Analysis of ttZ production in 4 lepton final states at CMS

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DESY Summer Student Program

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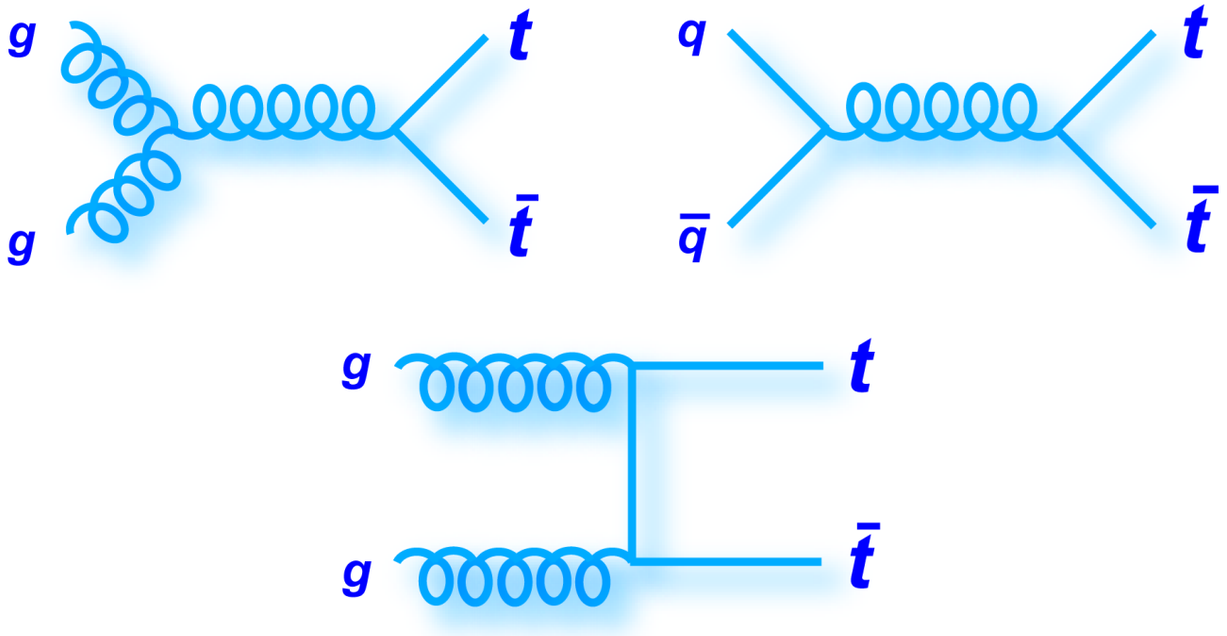
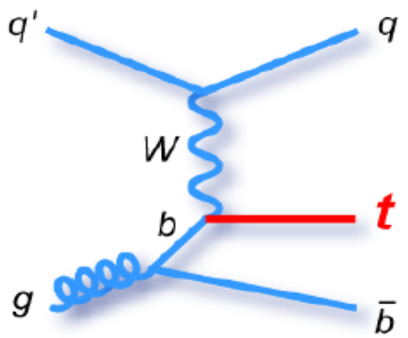
Outline

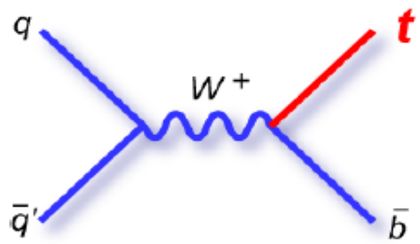
1. Top pair dilepton measurements
2. ttZ process
3. Optimisation of event selection
4. Results

Top production & decay

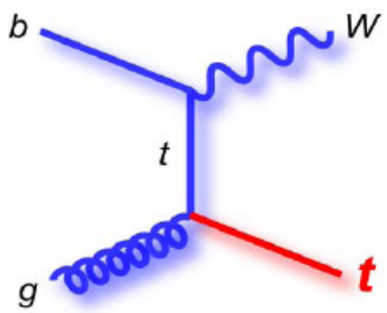




t-channel



s-channel



tW-channel

$\bar{c}s$	$\bar{u}d$	τ^-	μ^-	e^-	W decay
electron+jets	electron+jets	eτ	eμ	ee	e^+
muon+jets	muon+jets	μτ	μμ	eμ	μ^+
tau+jets	tau+jets	ττ	μτ	eτ	τ^+
all-hadronic	all-hadronic	tau+jets	muon+jets	electron+jets	$u\bar{d}$ $c\bar{s}$

