Measurement of the cross section of top quark pair production in association with a Z boson in pp collisions at 13 TeV

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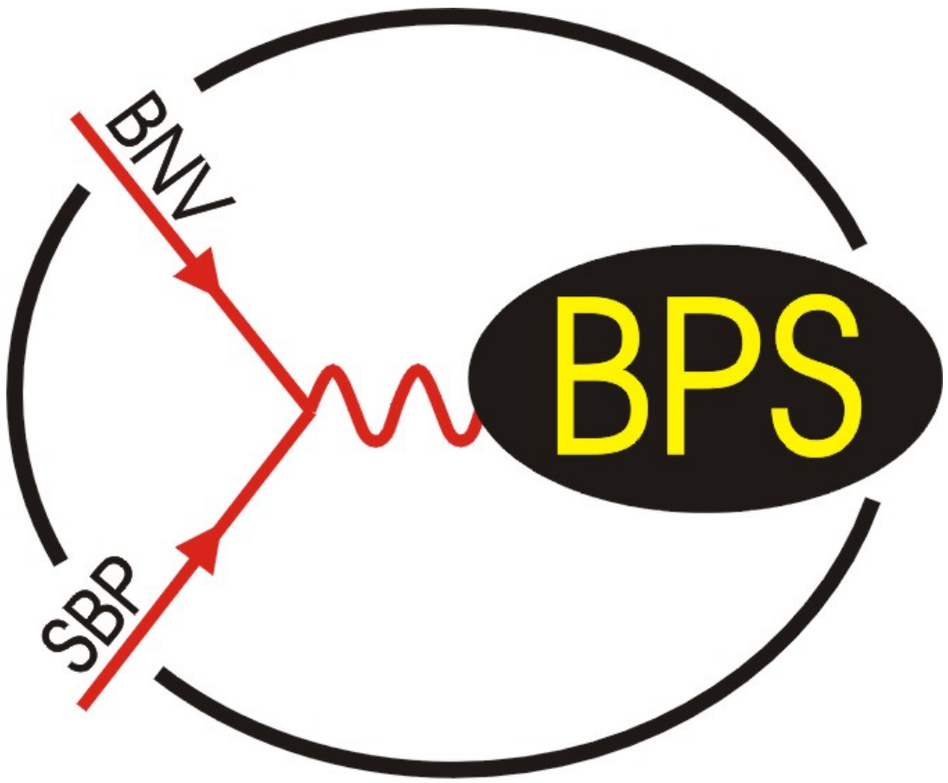
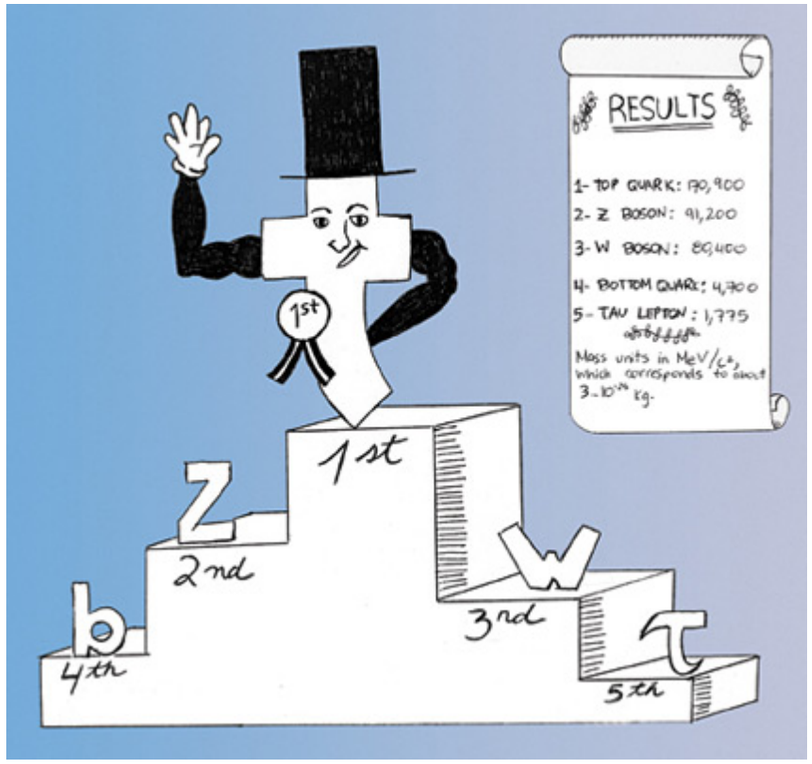
on behalf the CMS collaboration

General Scientific Meeting 2016 of the Belgian Physical Society, 18 May 2016, UGent, Ghent



top quark

Why is it still interesting after 20 years after its discovery?

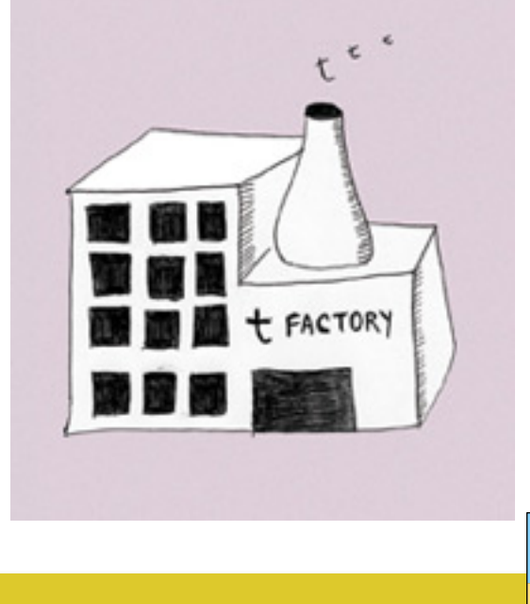


- the top quark is unique in SM:
  - the heaviest particle
  - decays before hadronisation " bare quark "
  - coupling to Higgs ~1 " a special role in EWSB? "

- precision measurements

- probe to new physics

- LHC is a top factory!



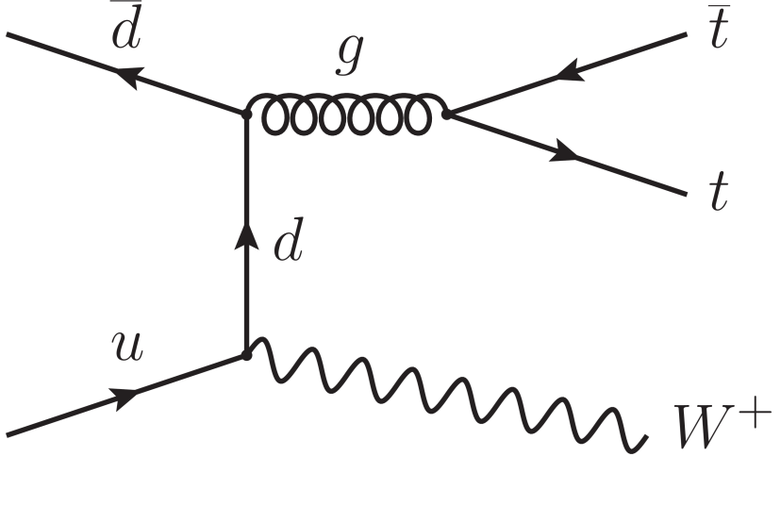
$t\bar{t}V$ (V = W,Z)

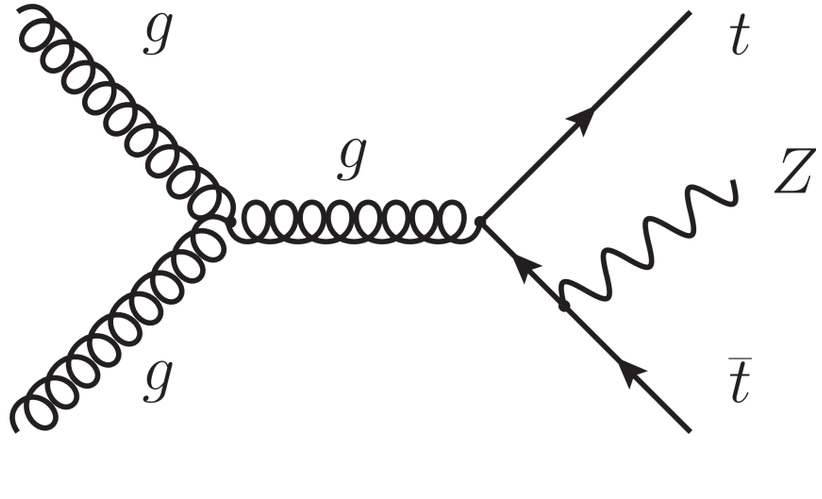
$t\bar{t}V$: associated production of a top quark pair with vector bosons

- background for $t\bar{t}H$ and many BSM processes
- top quark coupling with EW bosons
- extensions of SM modifies the couplings

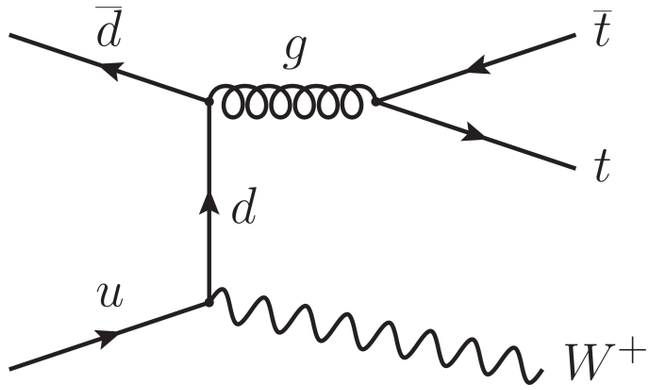
$t\bar{t}Z$: direct measurement of the top quark coupling to Z

