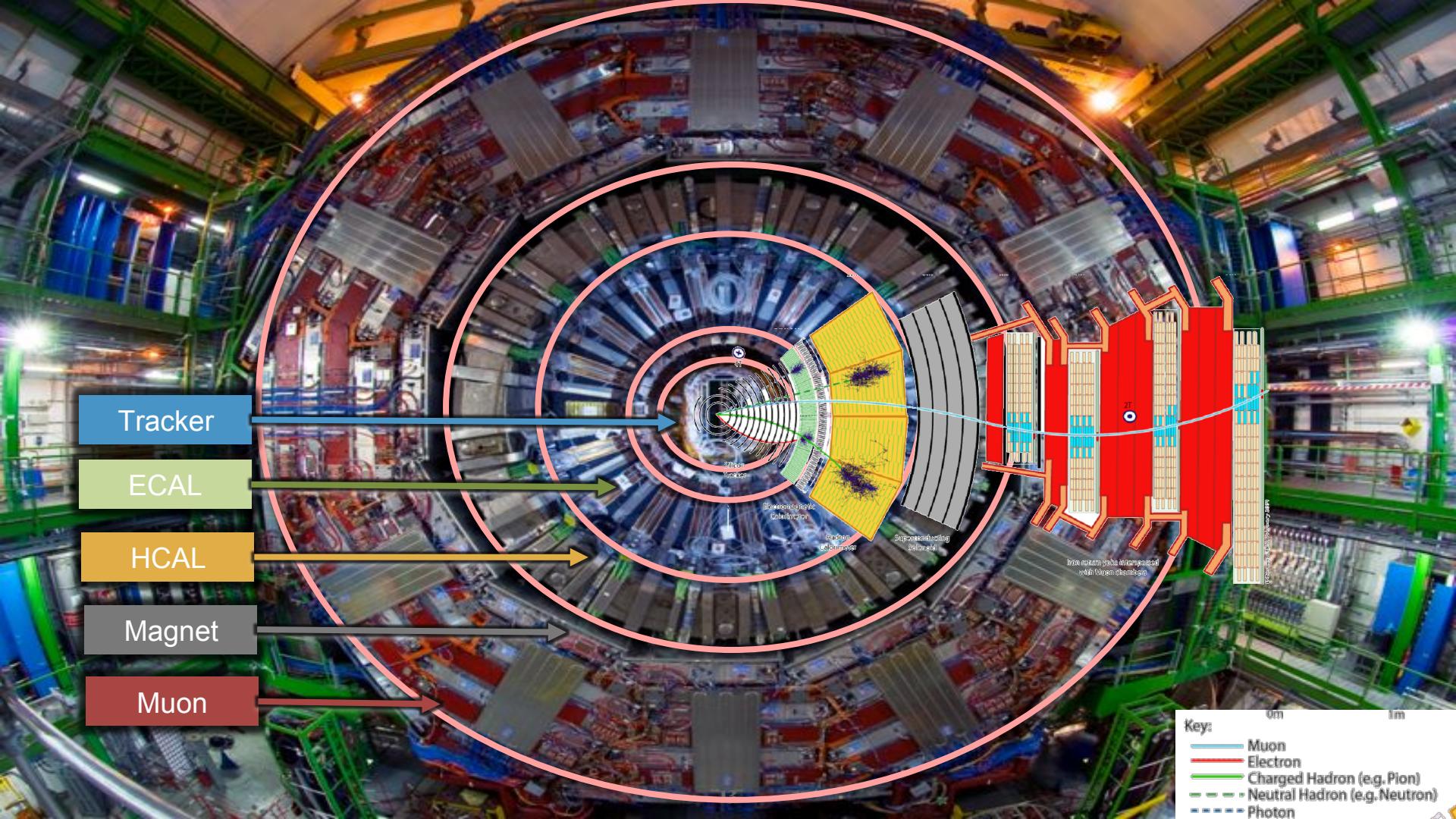


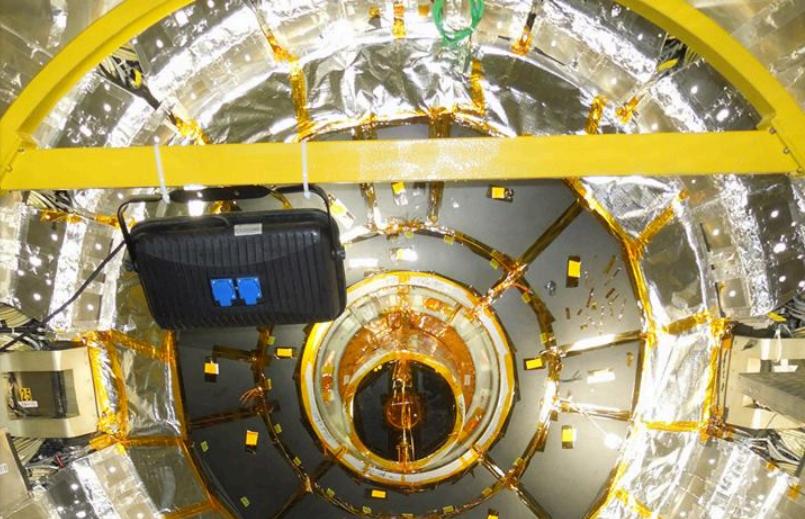
CMS detector



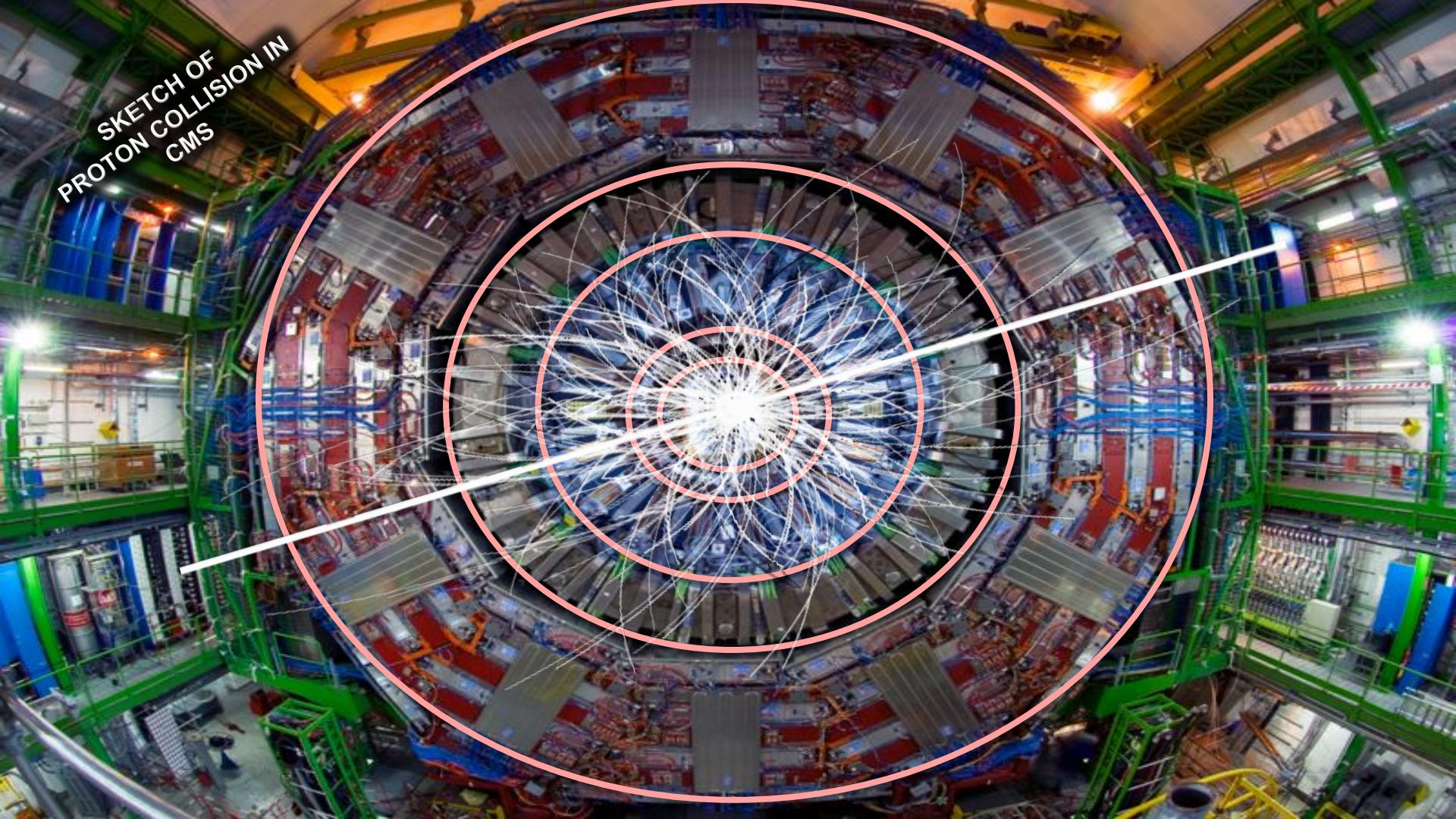
CMS detector



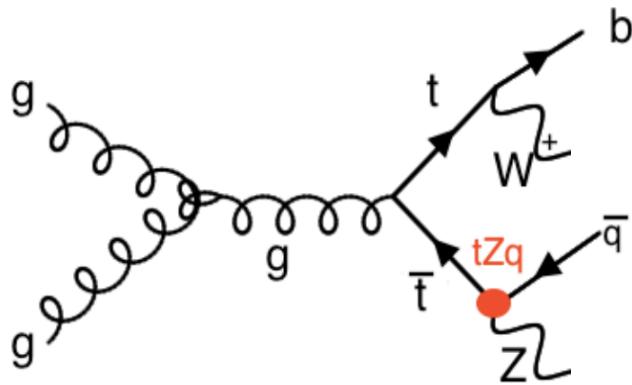




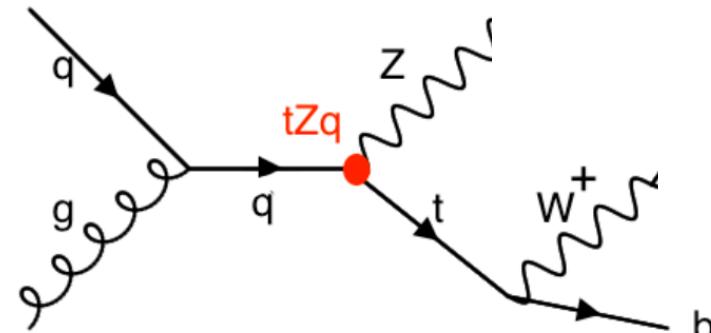
SKETCH OF
PROTON COLLISION IN
CMS



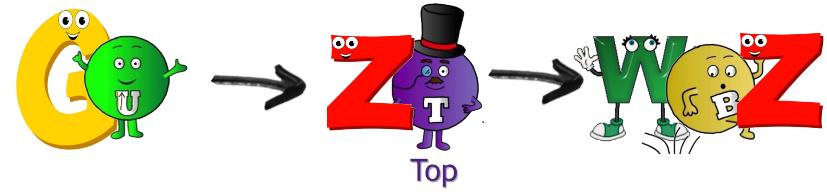
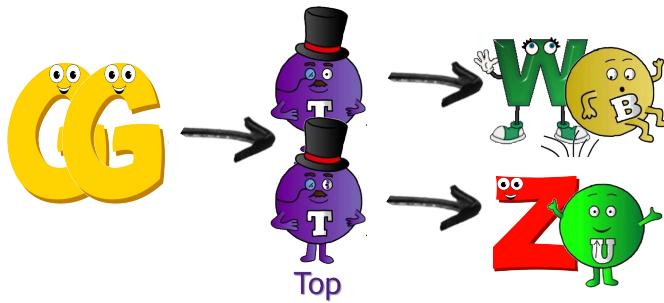
I am looking at two kinds of FCNC signal...