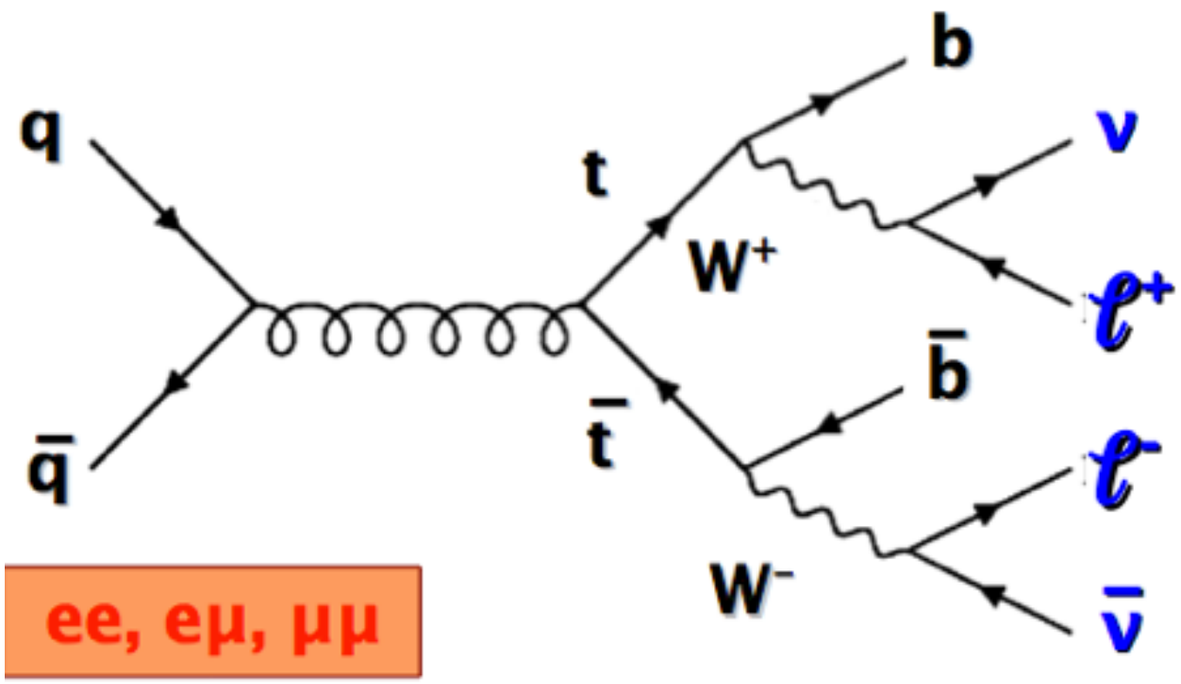
dileptons

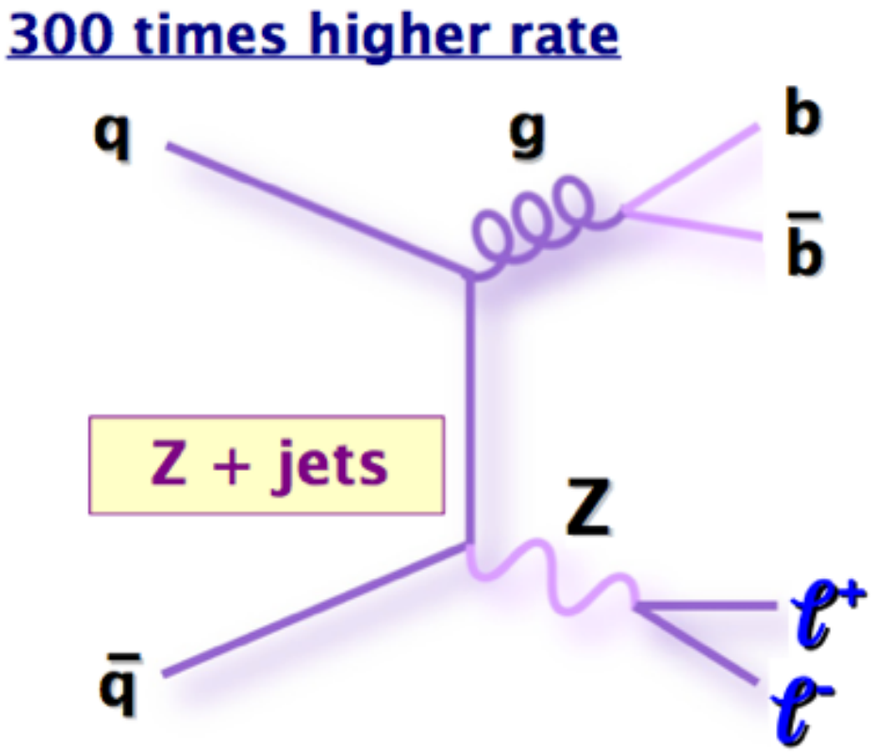
Direct dilepton (e, μ) decays 4.5%
Dilepton final states (inc τ) 6.4%