$t\bar{t}V$: limits to dimension-six operators





$t\bar{t}V$ decay channels

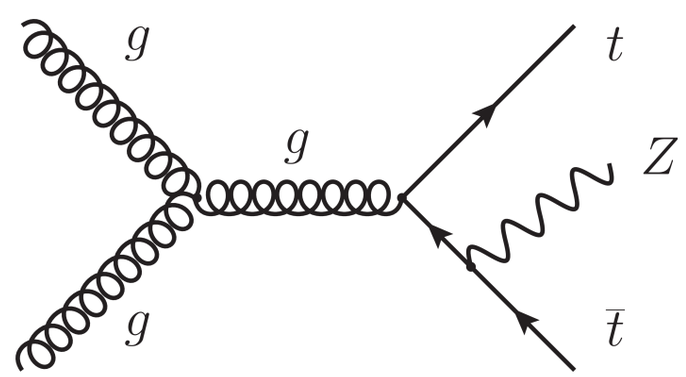


$$t\bar{t}W \to (bjj)(bjj)(jj)$$

$$t\bar{t}W \to (bjj)(bjj)(l\nu)$$

$$t\bar{t}W \to (b\ell\nu)(bjj)(\ell\nu)$$

$$t\bar{t}W \to (bl\nu)(bl\nu)(l\nu)$$



$$t\bar{t}Z \to (bjj)(bjj)(jj)$$

$$t\bar{t}Z \to (bjj)(bjj)(\ell\ell)$$

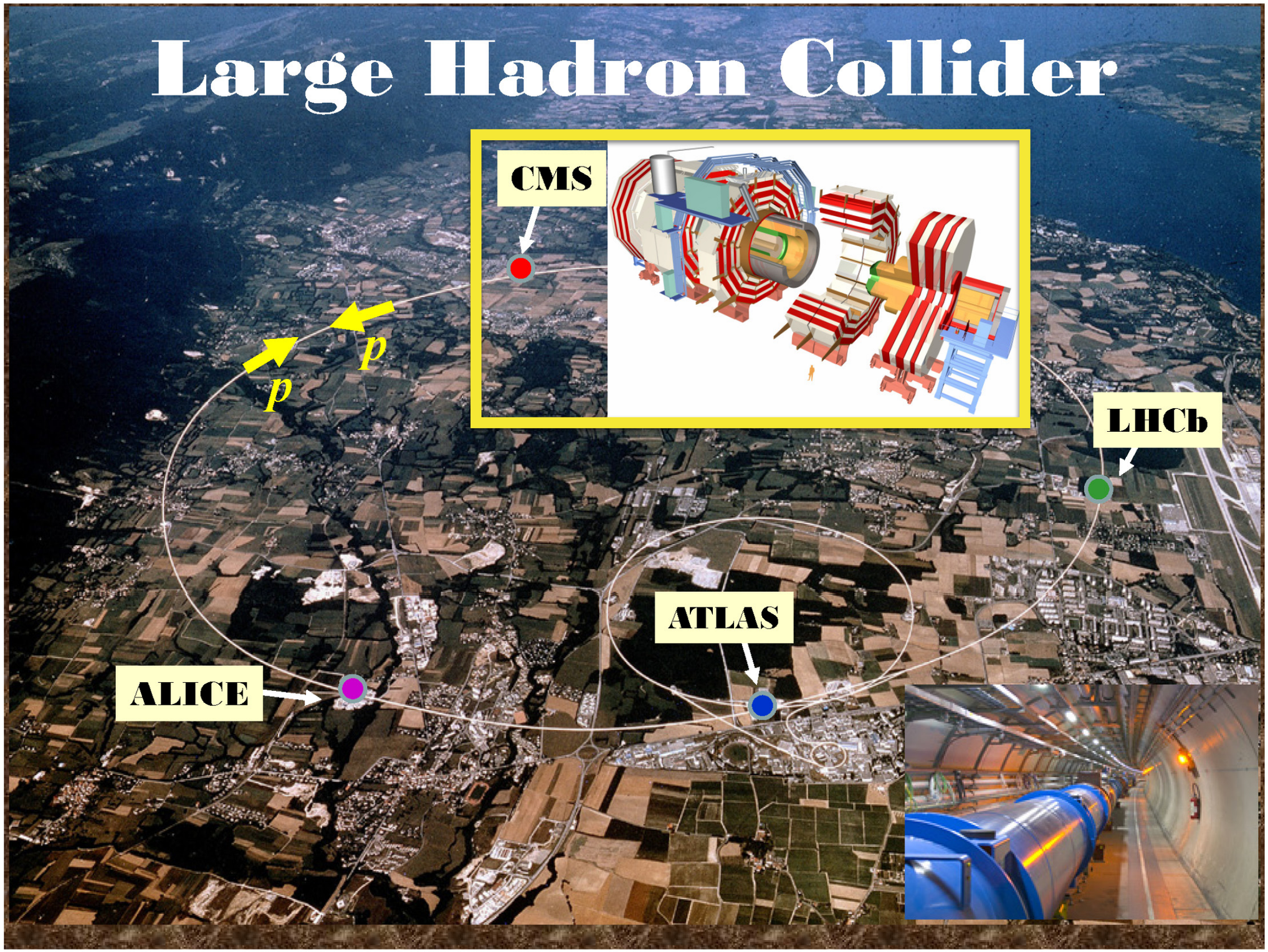
$$t\bar{t}Z \to (b\ell\nu)(bjj)(\ell\ell)$$

$$t\bar{t}Z \to (b\ell\nu)(b\ell\nu)(\ell\ell)$$

$t\bar{t}W$: 2 lepton final state — best signal/background — $t\bar{t}Z$: 3 lepton final state

the most sensitive channels to study ttV

the experiment and the detector



$t\bar{t}V$ overview

8 TeV 19.7 fb^{-1} 10.1140/epjc/s10052-014-3060-7

Cut and count analysis
- $t\bar{t}W$: SS final states
- $t\bar{t}Z$: 3l, 4l final states

$$\sigma_{t\bar{t}W} = 170^{+114}_{-106} \text{ fb with } 1.6\sigma$$

$$\sigma_{t\bar{t}Z} = 200^{+89}_{-76} \text{ fb with } 3.1\sigma$$

8 TeV 19.7 fb^{-1} 10.1007/JHEP01(2016)096

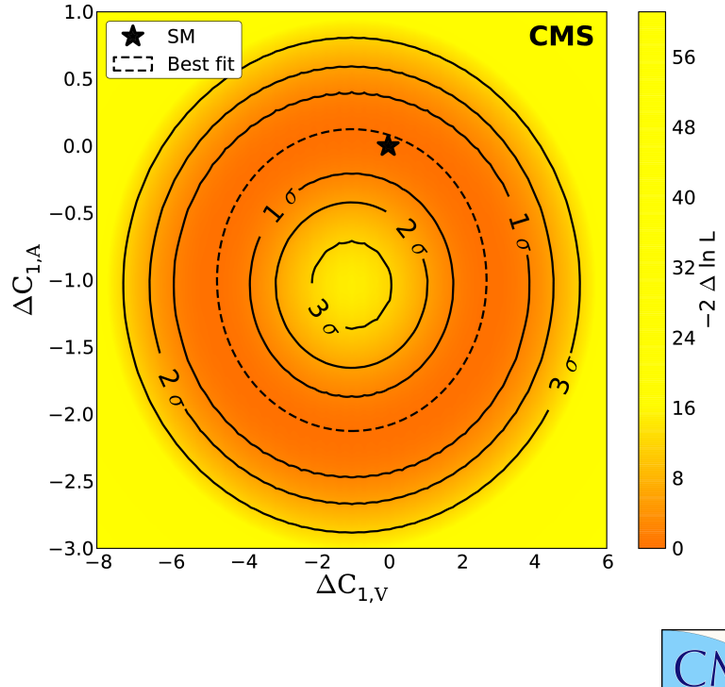
MVA + event reconstruction techniques
- $t\bar{t}W$: SS, 3l final states
- $t\bar{t}Z$: OS, 3l, 4l final states

$$\sigma_{t\bar{t}W} = 382^{+117}_{-102} \text{ fb with } 4.8\sigma$$

$$\sigma_{t\bar{t}Z} = 242^{+65}_{-55} \text{ fb with } 6.4\sigma$$

Constraints on new physics:
- Constraints on the axial and vector components of the tZ coupling
- Constraints on dimension-six operators

Operator	Best fit point(s)	1 standard deviation CL	2 standard deviation CL
$\bar{c}_{uB}$	−0.07 and 0.07	[−0.11, 0.11]	[−0.14, 0.14]
$\bar{c}_{3W}$	−0.28 and 0.28	[−0.36, −0.18] and [0.18, 0.36]	[−0.43, 0.43]
$\bar{c}'_{HQ}$	0.12	[−0.07, 0.18]	[−0.33, −0.24] and [−0.02, 0.23]
$\bar{c}_{Hu}$	−0.47 and 0.13	[−0.60, −0.23] and [−0.11, 0.26]	[−0.71, 0.37]
$\bar{c}_{HQ}$	−0.09 and 0.41	[−0.22, 0.08] and [0.24, 0.54]	[−0.31, 0.63]