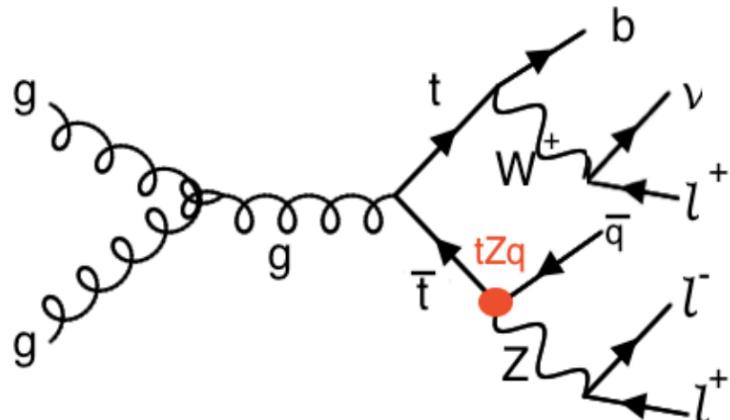
top quark pair decay



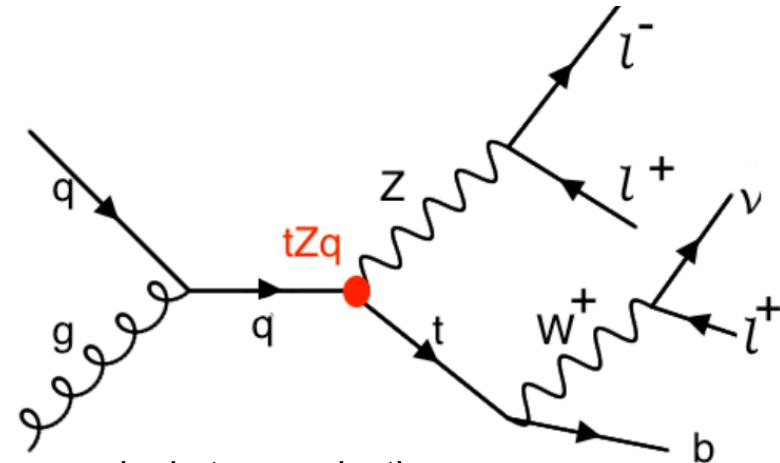
single top production



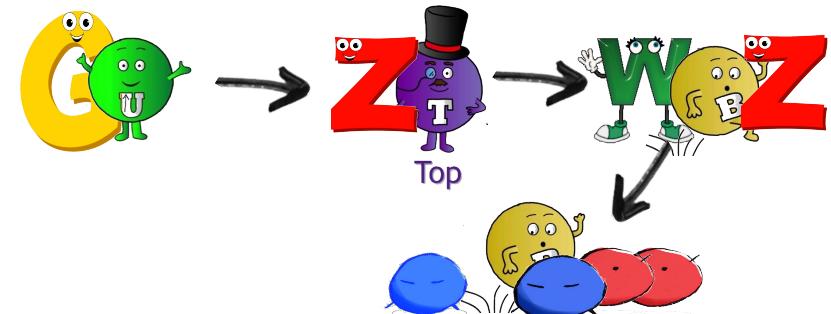
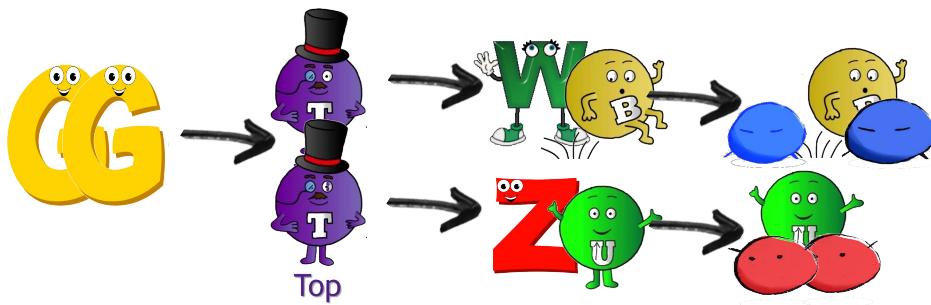
I am looking at two kinds of FCNC signal... in the 3 lepton channel



top quark pair decay



single top production

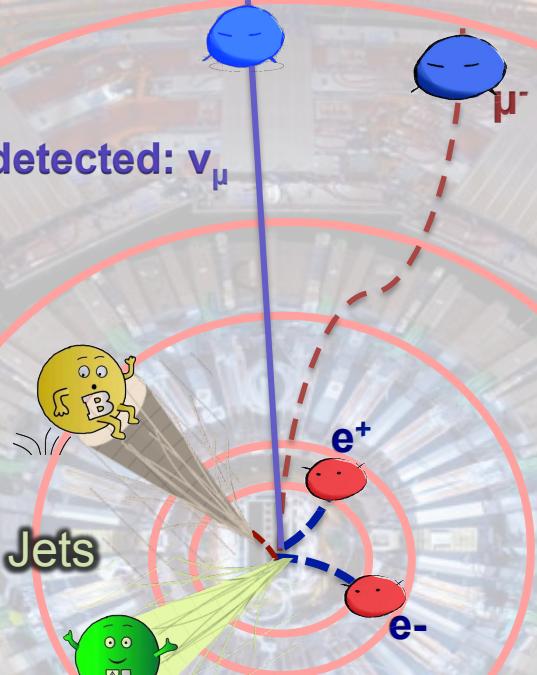


SKETCH OF
FCNC
SIGNATURE

Undetected: ν_μ

Jets

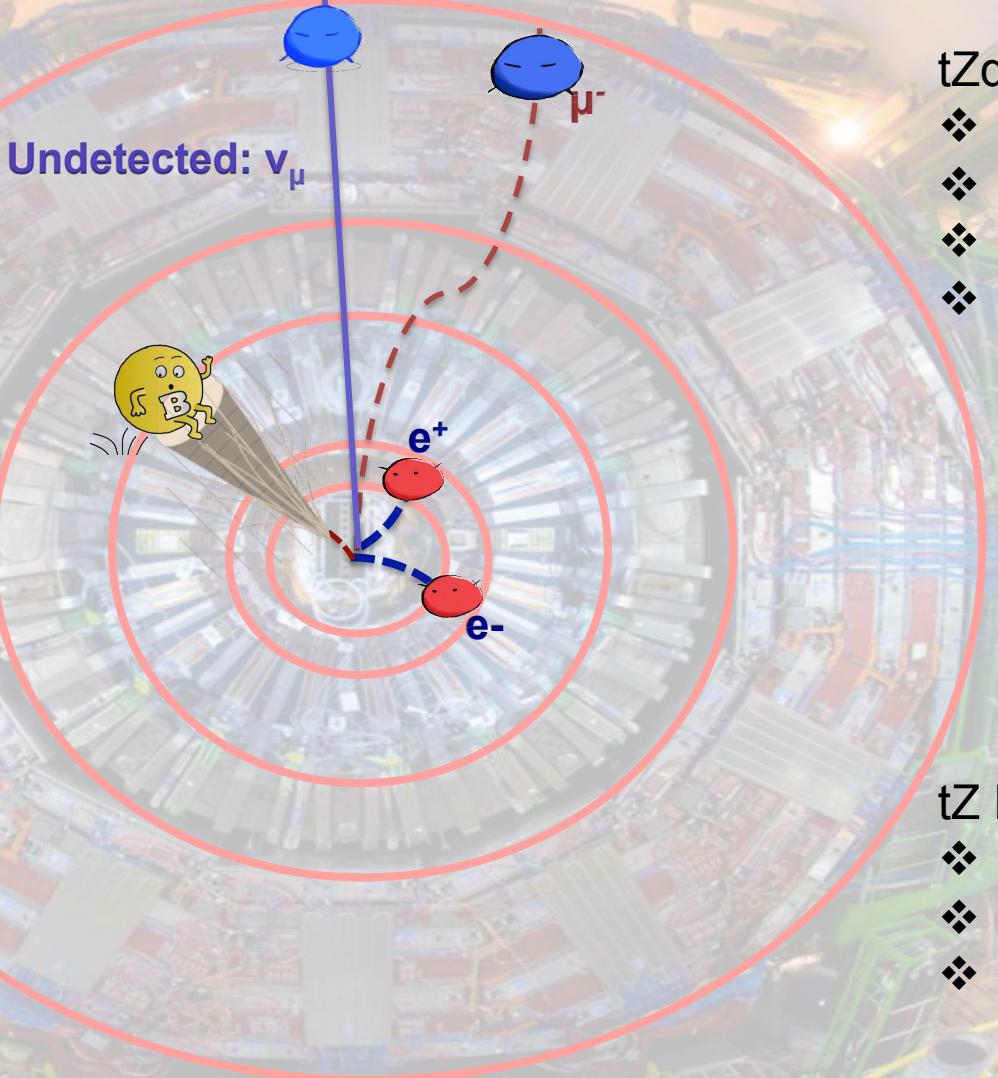
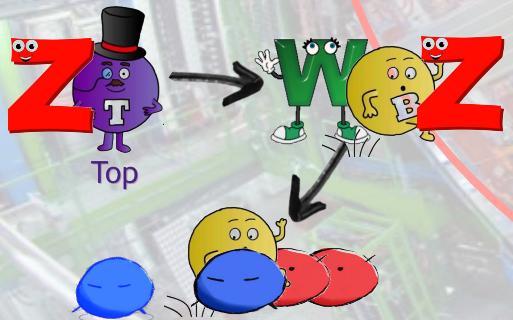
TOP QUARK PAIR DECAY