- Tops mainly produced in pairs
- Top pair decays can be classified by decays of the two W bosons

Dilepton channel & backgrounds

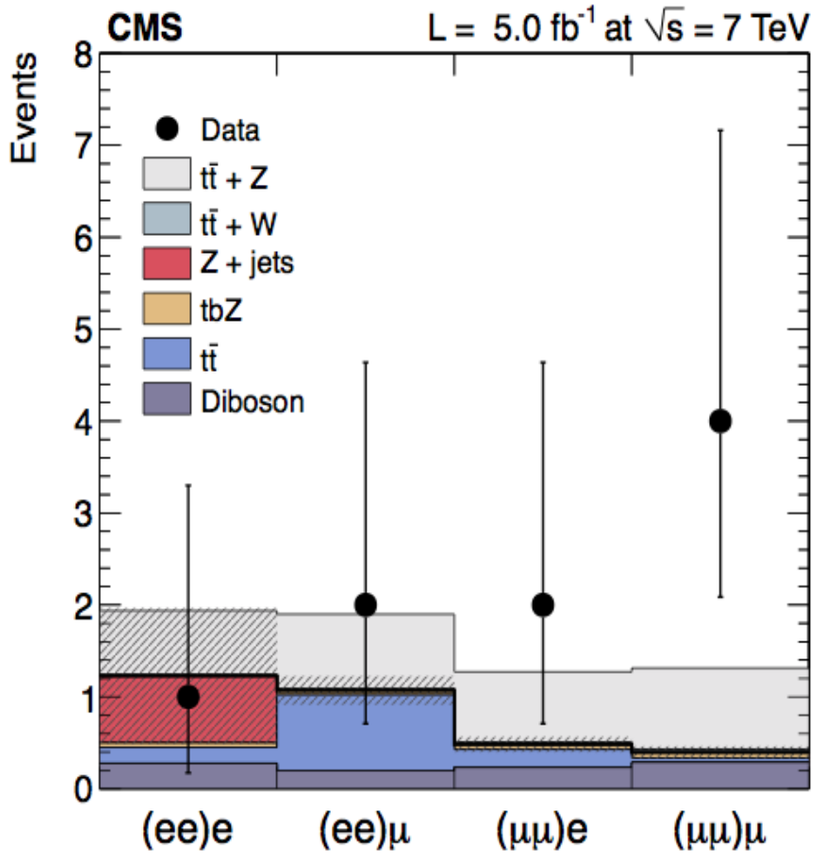
- Branching ratio for dilepton final states low compared to others
- Lepton reconstruction much more precise than jets/hadrons
- Very clean signatures: small systematic effects and small backgrounds
  - Especially eμ final state - quasi background free