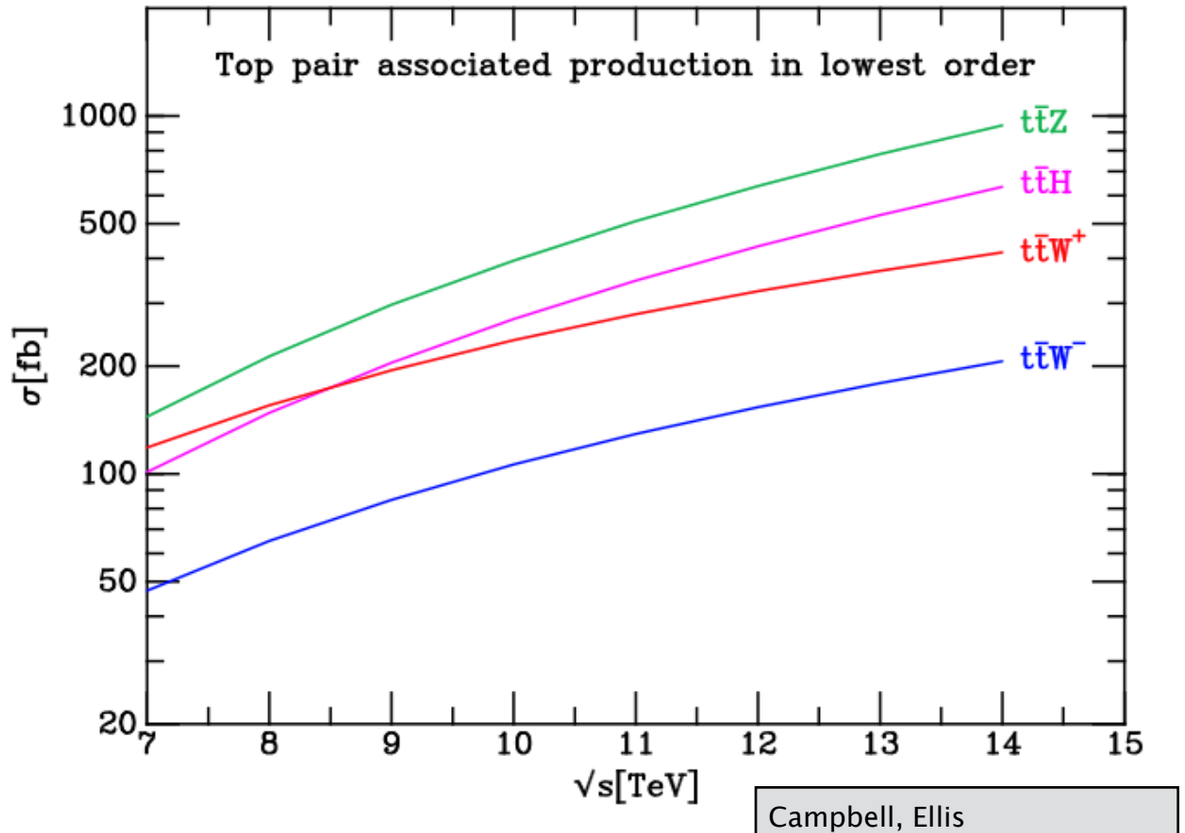
$t\bar{t}Z$ at 13 TeV

13 TeV 2.7 fb^{-1} TOP-16-009

$t\bar{t}Z$: 3lepton, 4lepton final states

SM cross sections

Process	8 TeV	13 TeV	13 TeV / 8 TeV
ttZ(inclusive)	0.206	0.760	3.69
ttW(inclusive)	0.232	0.57	2.46
tt(inclusive)	234	831	3.55
ZZ (to 4l)	0.078	0.157	2.03
WZ (to 3l)	1.058	2.165	2.05
Wj (to l+j)	37509	61526.7	1.64
Zj (to 2l+j)	3533	6025	1.71
ttH (inclusive)	0.129	0.509	3.94



Campbell, Ellis
10.1007/JHEP07(2012)052

8 TeV to 13 TeV

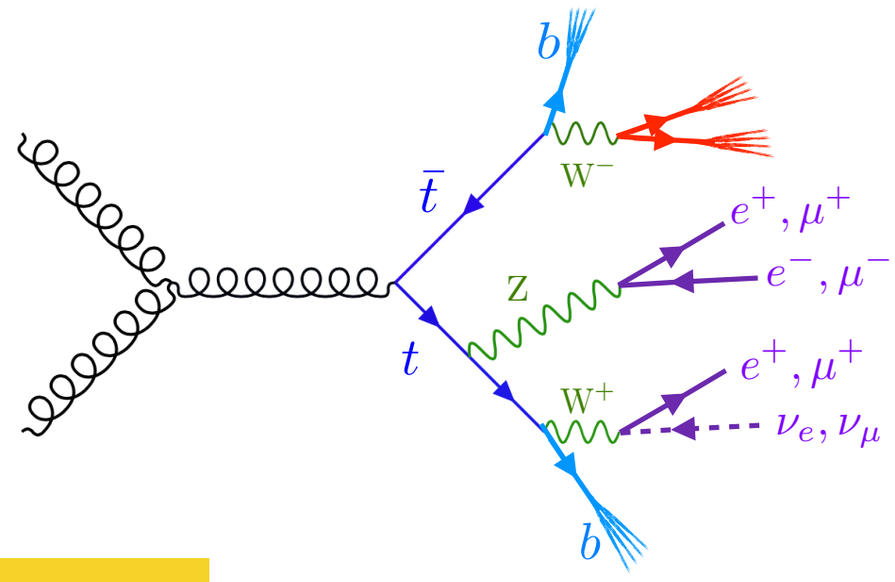
★ signal / background favoured

★ 3σ sensitivity with 2.5 fb^{-1}

$t\bar{t}Z$ 3 lepton channel

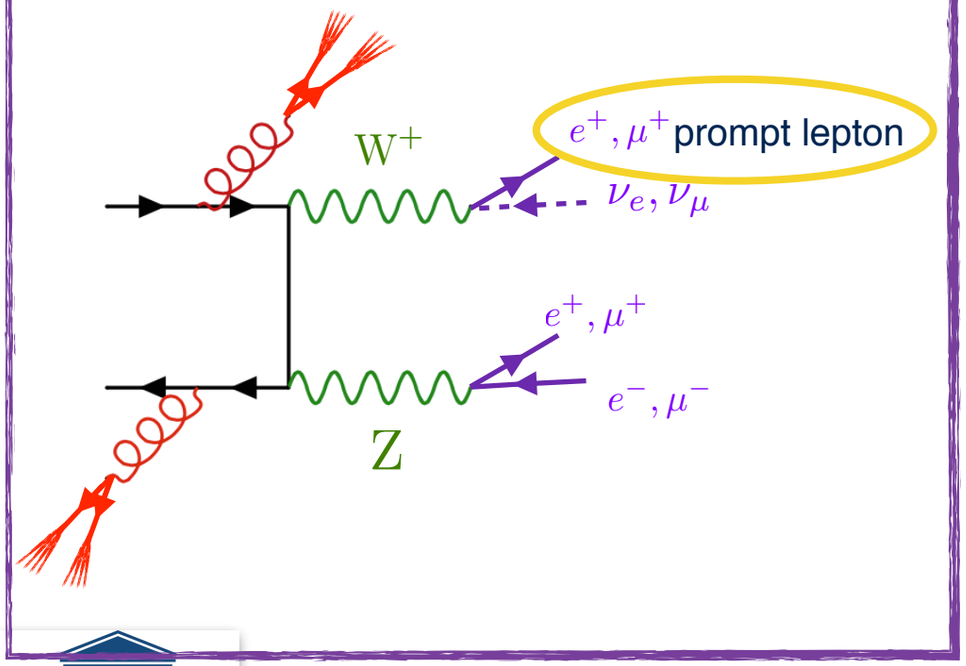
Final state:

- 3 leptons:
  where a Same Flavour Opposite Sign from Z boson
- 4 jets where 2 of them b-jets

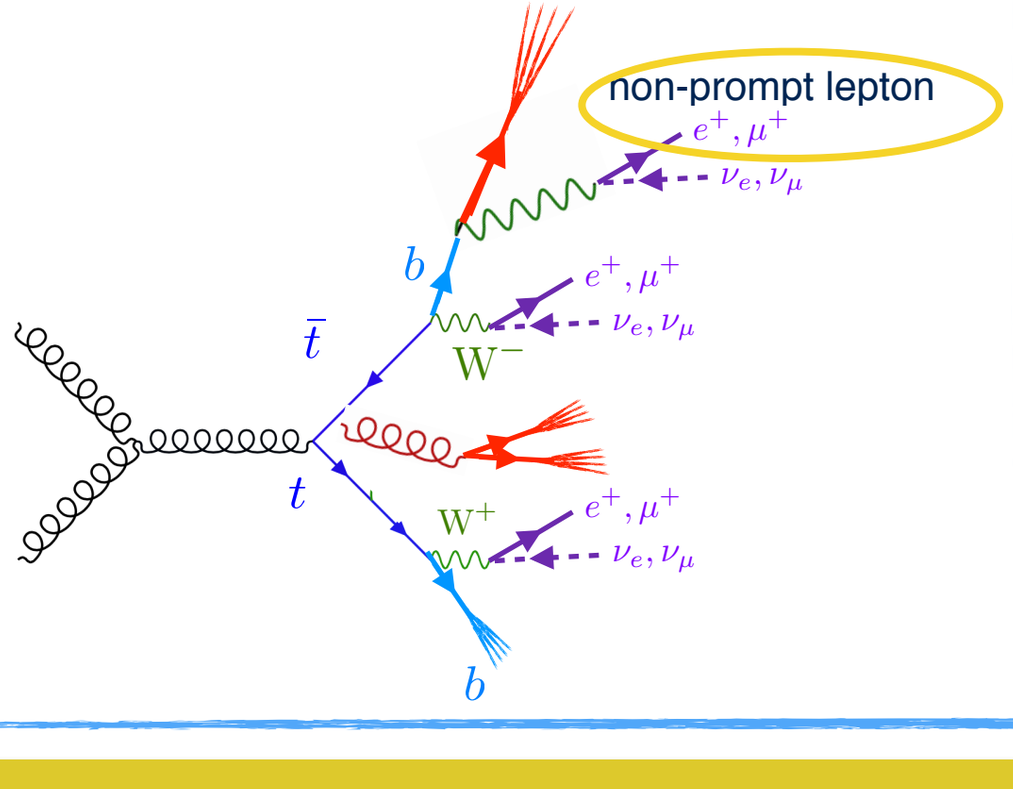


Background contributions:

- WZ: semi-datadriven
  - 3 prompt leptons



- non-prompt leptons: data-driven
  - heavy or light jet decaying to leptons
  - misidentified jets as leptons (fakes)



- ttX:
  (ttW, ttH, tZq)
- rare:
  (ZZ, Zγ, WZZ, ZZZ)
- 3-4 prompt leptons

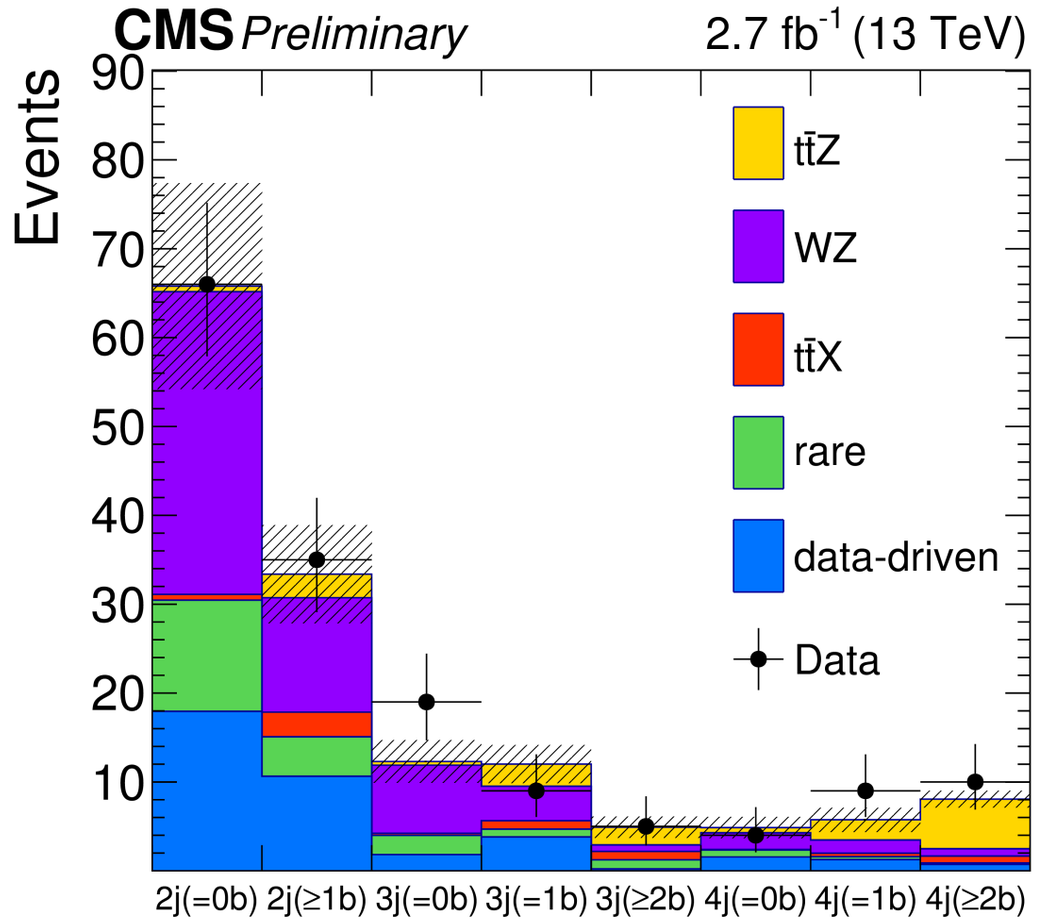
optimisation of the analysis

baseline selections:

- exactly 3 leptons (p_T > 30, 20,10 GeV)
- | $m_{(SFOS)}$ - m_Z | < 10 GeV

Signal extraction in 8 different bins:
baseline selections and:

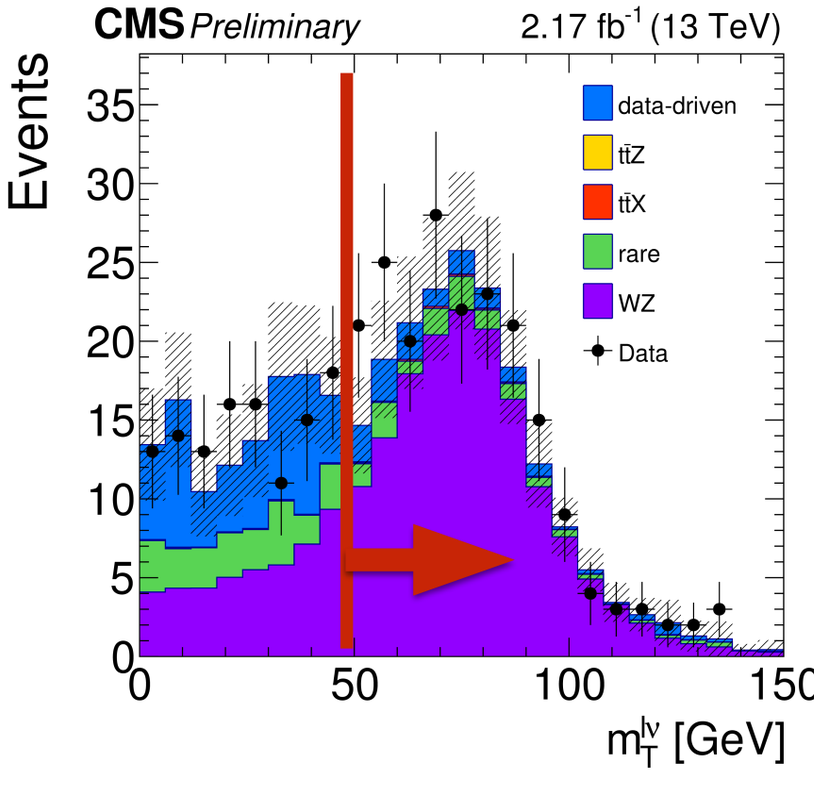
- Njets = 2 and Nbjets = 0, ≥ 1
- Njets = 3 and Nbjets = 0, = 1, ≥ 2
- Njets ≥ 4 and Nbjets = 0, = 1, ≥ 2

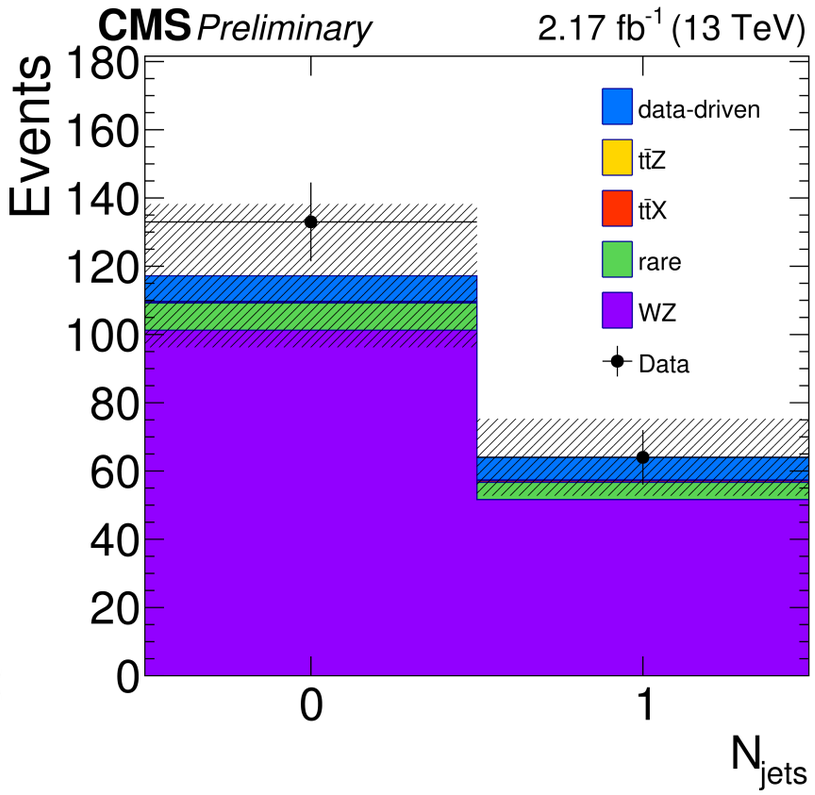


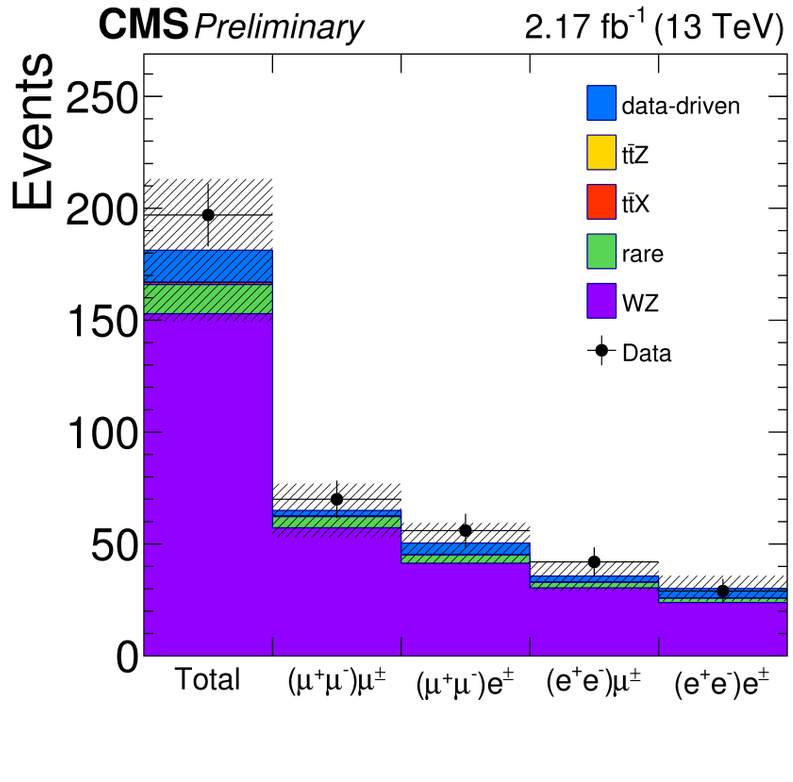
- 2 jets bin: to constraint the background
- 3 jets bin: to gain sensitivity
  when a jet is misidentified

WZ background

- semi data-driven approach:
  - data/MC in WZ control region
  - 3 leptons (p_T > 30,20,10 GeV)
  - | $m_{(ll)}$ -m_Z | <10 GeV
  - MET > 30 GeV and mT_{lmet} > 50 GeV
  - Njets < 2 and Nbjets =0







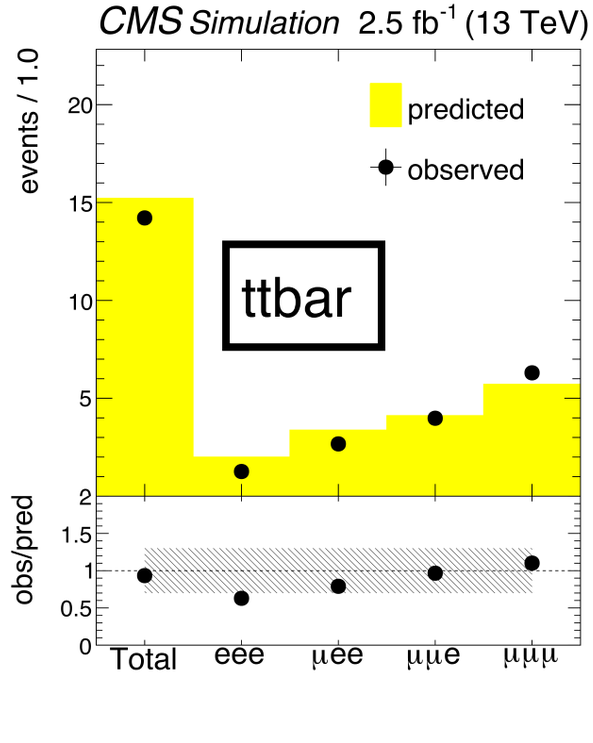
- purity ~85%
- data/MC = 1.1 ± 0.1

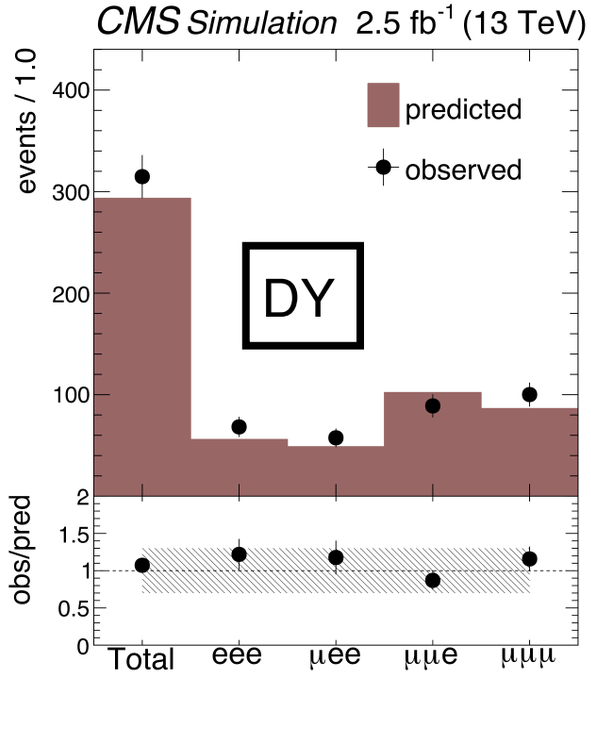
Non-prompt background estimation

- estimate the probability of a non-prompt (fake) lepton to pass the analysis selections —> Fake Rate (FR)
- measure FR as a function of pT and η in a QCD enriched control region dominated by non prompt leptons