- tZq FCNC
- ❖ 1 b jet
 - ❖ 1 c/u jet
 - ❖ 3 leptons
 - ❖ missing E_T

SKETCH OF
FCNC
SIGNATURE

SINGLE TOP QUARK
PRODUCTION



tZq FCNC

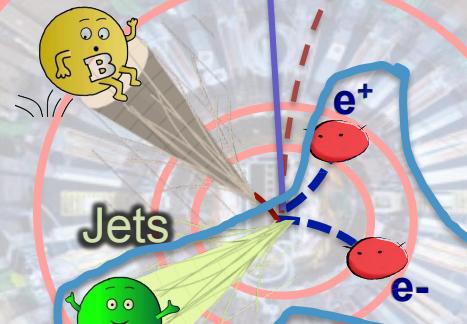
- ❖ 1 b jet
- ❖ 1 c/u jet
- ❖ 3 leptons
- ❖ missing E_T

tZ FCNC

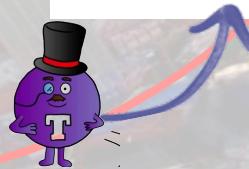
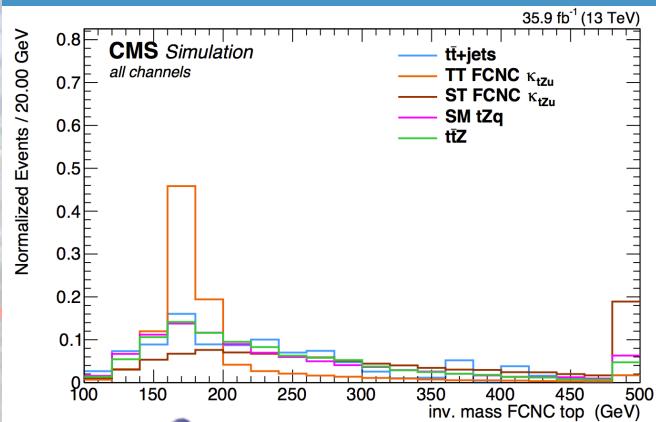
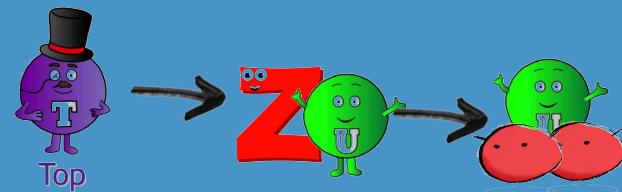
- ❖ 1 b jet
- ❖ 3 leptons
- ❖ missing E_T

SKETCH OF
FCNC
SIGNATURE

Undetected: ν_μ



The invariant mass of these objects should give the mass of the top quark



How to distinguish signal processes from background processes

Look at the properties!

Example: Is my dog there?

Obvious properties... size, colour, weight, species...

Also less obvious properties...

What is his DNA, does he know physics?, ...



How to distinguish signal processes from background processes

Look at the properties!

Example: Is my dog there?



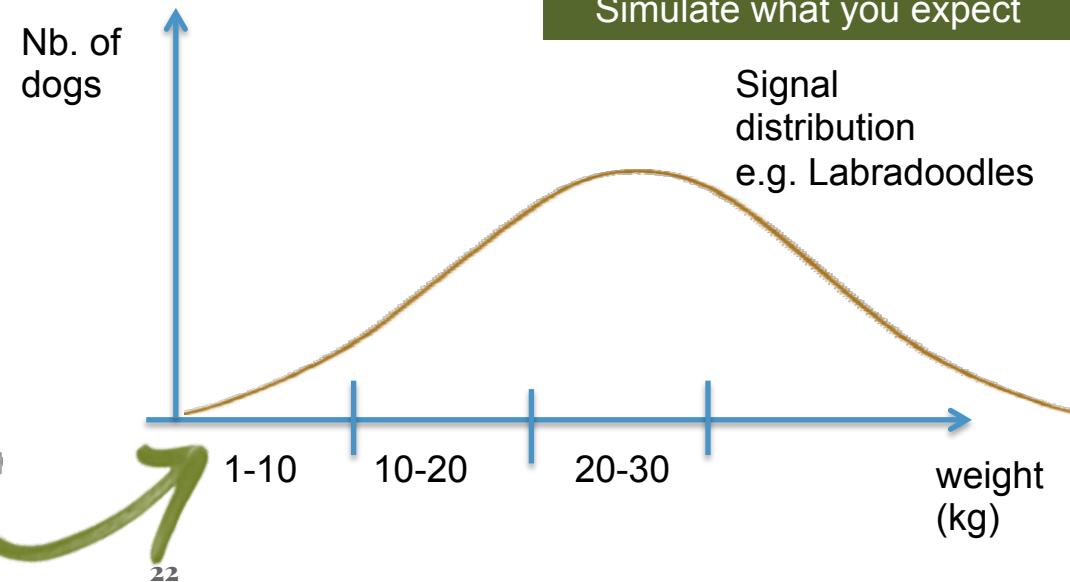
Obvious properties... size, colour, weight, species...

Also less obvious properties...

What is his DNA, does he know physics?, ...

Simulate what you expect

Signal distribution
e.g. Labradoodles



How to distinguish signal processes from background processes

Look at the properties!

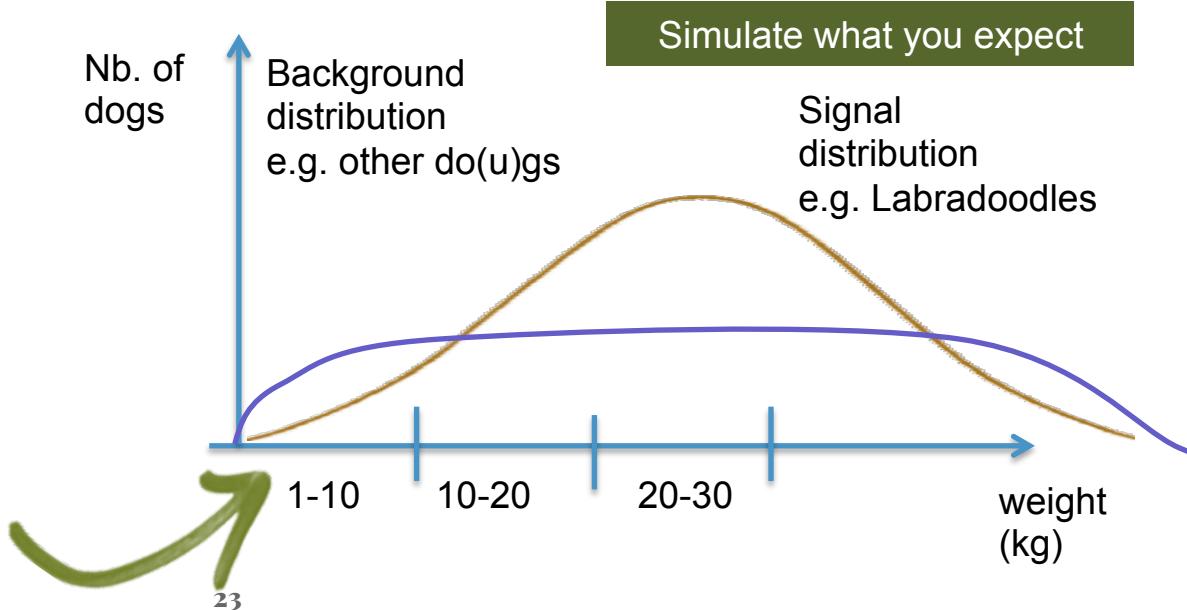
Example: Is my dog there?



Obvious properties... size, colour, weight, species...

Also less obvious properties...

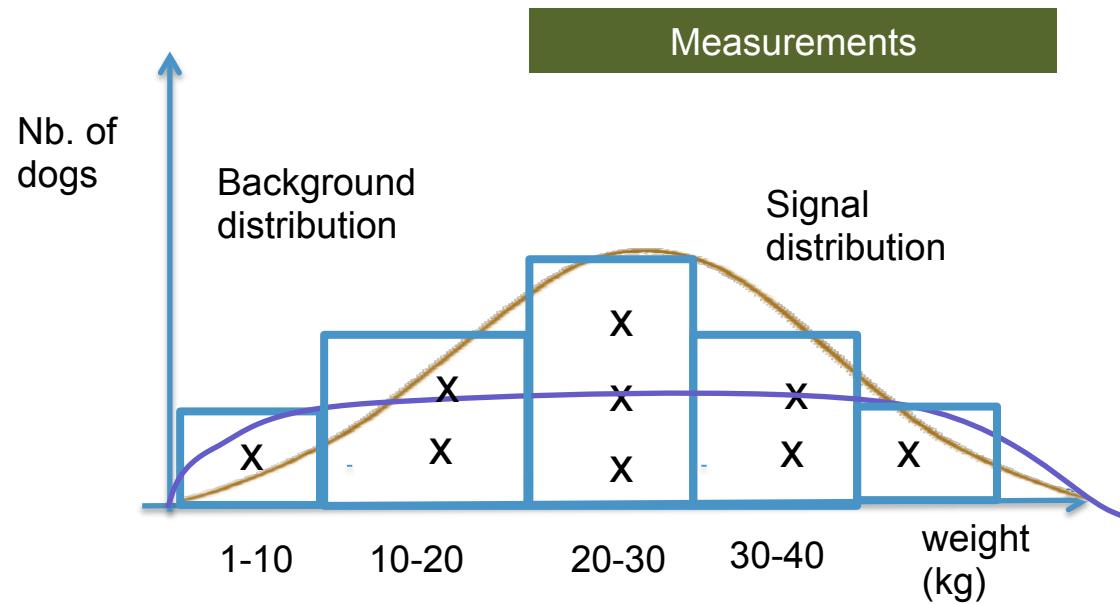
What is his DNA, does he know physics?, ...