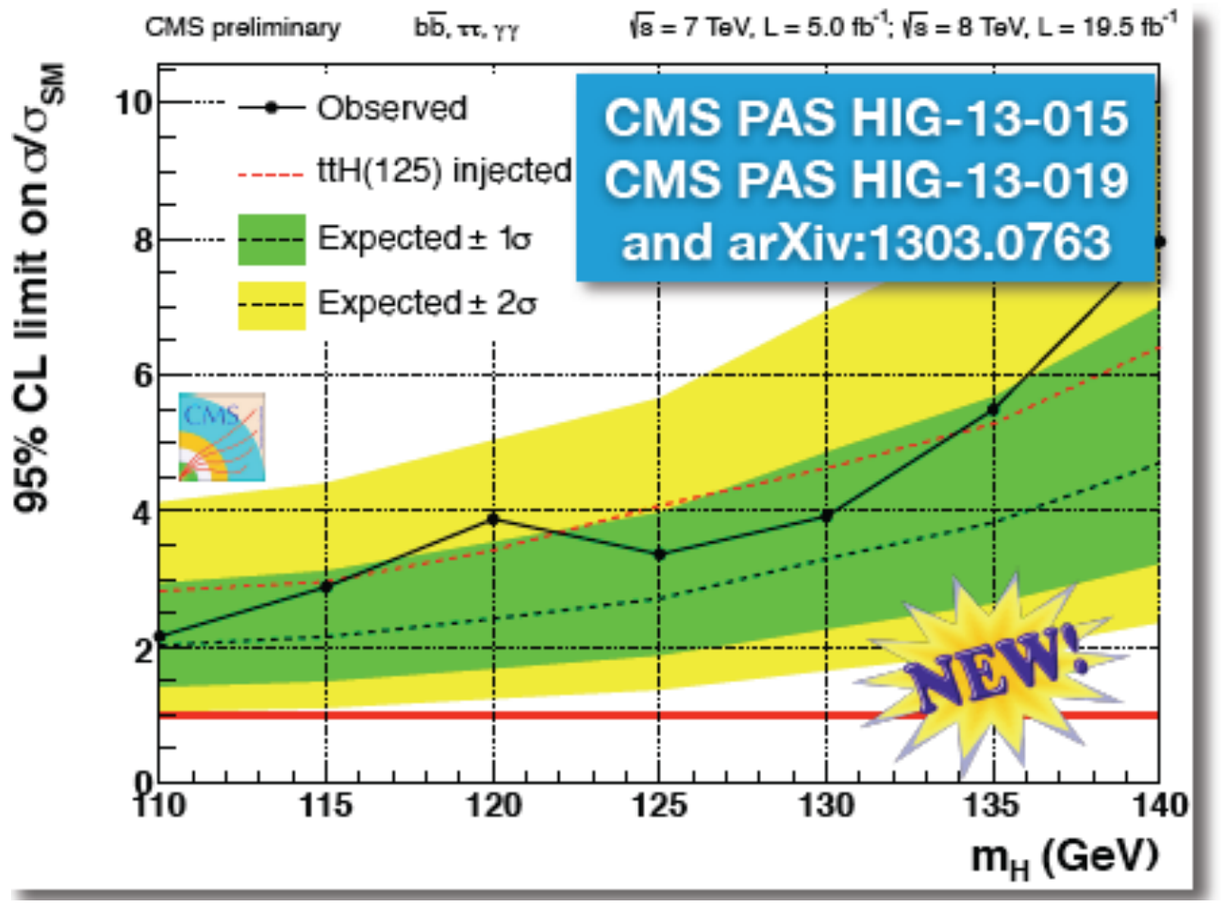


Motivation of ttZ study

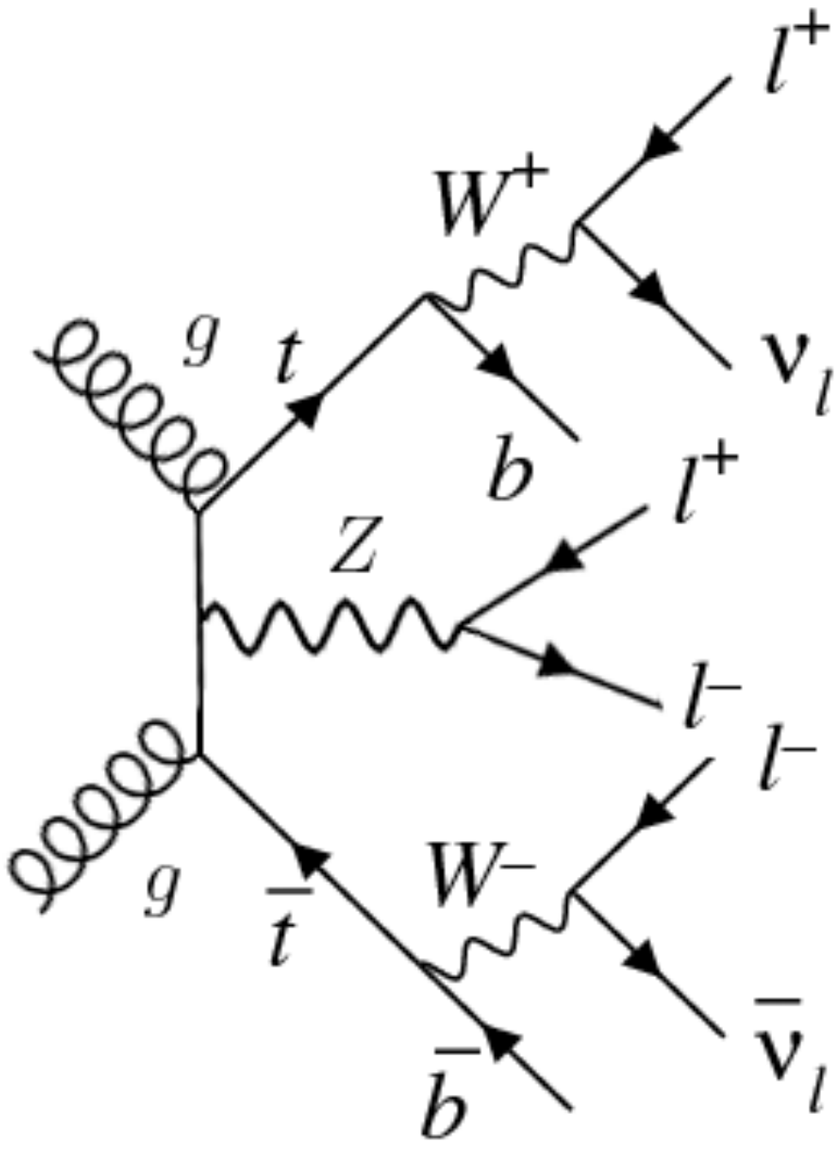
- Compare CMS 2012 data with MC predictions and theory calculations to test SM
- Public result available at 7 TeV in 3 lepton final state
- Relevant background in all rare multilepton processes and searches
- ttZ(Z→bb) is a relevant background for ttH searches