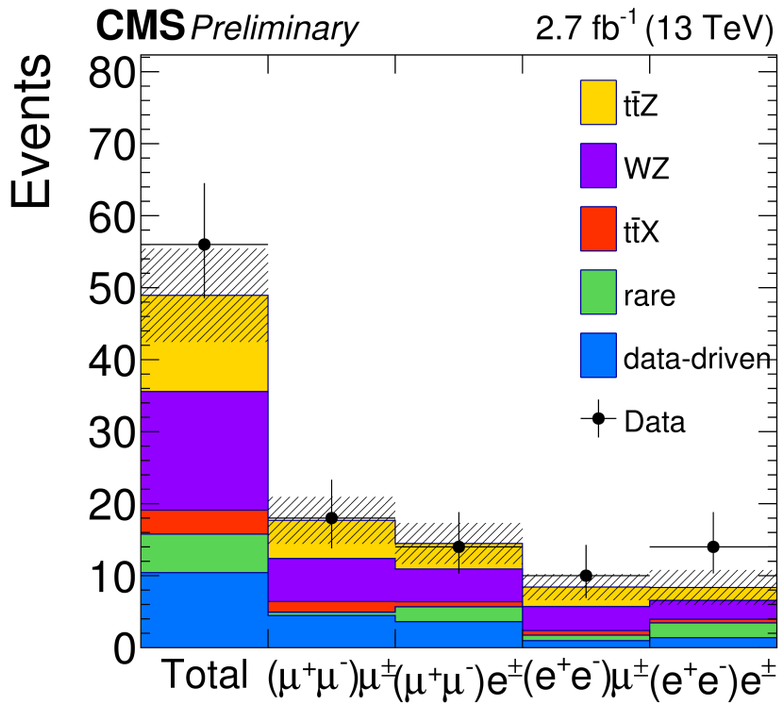
  - FR in data is ~5-40%
  - data and MC agrees up to 30%
  - the statistical uncertainty 10-30%

- Closure test of the FR: using QCD MC
- application region: ttbar and DY
  - 3 leptons where SFOS lepton pair is a Z candidate
  - at least one of the leptons fail tight selection but pass loose selection