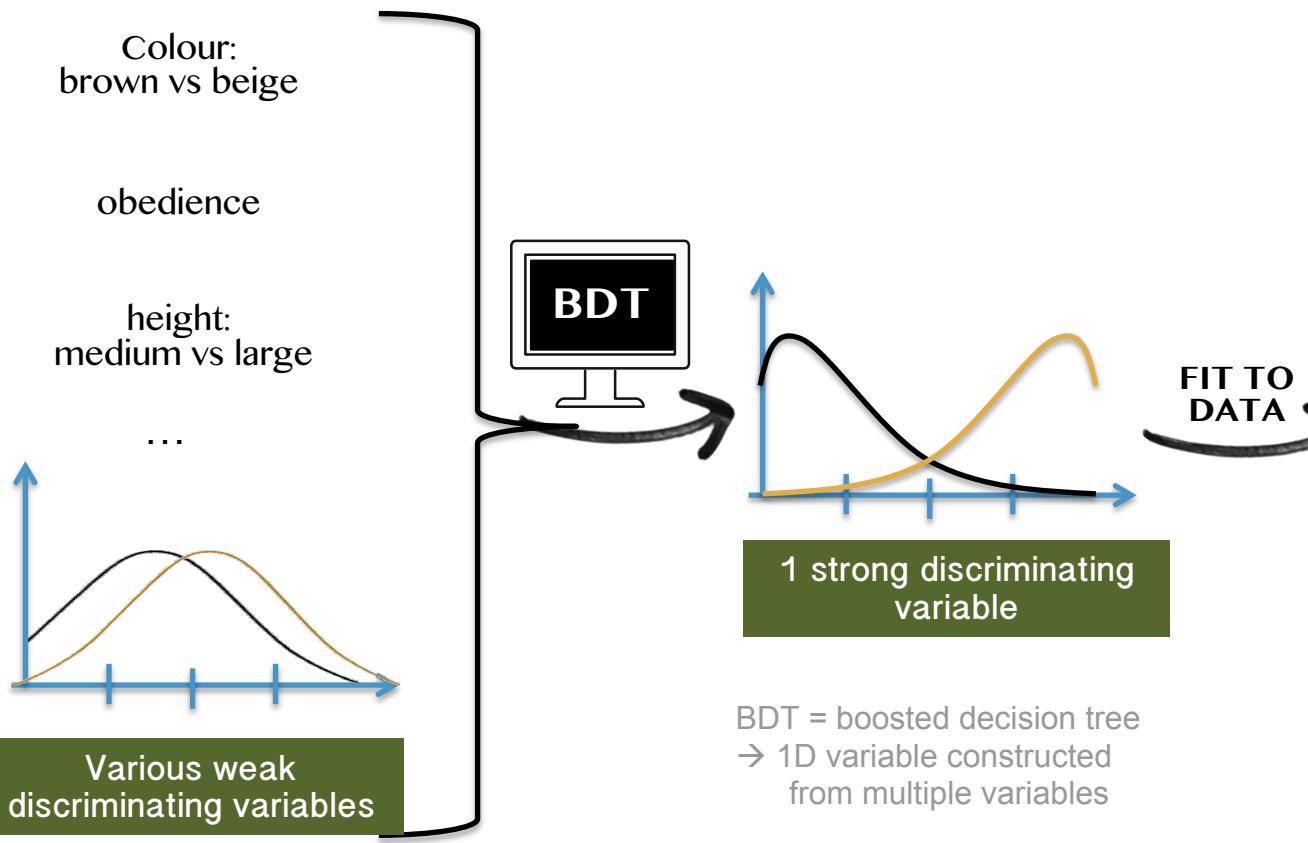
How to distinguish signal processes from background processes

Look at the properties!

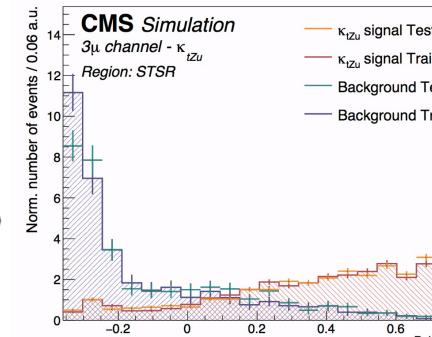
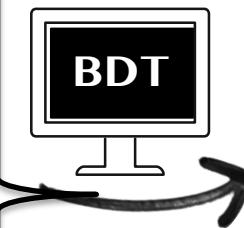
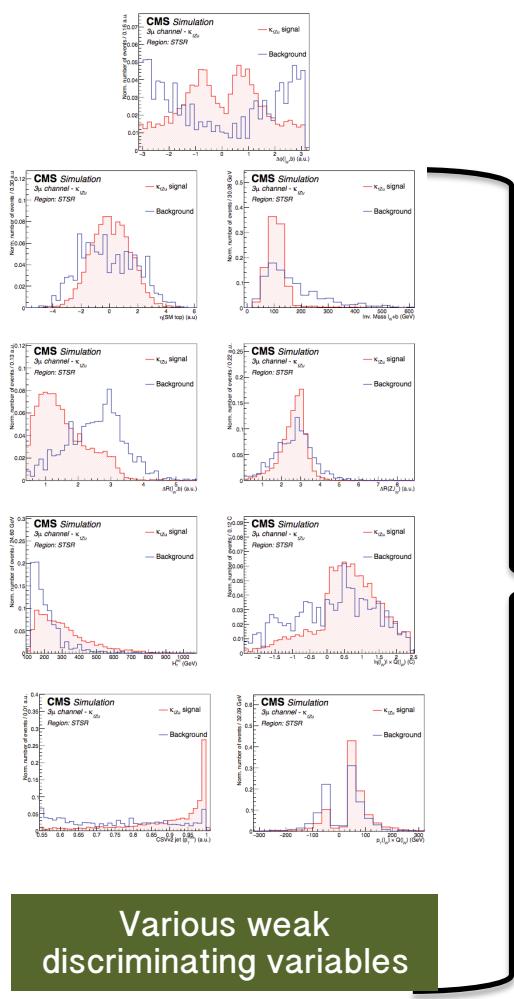
Example: Is my dog there?



Multivariate analysis



Multivariate analysis: physics case



1 strong discriminating variable

FIT TO DATA →

My limit!



ATTENTION!!

NOVEL STRATEGY

2 signal regions

top quark pair
signal region

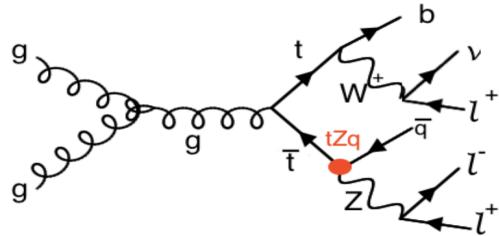
- ❖ 3 leptons
- ❖ 1 jet
- ❖ 1 b jet

TTSR

Estimate top quark pair FCNC

STSR

Estimate single top quark FCNC



Separate trainings:

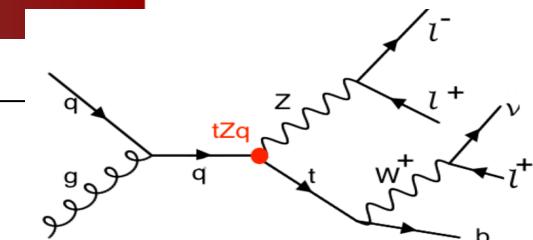
- ❖ 4 three-lepton channels:
eee - eep μ - $\mu\mu e$ - $\mu\mu\mu$