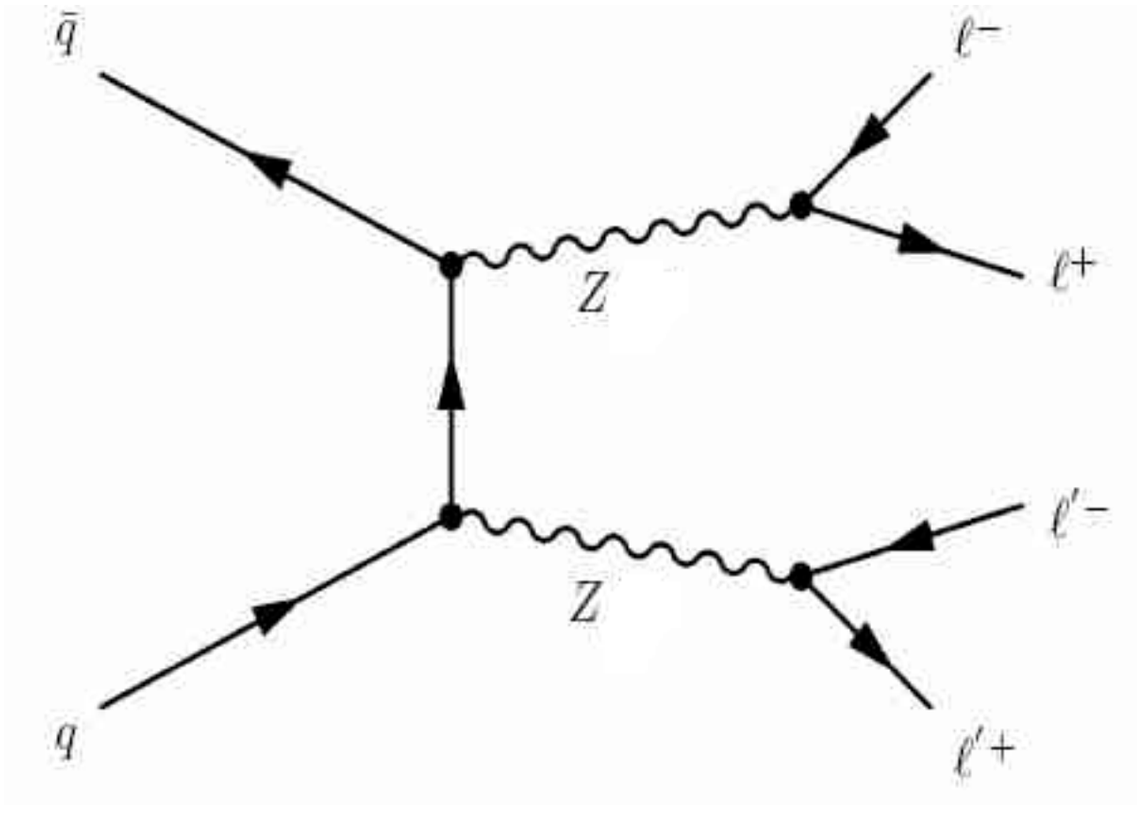
$$\sigma_{t\bar{t}Z} = 0.28^{+0.14}_{-0.11}\,(\text{stat.})\ ^{+0.06}_{-0.03}\,(\text{syst.})\,\text{pb}$$