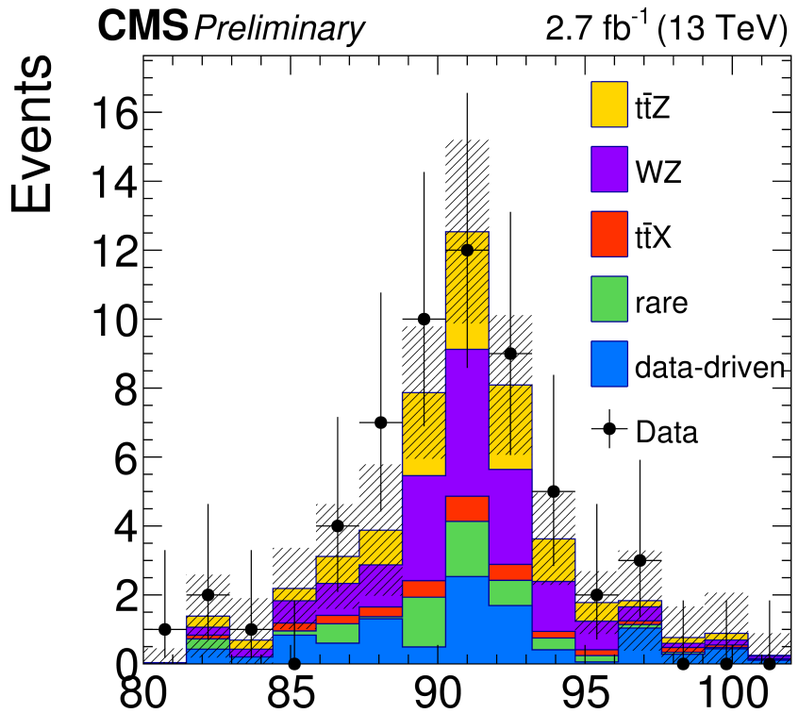


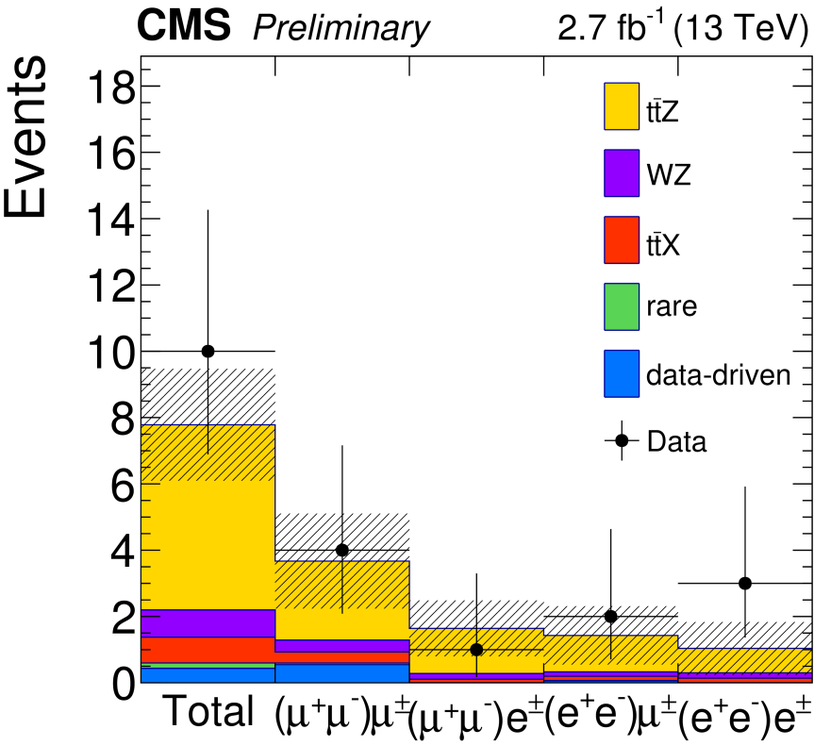


predicted signal and background yields

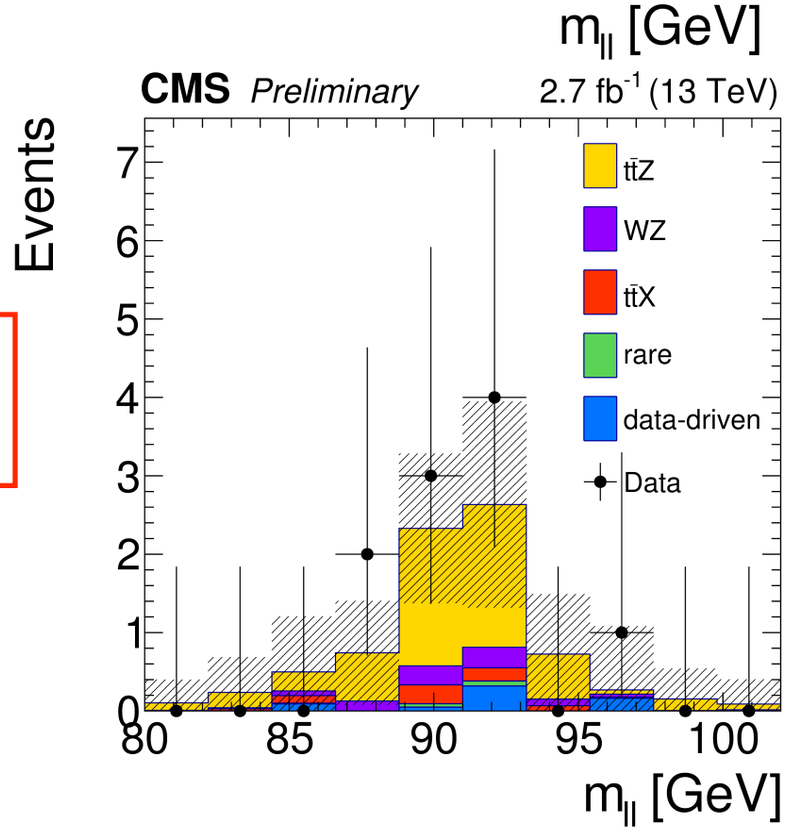


Njets ≥ 3

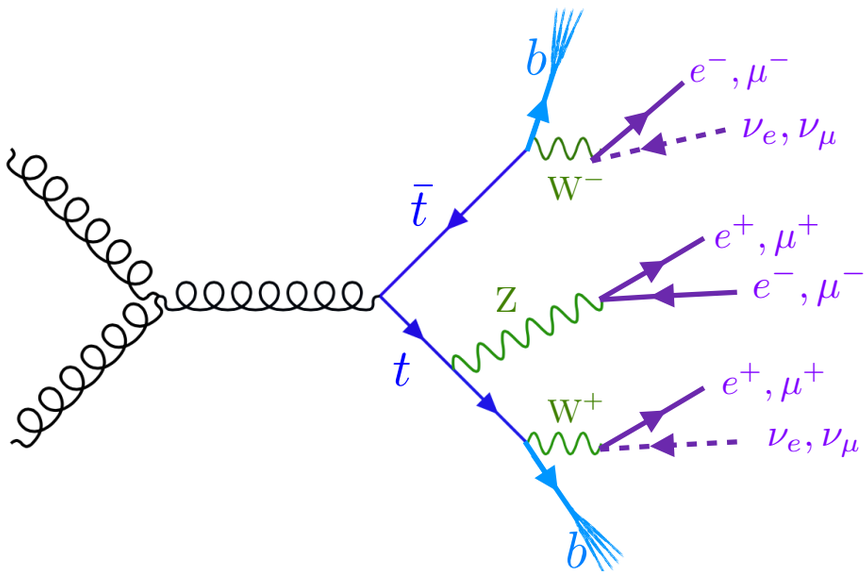


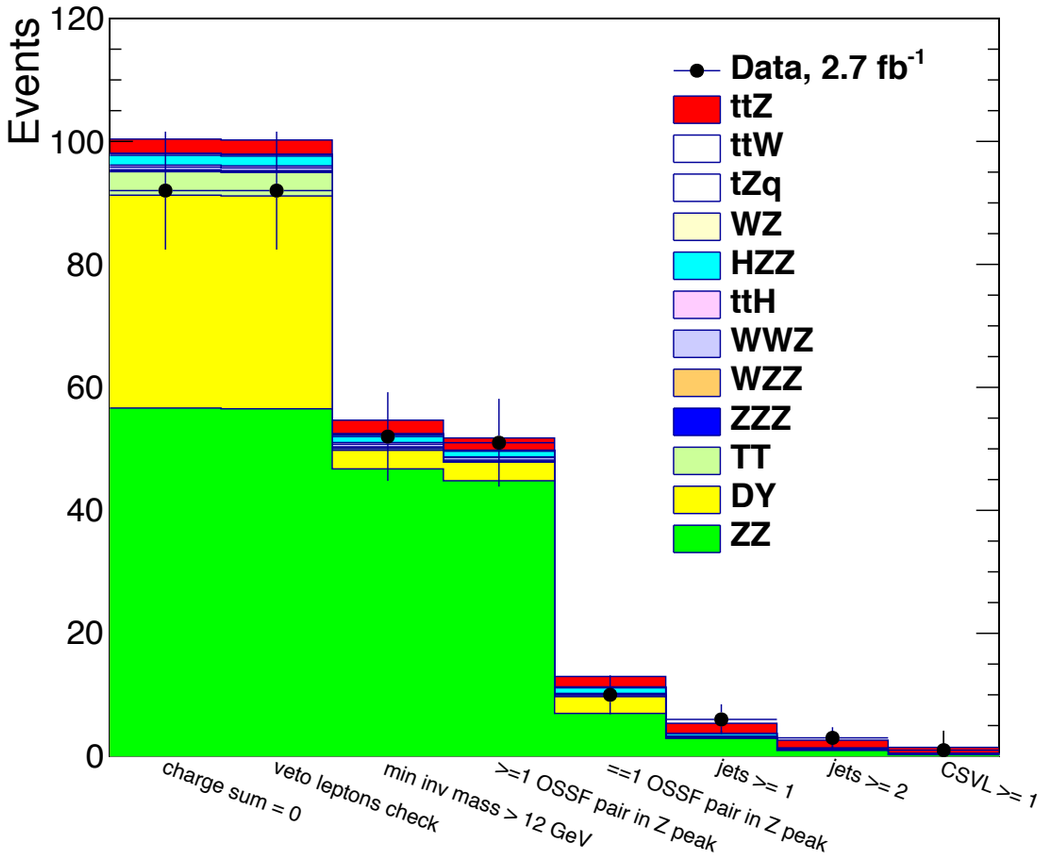


Njets ≥ 4 and Nbjets ≥ 2
the most sensitive bin



ttZ 4 lepton channel





Final state:

- exactly 4 leptons with (p_T > 20,10,10, 10 GeV)
- lepton charge sum = 0
- $m_{(ll)}$ > 12 GeV
- ≥ 1 SFOS pair, $|m_{(ll)} - m_Z| < 20$ GeV
- second Z veto for the 2nd SFOS
- ≥ 2 jets
- ≥ 1 loose b tag-jets

Event selection in two categories:

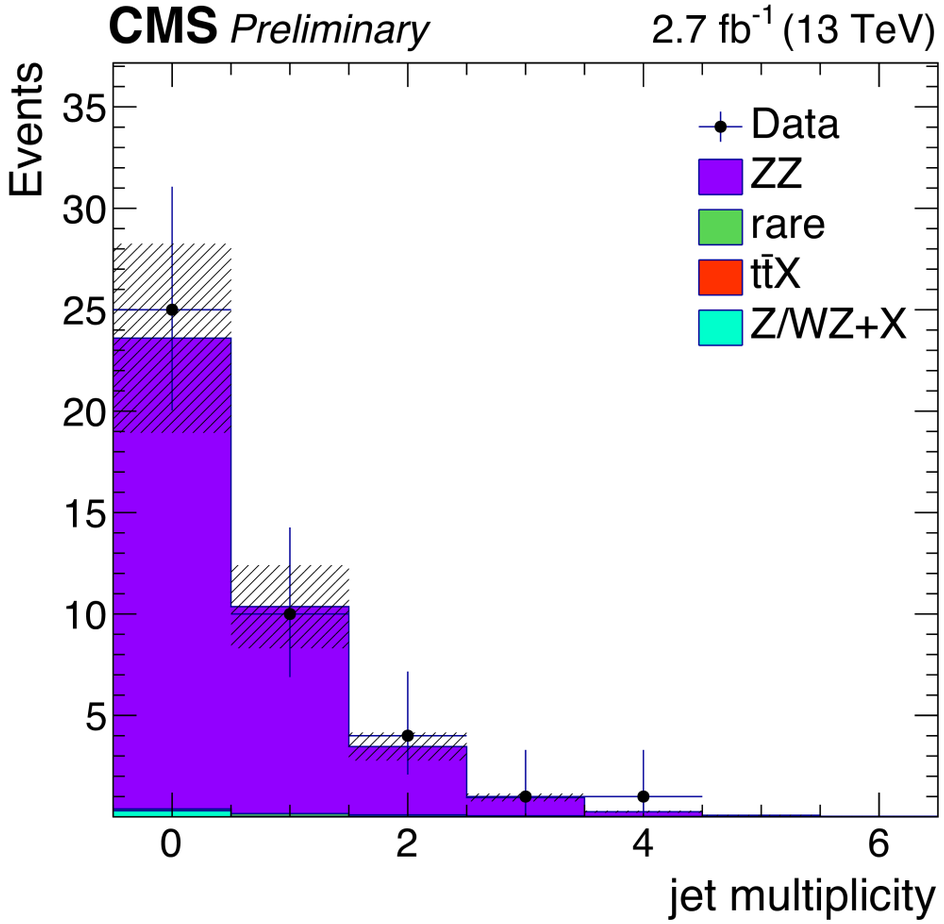
- Njets ≥ 2 and Nbjets = 0
- Njets ≥ 2 and Nbjets ≥ 1

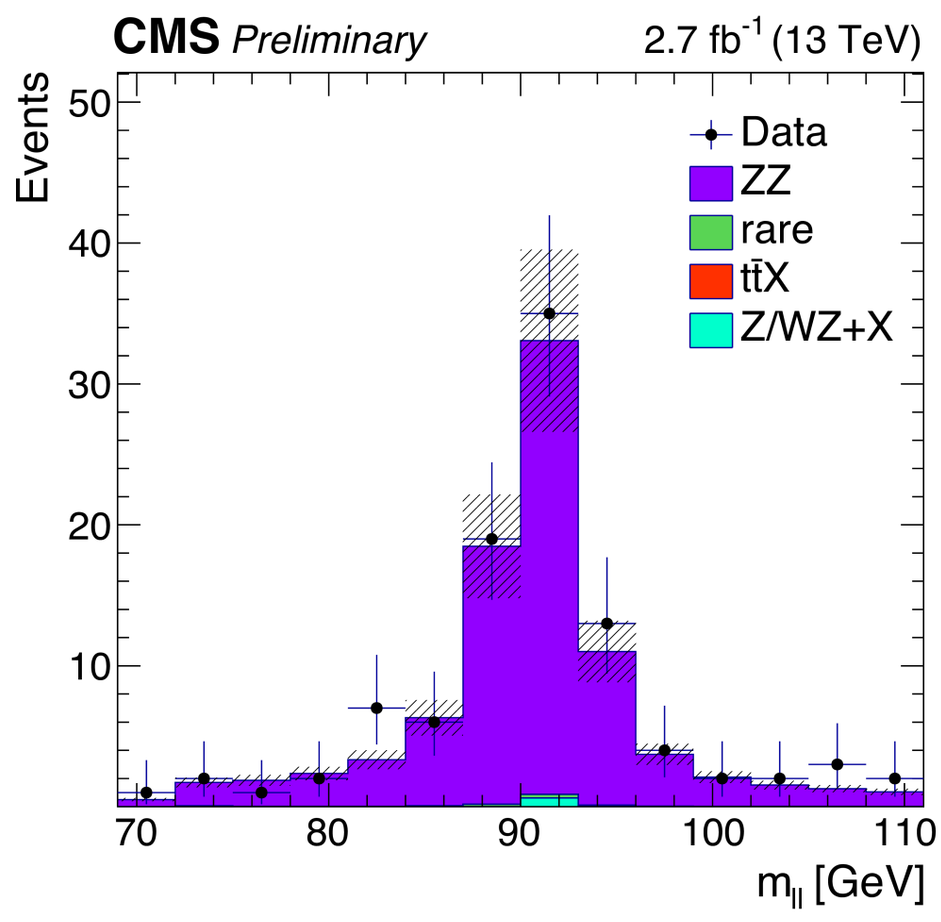
- Backgrounds:
  ZZ(main), H—>ZZ, ttH, WWZ(small): estimated from MC

ZZ background

- 4 leptons
- lepton charge sum = 0
- $m_{(ll)} > 12$ GeV
- ≥ 2 SFOS pair, $|m_{(ll)} - m_Z| < 20$ GeV

very pure ZZ selection!