- ❖ 2 couplings: up and charm



single top quark
signal region

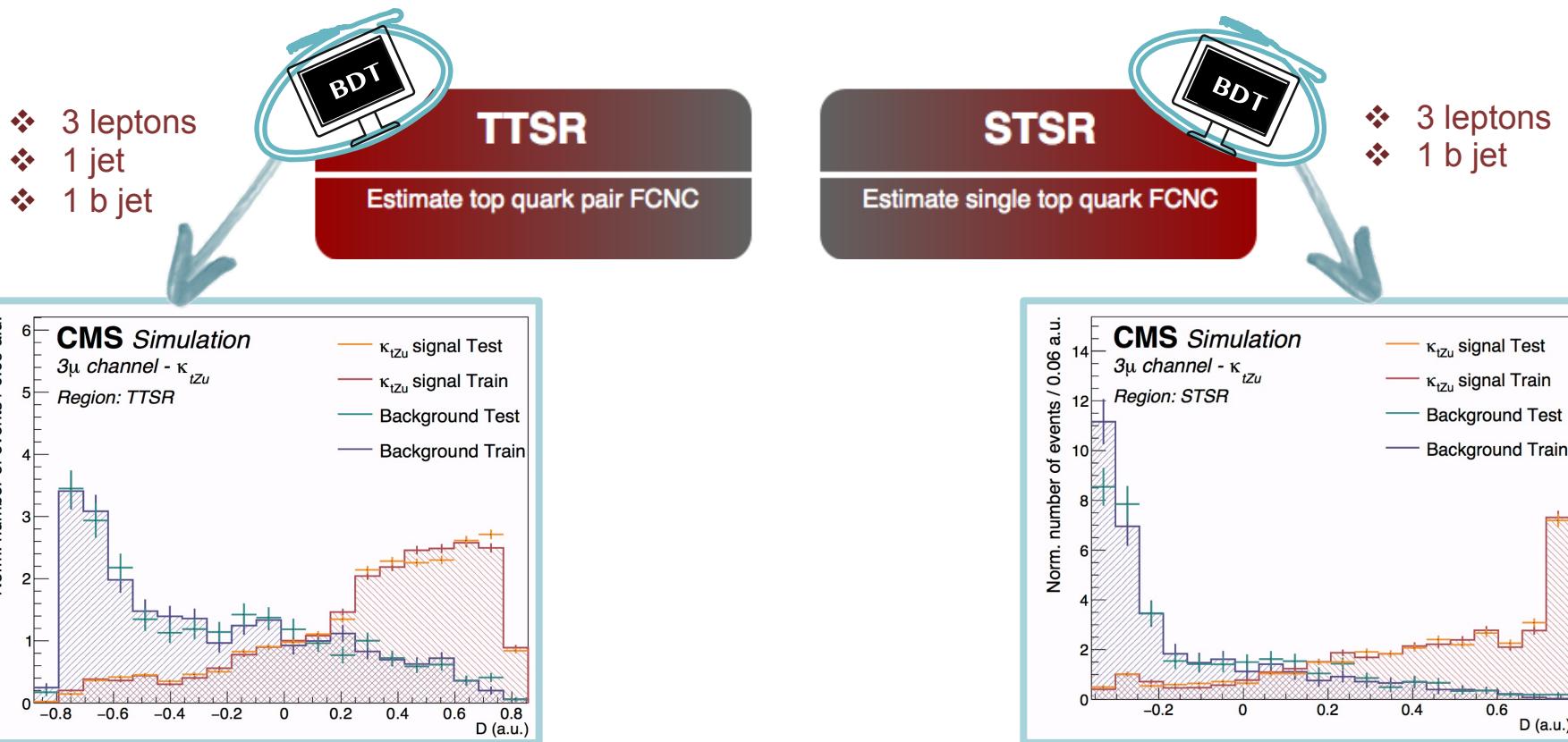
- ❖ 3 leptons
- ❖ 1 b jet



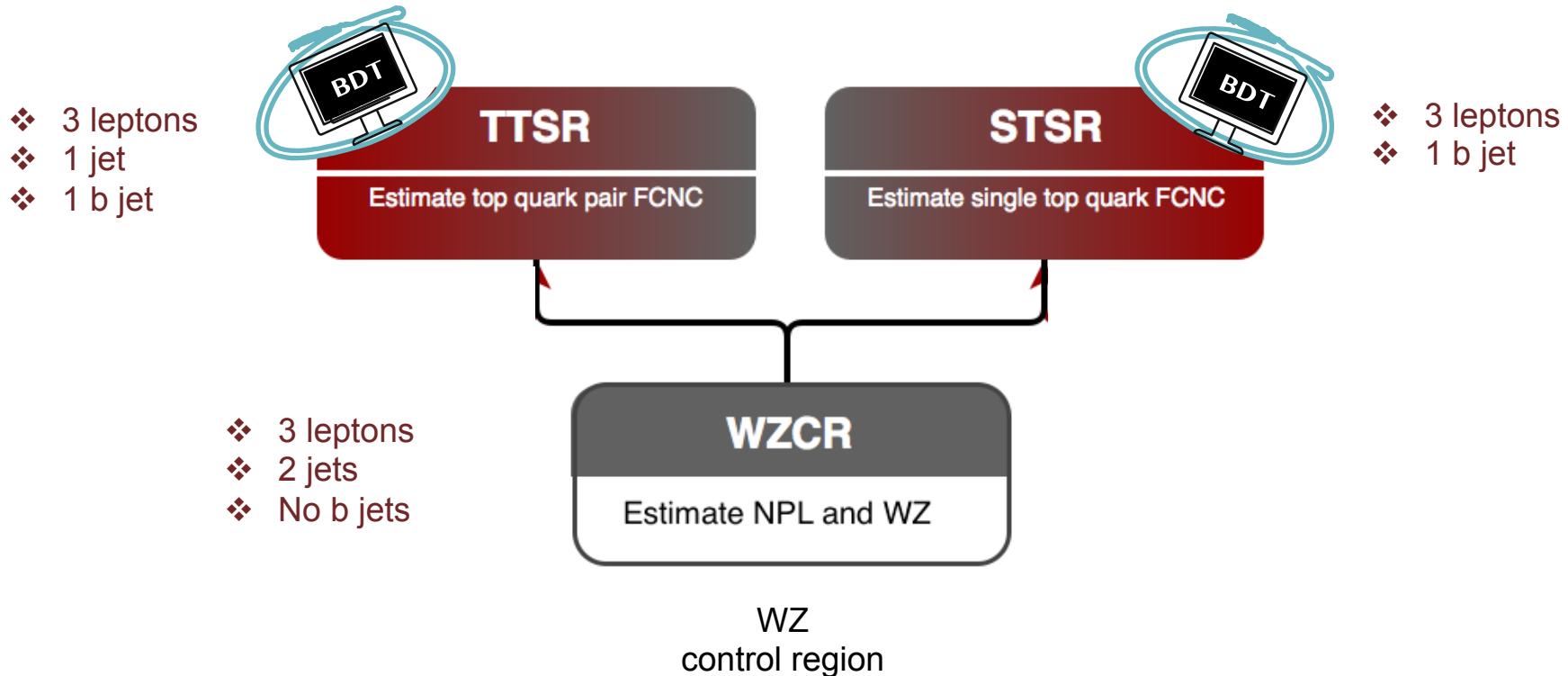
Main backgrounds:

- ❖ WZ+jets
- ❖ tZq
- ❖ ttZ
- ❖ Not prompt-leptons (NPL)

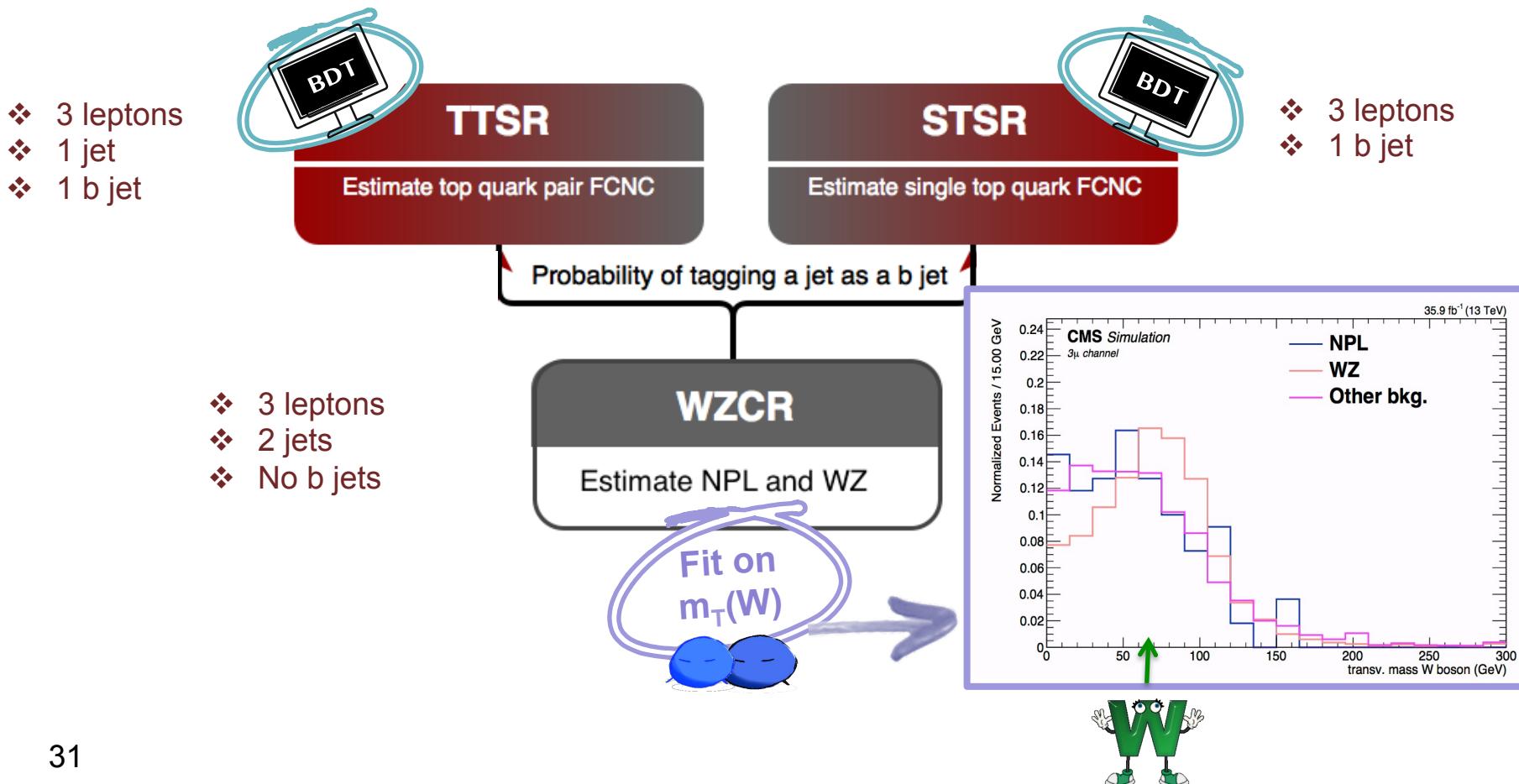
multivariate analysis



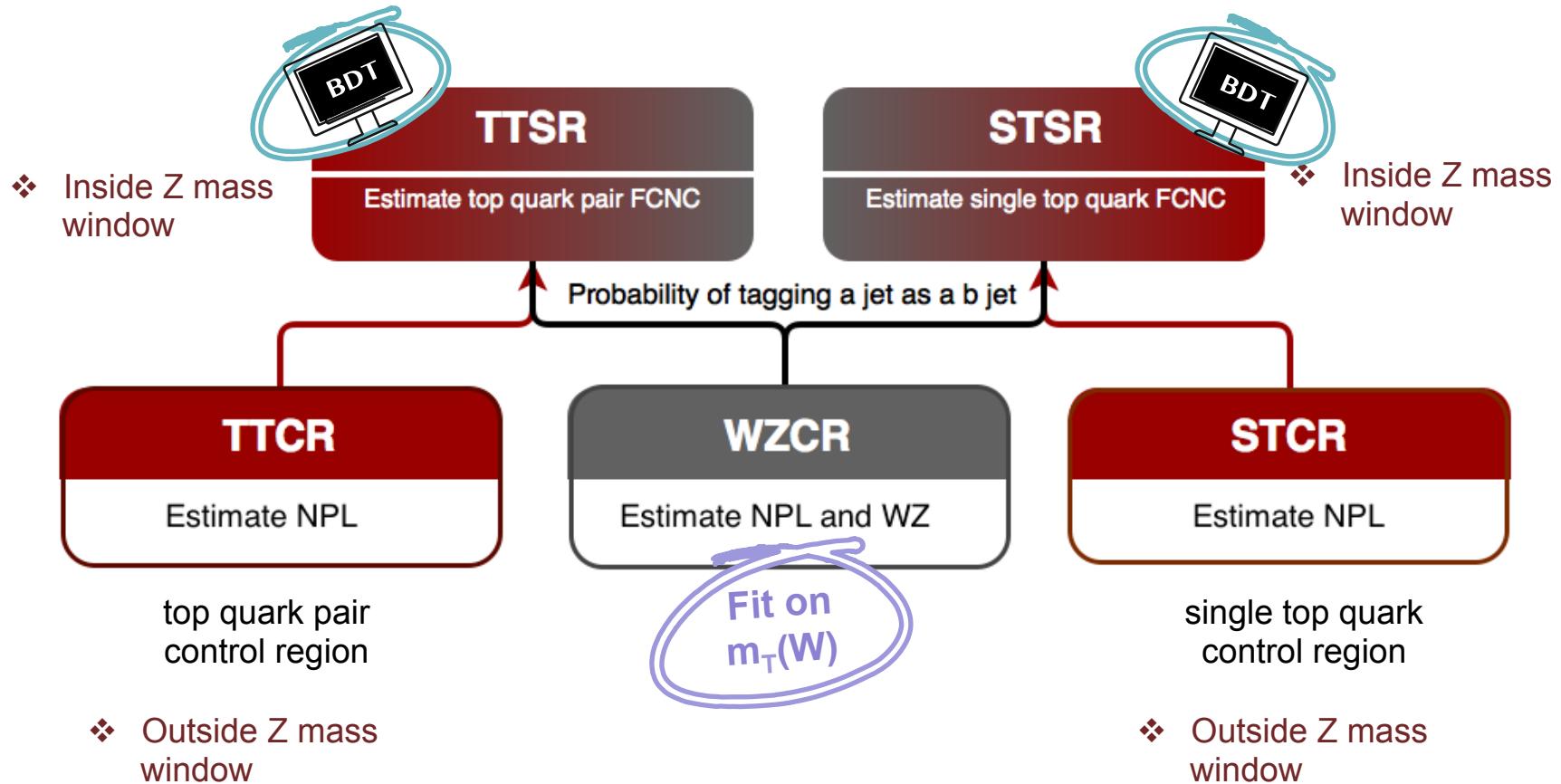
Get a better handle on the main backgrounds!