Process description



signal



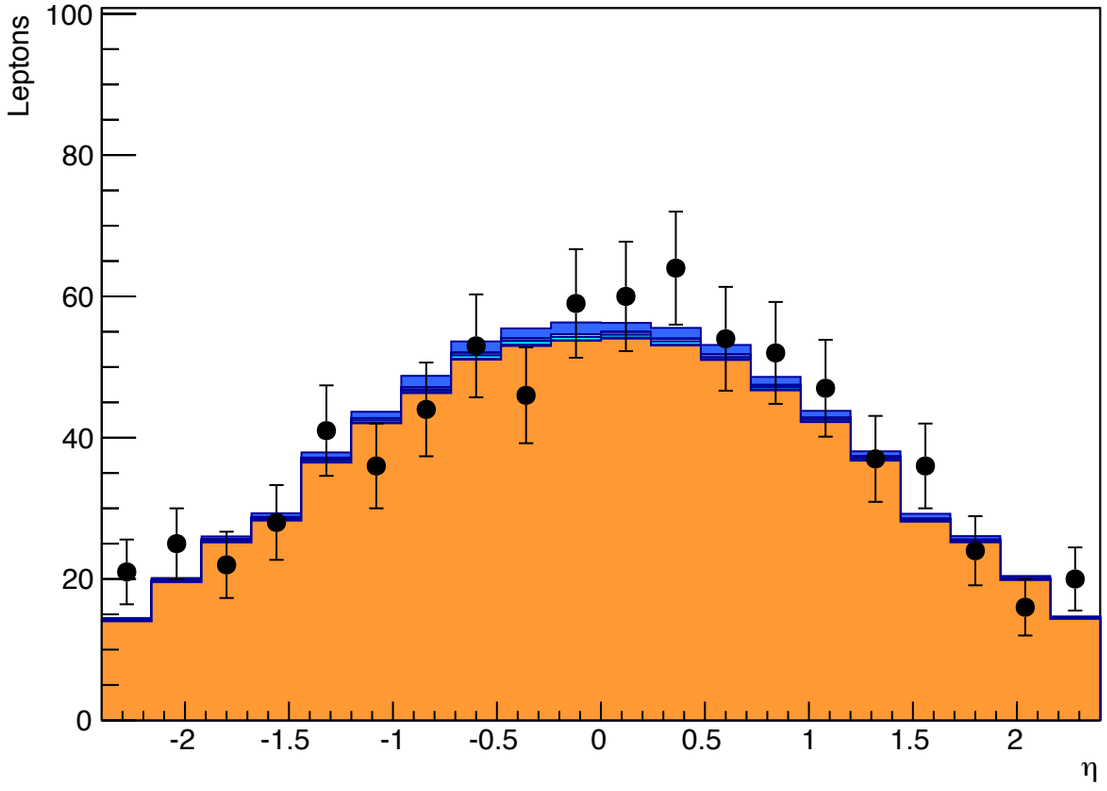
background

- **Signal**: 4 leptons (at least 1 OSSF pair), 2 bjets and some missing E_T in final state.
- Main goal of this analysis: development & optimisation the event selection