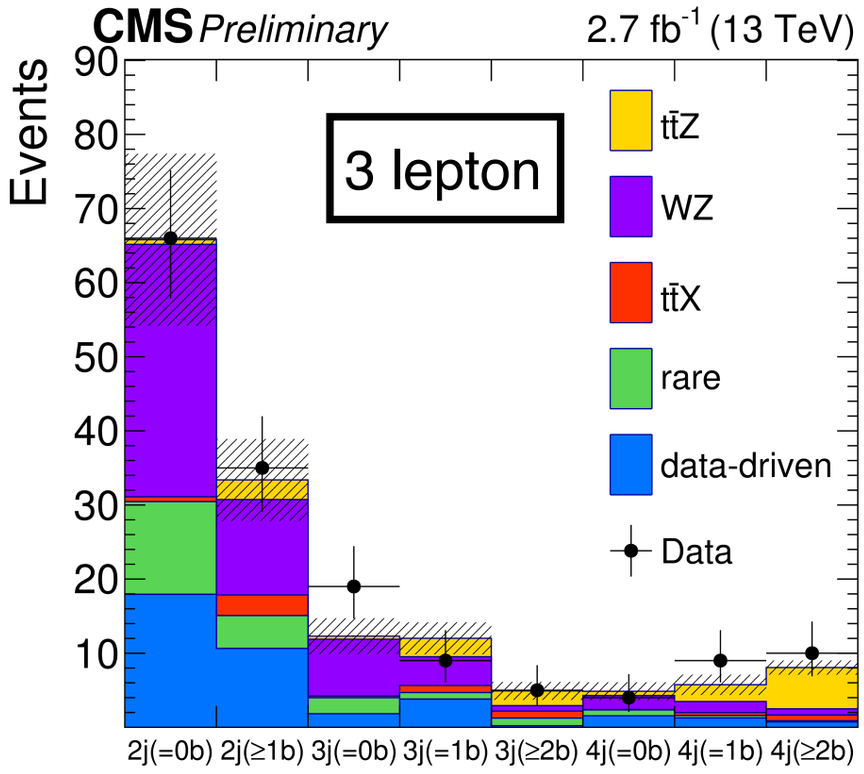


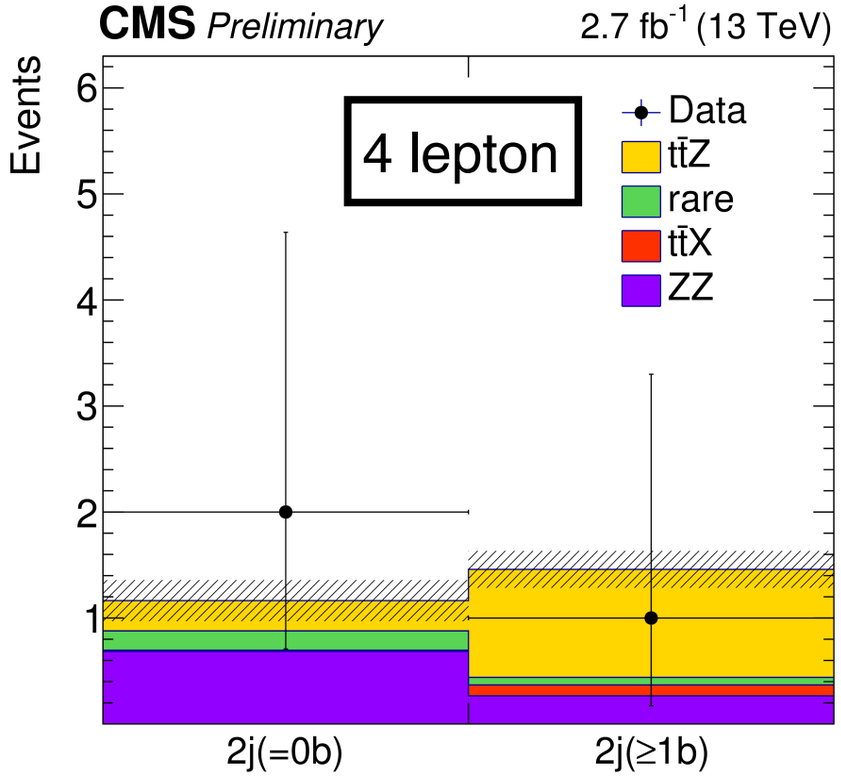


summary of systematics

Source	Syst. uncertainties $t\bar{t}Z$ in 3L	Syst. uncertainties $t\bar{t}Z$ in 4L
Luminosity	2.7%	2.7%
Jet Energy Scale	2-8%	1-7%
Jet Energy Resolution	1-6%	1%
Trigger	3%	1%
BTagging	1-8%	1-5%
PU modeling	3%	1%
Lepton Id., Eff.	4.5%	5-7%
μ_R/μ_F scale choice	3-4%	4%
PDF choice	3%	3%
Non-prompt background	30%	-
WZ background cross section	20%	-
ZZ background cross section	20%	20%
Rare SM bkg	50%	50%
$t\bar{t}W/t\bar{t}H/tZq$ bkg	25%	25%
$t\bar{t}Z$ MC stat. uncertainty	5-17%	13-20%

results 3 lepton + 4 lepton





binned likelihood fit to all categories

Channel	Expected significance	Observed significance
3ℓ analysis	2.9	3.5
4ℓ analysis	1.2	0.9
3ℓ and 4ℓ combined	3.1	3.6

$$\sigma_{\mathrm{t\bar{t}}Z} = 1065^{+352}_{-313}(\mathrm{stat.})^{+168}_{-142}(\mathrm{sys.})\ \mathrm{fb}$$

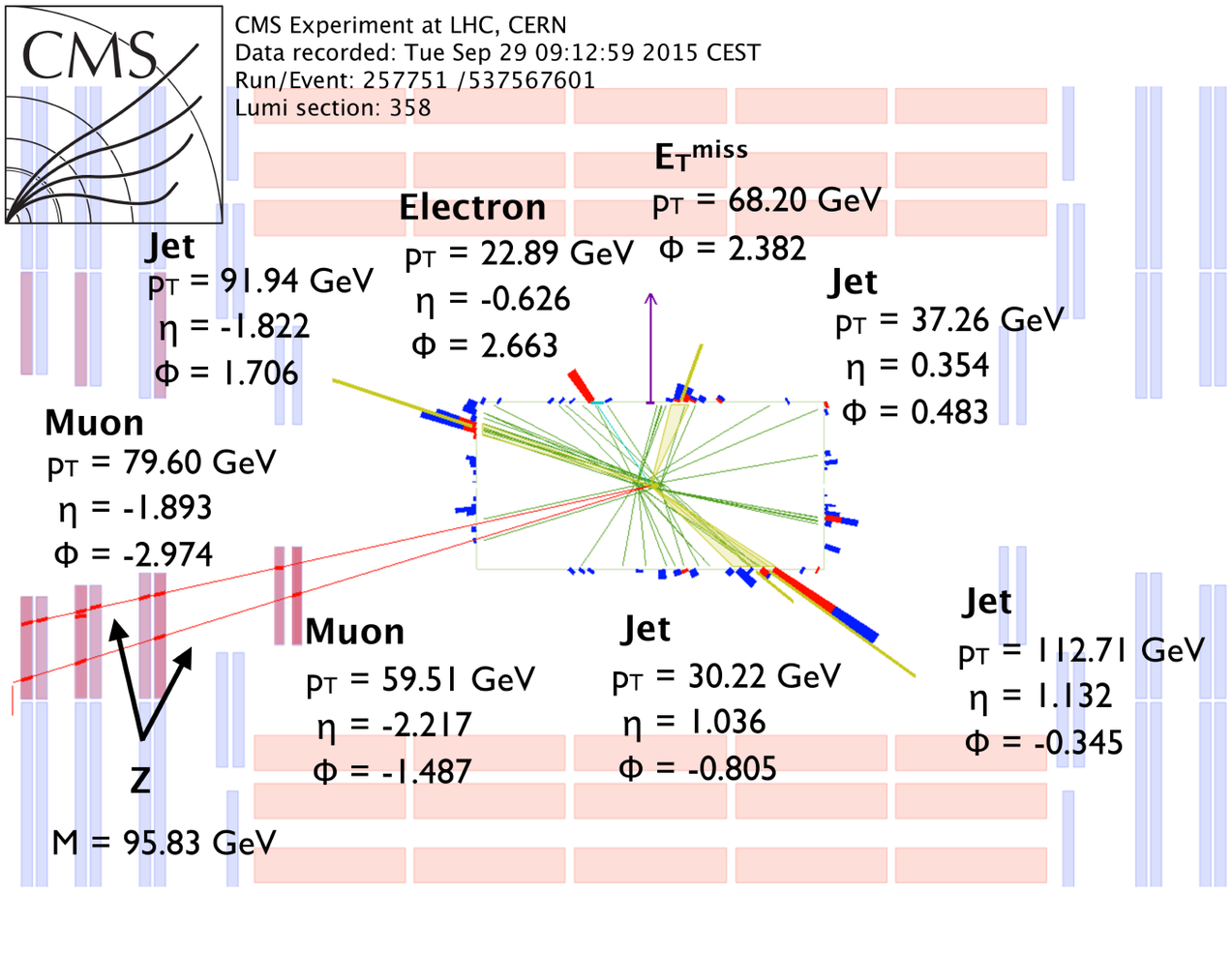
$$\mathrm{aMCatNLO} = 839.3^{+80}_{-92}(\mathrm{scale})^{+25}_{-25}(\mathrm{pdf})^{+25}_{-25}(\alpha_s)\ \mathrm{fb}$$