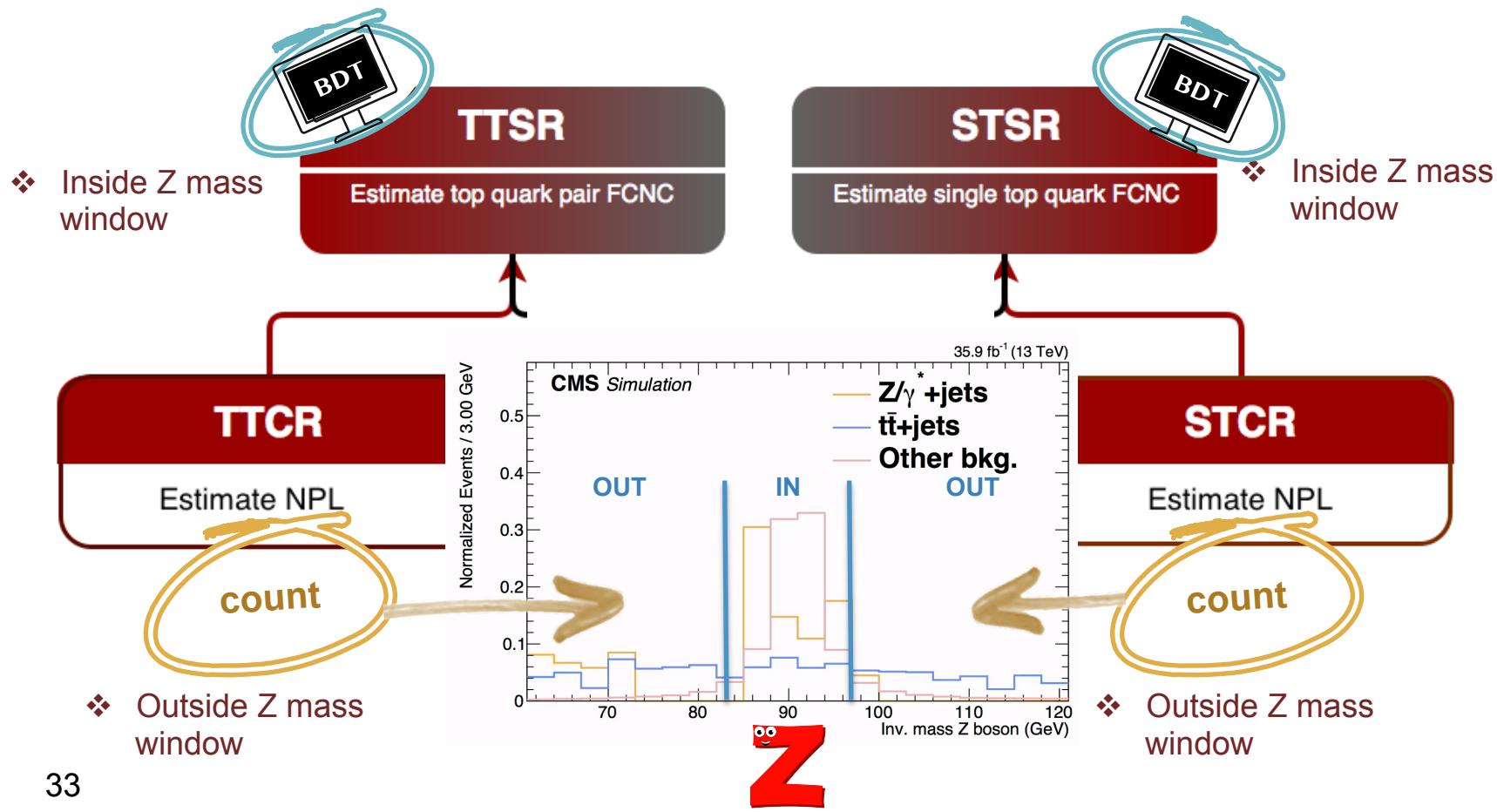
Get a better handle on the main backgrounds!



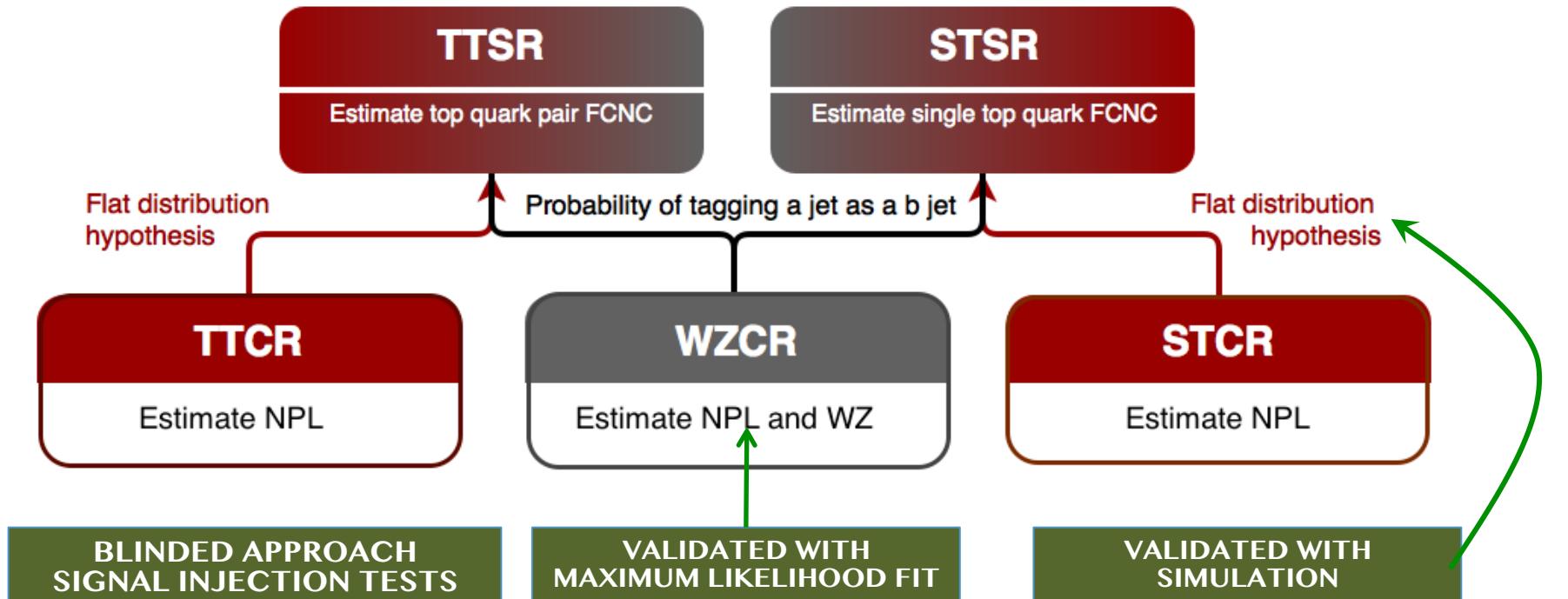
Get a better handle on the main backgrounds!



Get a better handle on the main backgrounds!



Analysis strategy

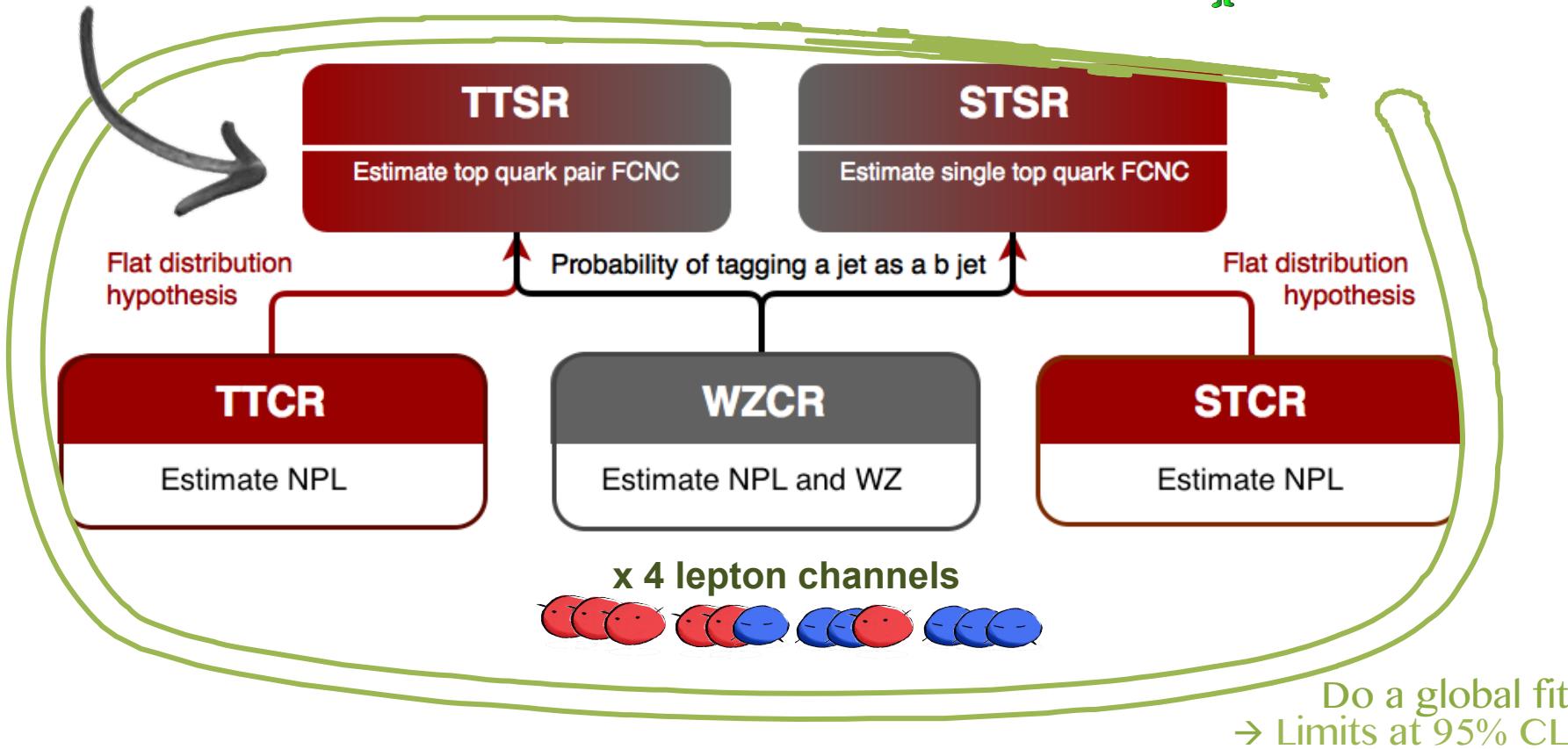




Add systematic uncertainties
e.g. normalisation: Luminosity,
shape: Jet energy scale