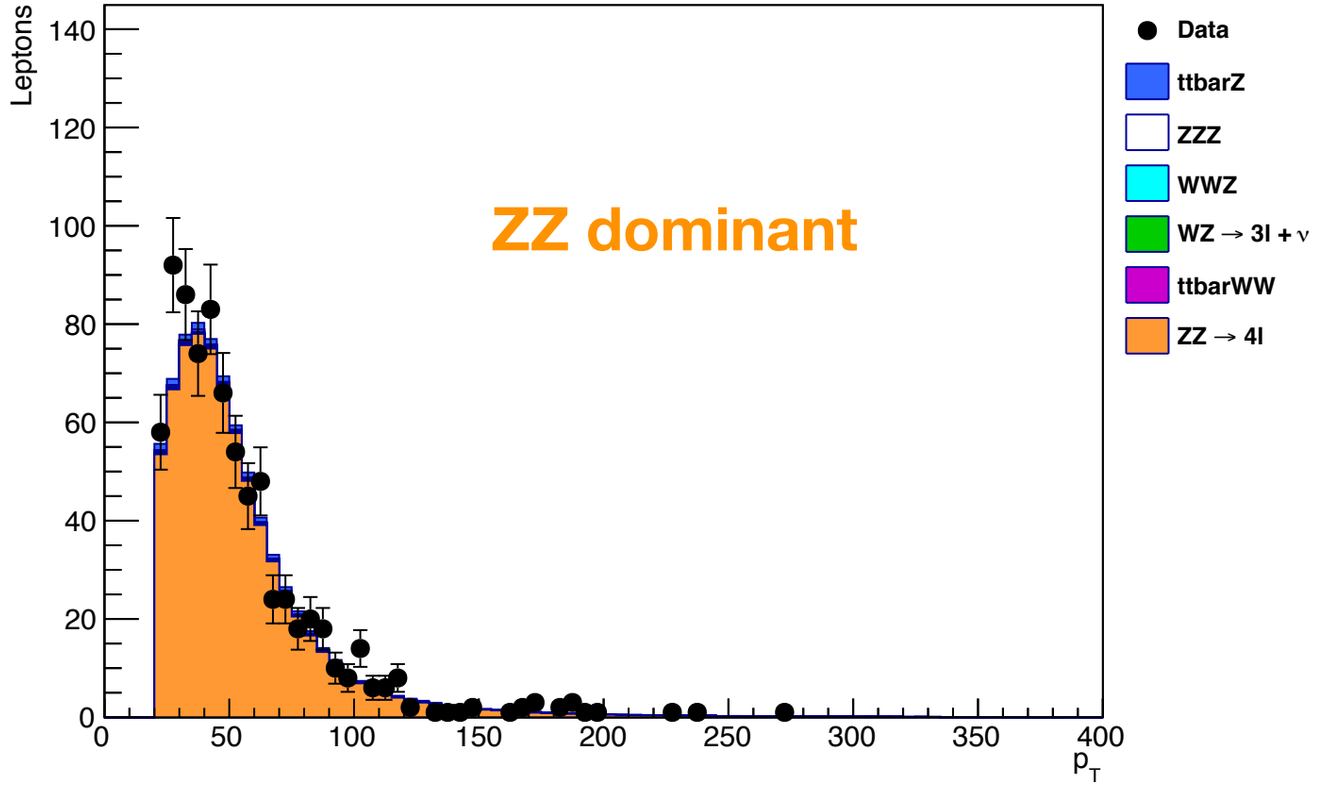
4-lepton final state

- Signal events require 4 spatially isolated leptons (electrons & muons)
  - p_T > 20 GeV and η < |2.4|, passing trigger requirements
- Build Z from OSSF pair closest to the nominal Z mass (91 GeV)
- Dilepton top system chosen as OS pair from remaining leptons