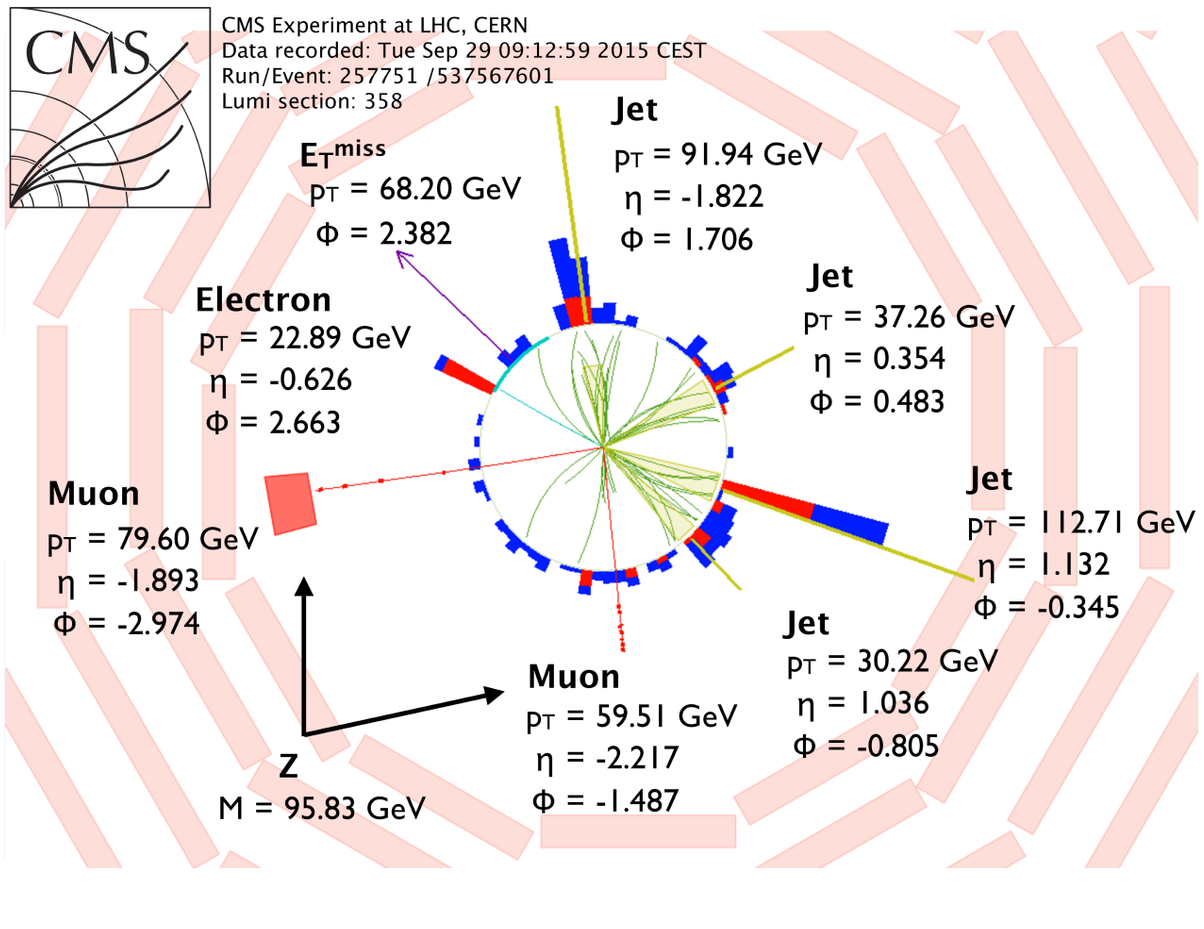
evidence of tt̄Z at 13 TeV

event display 2015 data

- 3 lepton channel

$$t\bar{t}Z \rightarrow (t \rightarrow be^{\pm}\nu)(t \rightarrow bjj)(Z \rightarrow \mu^{+}\mu^{-})$$

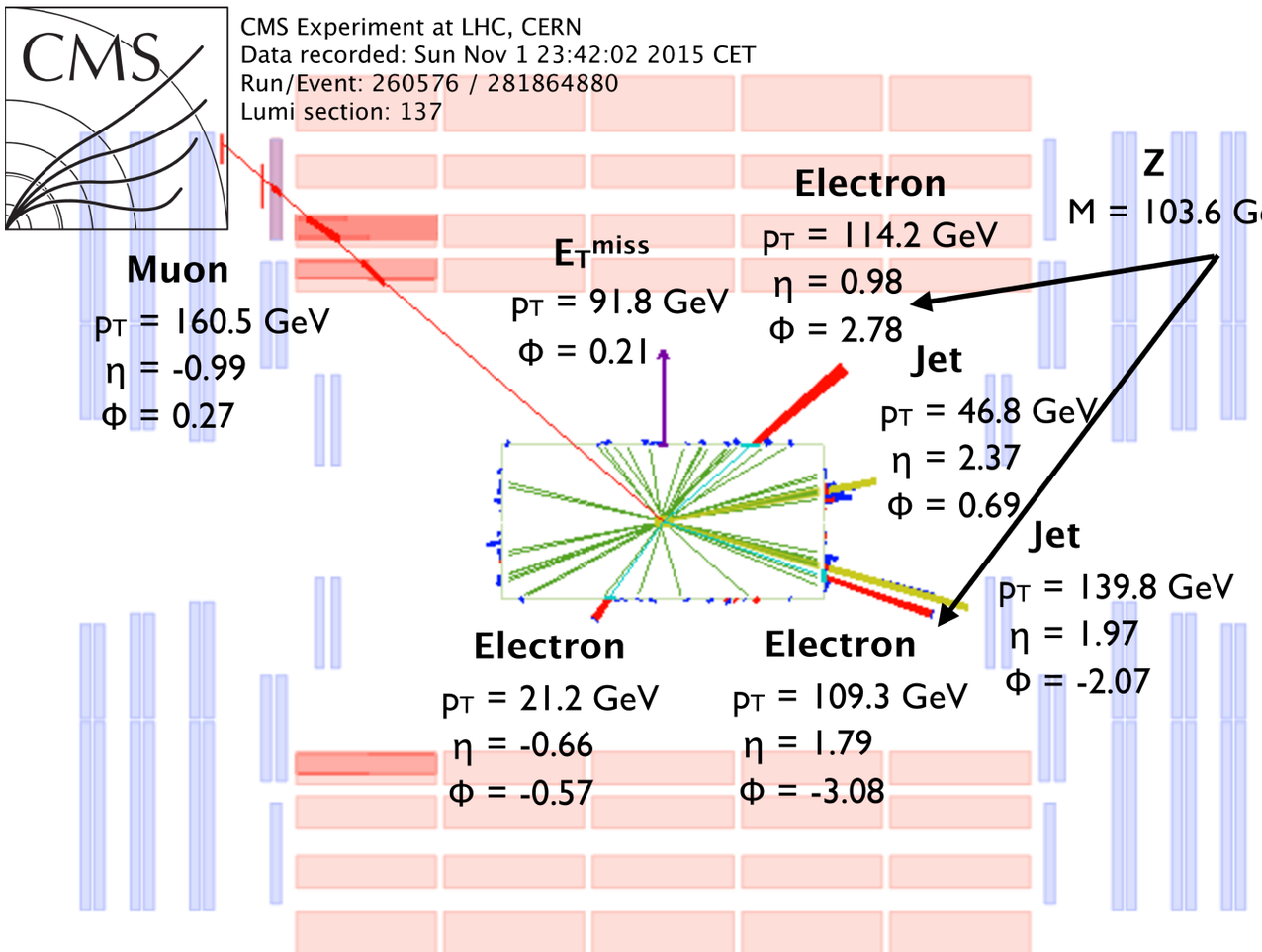


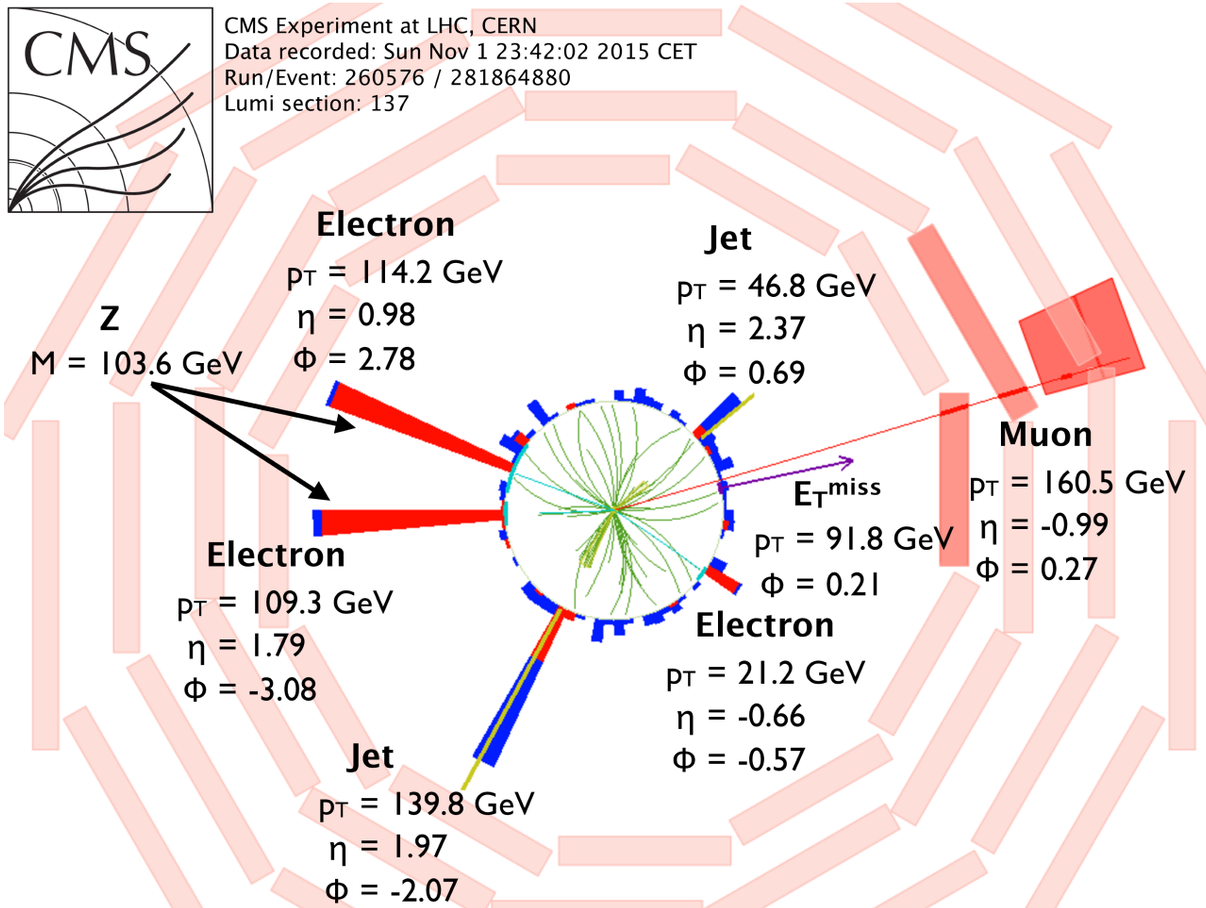


event display 2015 data

- 4 lepton channel

$$t\bar{t}Z \rightarrow (t \rightarrow be^{\pm}\nu)(t \rightarrow b\mu^{\mp}\nu)(Z \rightarrow e^{+}e^{-})$$





summary

- ttZ cross section measurement with 2015 Data corresponding to 2.7 fb^{-1} at 13 TeV in 3 lepton and 4 lepton channels are presented

- looking forward to 2016 Data for more precise results!!
- with more statistics new physics interpretation!

Thanks for your attention!