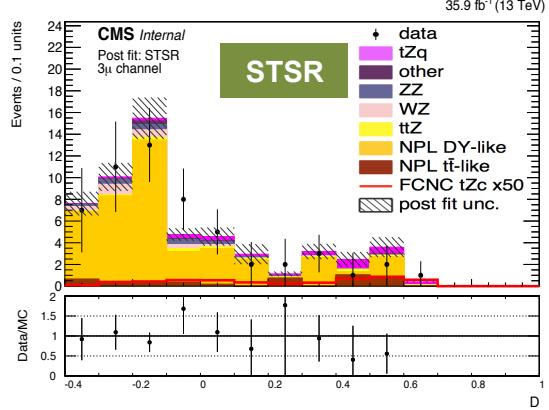
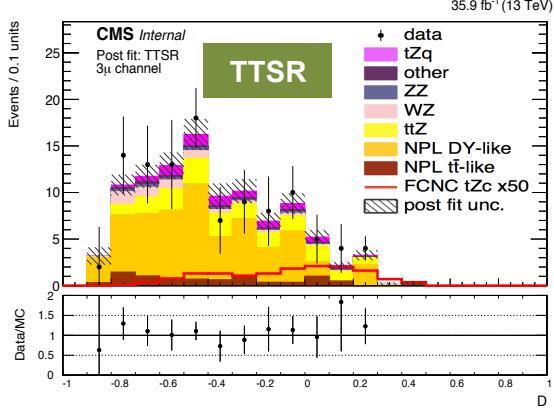
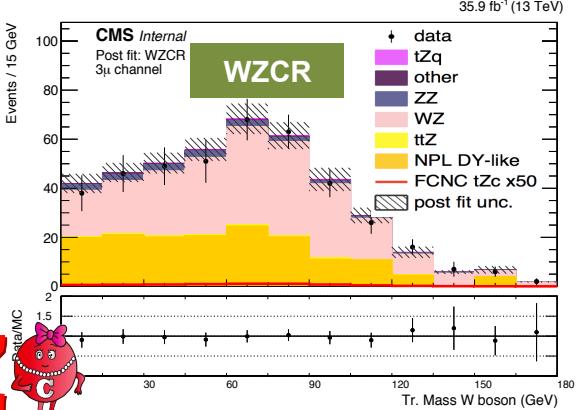
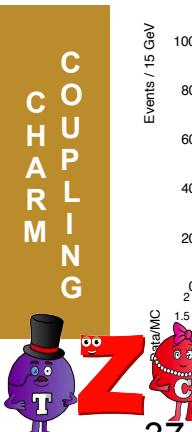
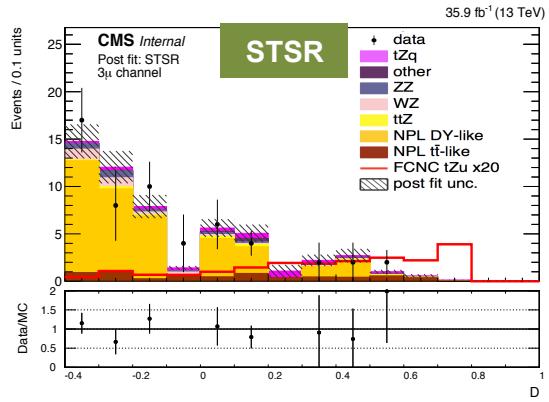
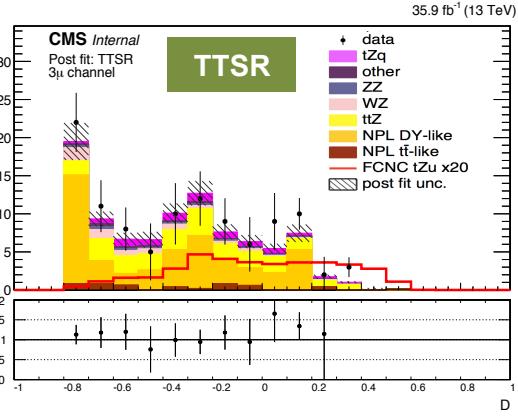
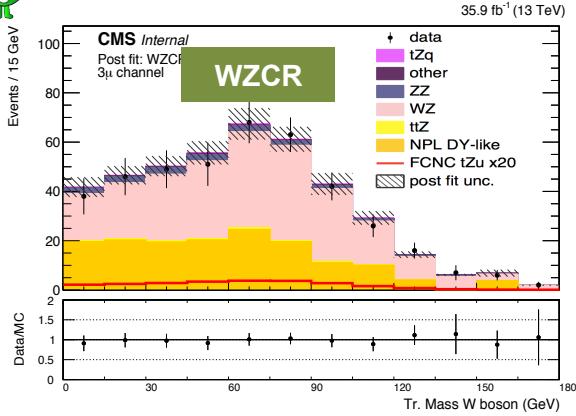
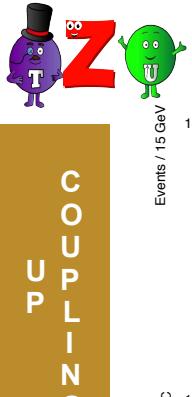


One analysis for tZc
One analysis for tZu

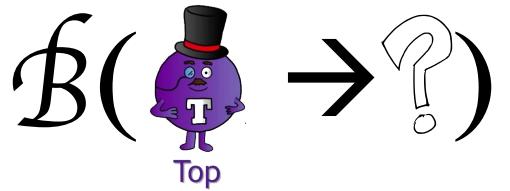




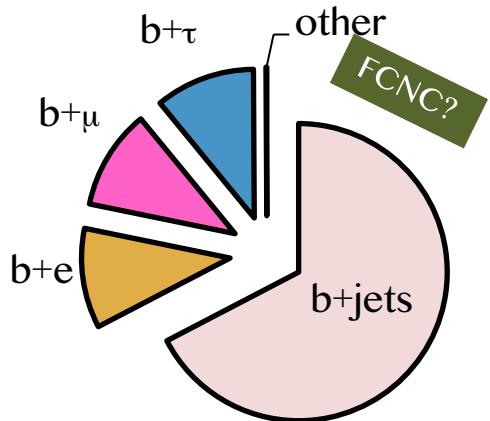
Post fit results



I will set limits on branching fractions



Single top quark branching fractions



Branching fraction \mathcal{B} =

$$\frac{\# \text{ particles which decay by an individual decay mode}}{\text{total number of particles which decay}}$$

single top quark and top quark pair
FCNC search @ 8 TeV

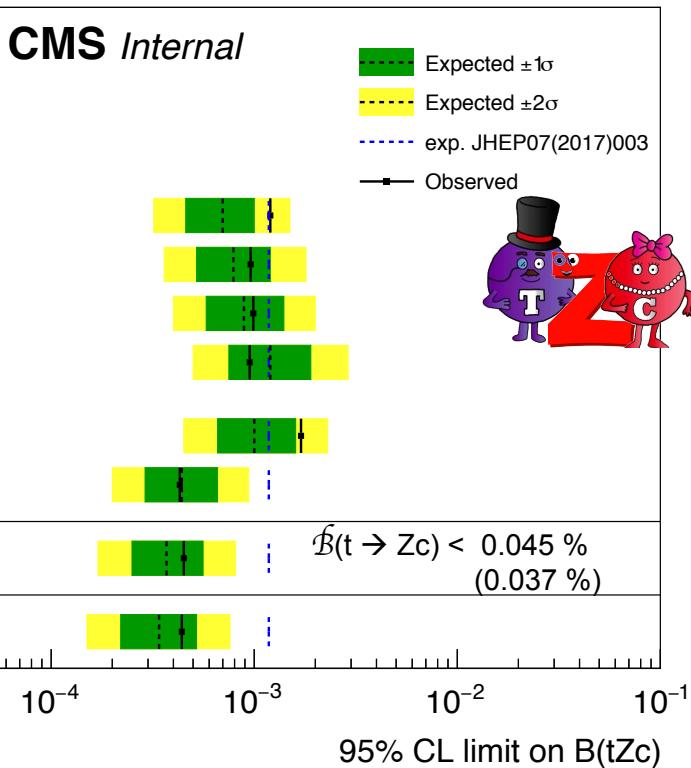
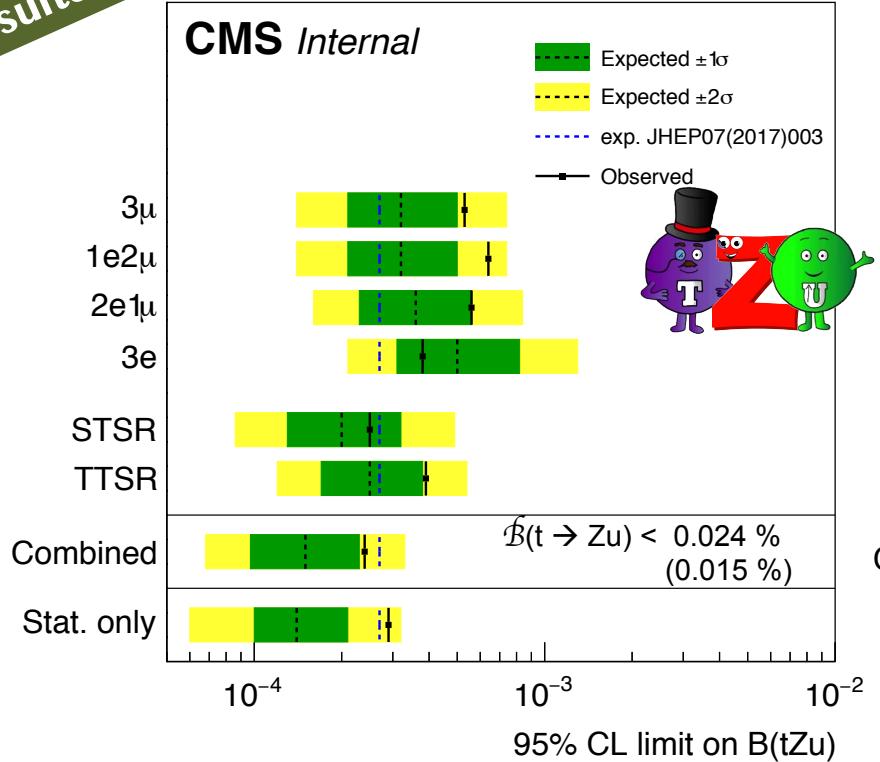
$$\mathcal{B}(t \rightarrow uZ) < 0.022 \%$$

$$\mathcal{B}(t \rightarrow cZ) < 0.049 \%$$



Results

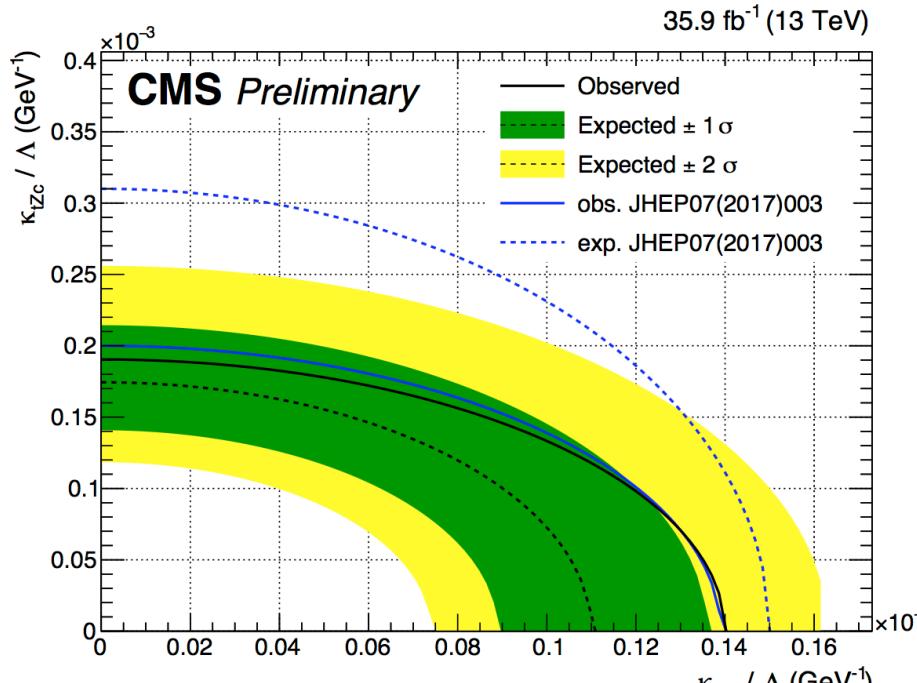
35.9 fb⁻¹ (13 TeV)



More stringent than previous best limits of CMS!

Expected limits for tZu better than ATLAS!

Resulting 2D limits on the couplings



$$\mathcal{L}_{\text{EFT}}^t = \frac{\sqrt{2}}{2} \sum_{q=u,c} \left[\frac{g}{2\cos\theta_W} \frac{\kappa_{tZq}}{\Lambda} Z_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_{Zq}^L P_L + f_{Zq}^R P_R) q + \text{h.c.} \right]$$

Results

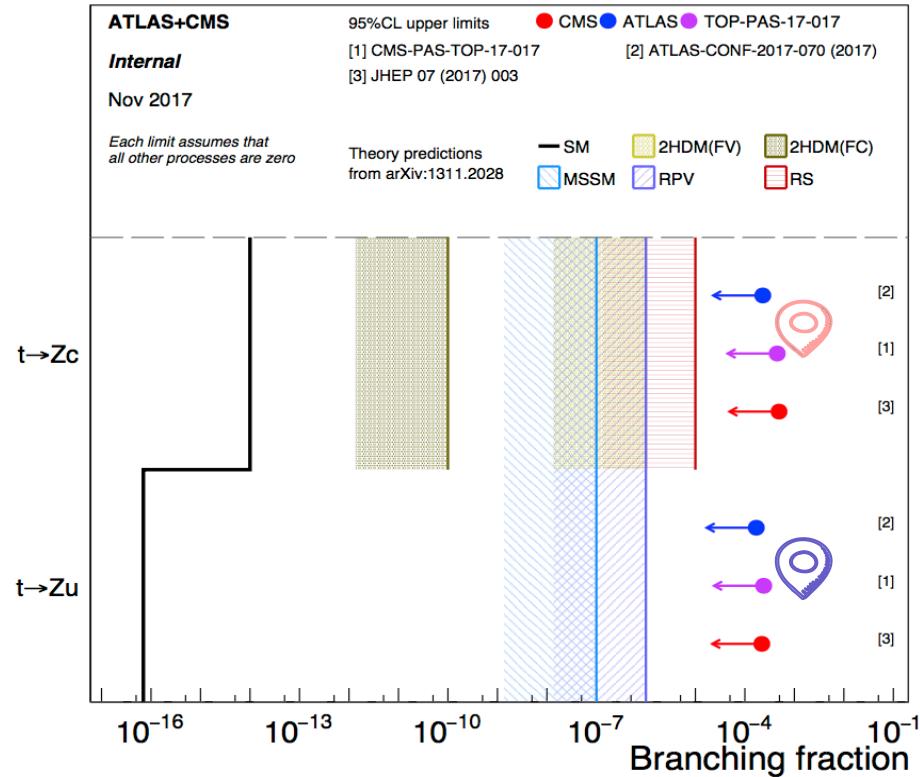


$\mathcal{B}(t \rightarrow Zc) < 0.045\% (0.037\%)$



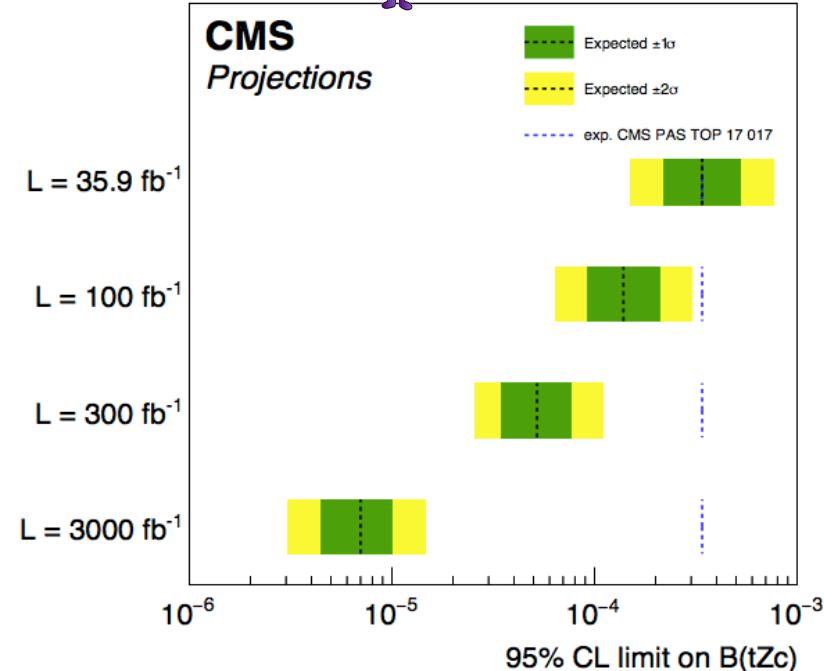
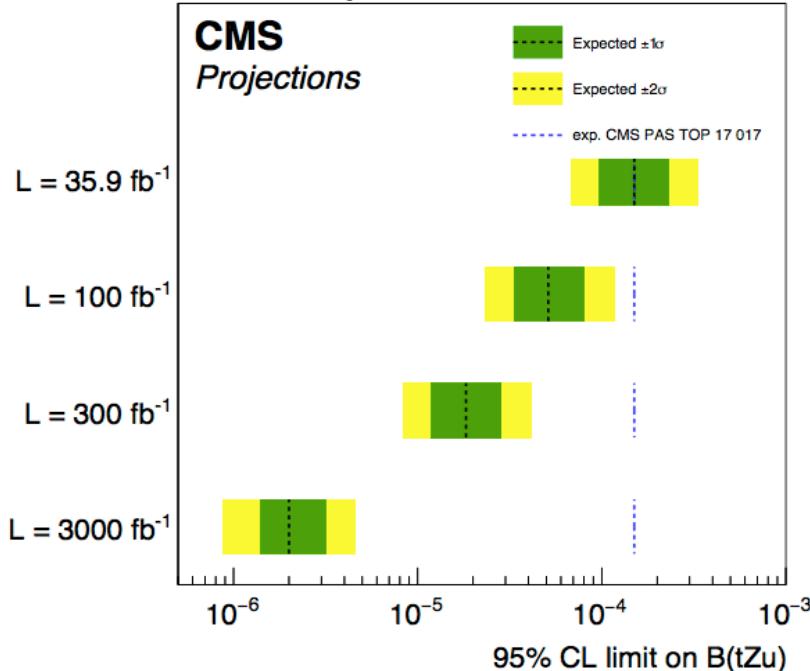
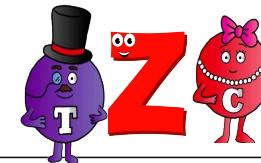
$\mathcal{B}(t \rightarrow Zu) < 0.024\% (0.015\%)$

Looking at the greater picture





Outlook



Extra control region for ttZ background, charm tagging, global EFT fit, ...

What have I been doing



- ◆ Tracker shifts
- ◆ Phenomenology study of all top FCNC couplings
- ◆ Worked on top-Z FCNC analysis at 8 TeV 
- ◆ Spoken at several conferences
- ◆ Convenor of the SM/FCNC tZq group that produced two publications

- ◆ Paving the way for tZq FCNC with an EFT approach
- ◆ Novel and improved strategy with better handle on NPL background
- ◆ Top quark pair and single top FCNC studied together
- ◆ Limit is better than the most stringent 8 TeV result 
- ◆ Analysis performed in the same timeframe as ATLAS
- ◆ Expected limits comparable/better with most stringent limit from ATLAS 