η of all leptons



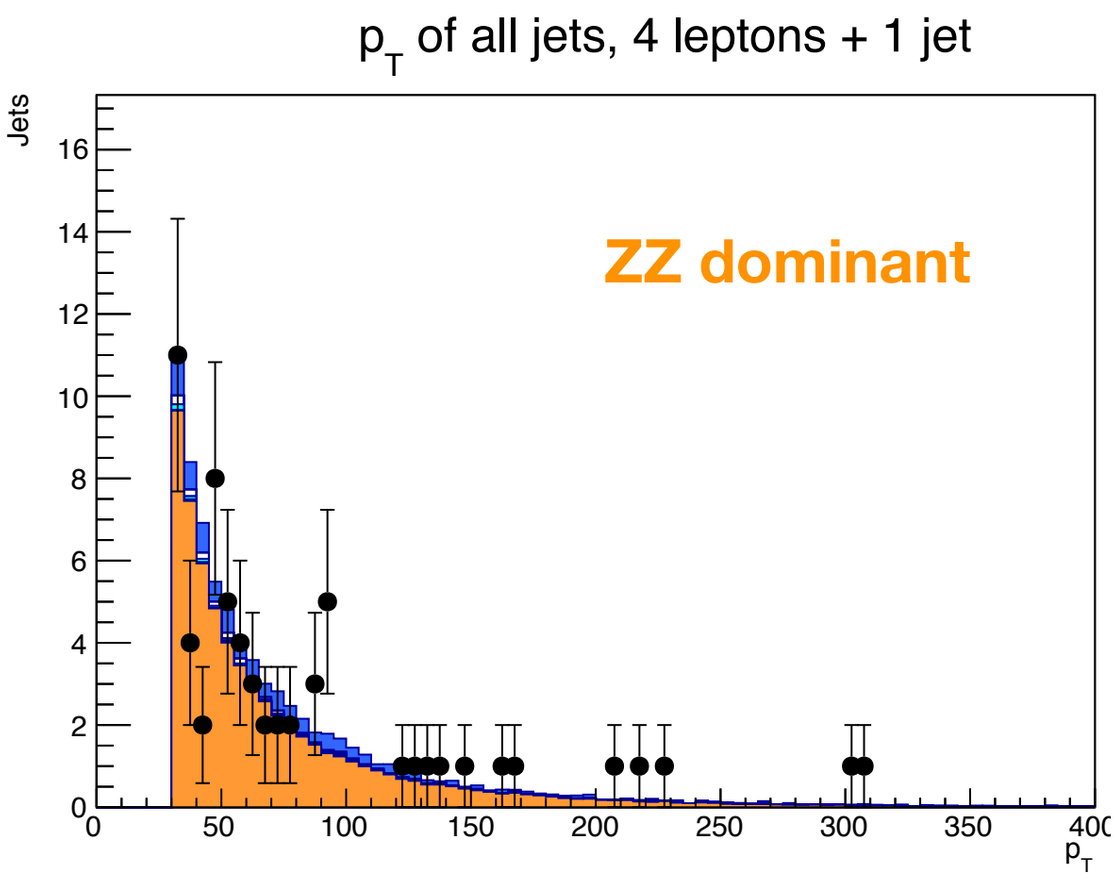
p_T of all leptons

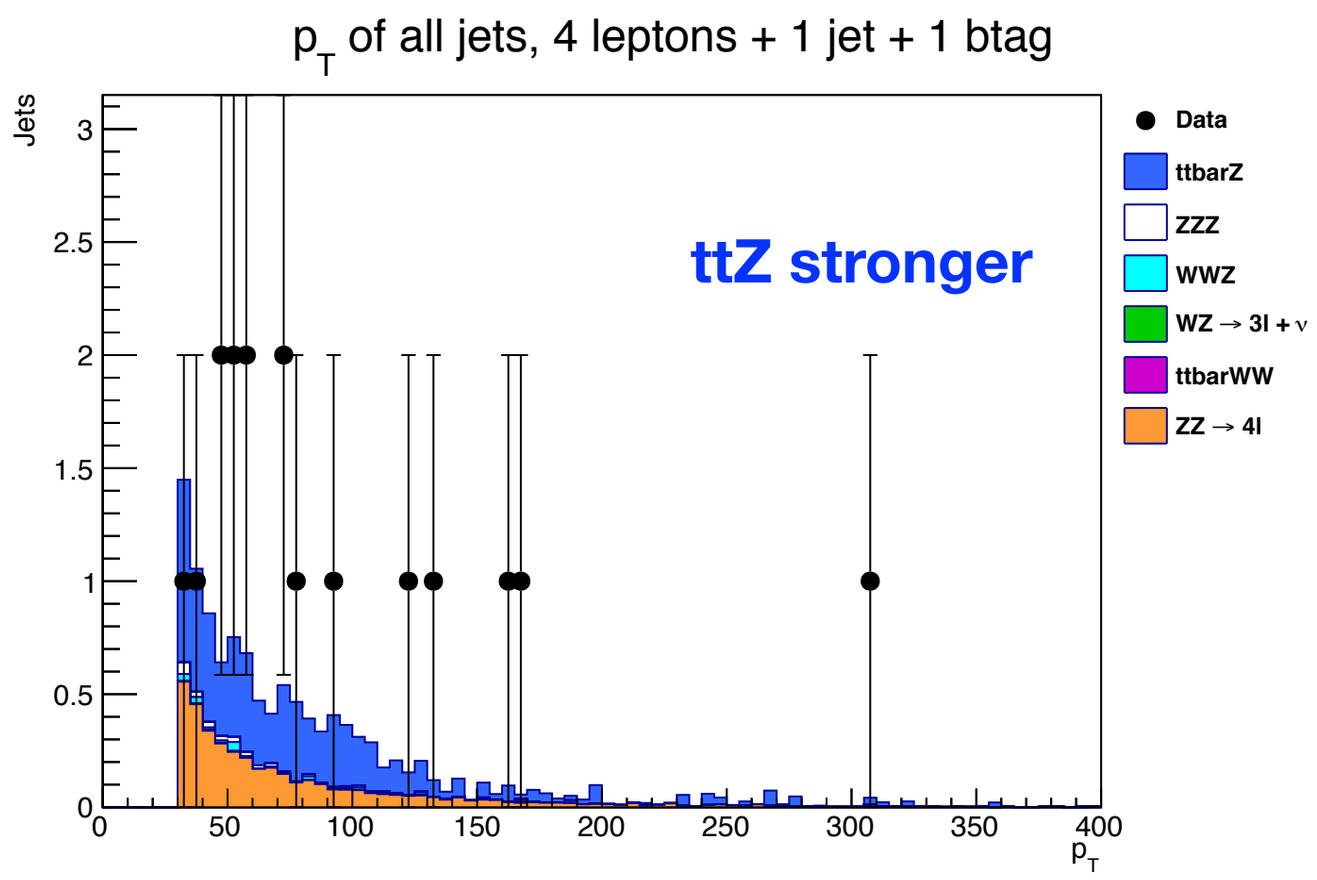


Good data-to-MC agreement

Jet requirements

- Jets are required to have $p_T > 30$ GeV and $\eta < |2.4|$
- bjets identification based on combined secondary vertex (CSV) algorithm





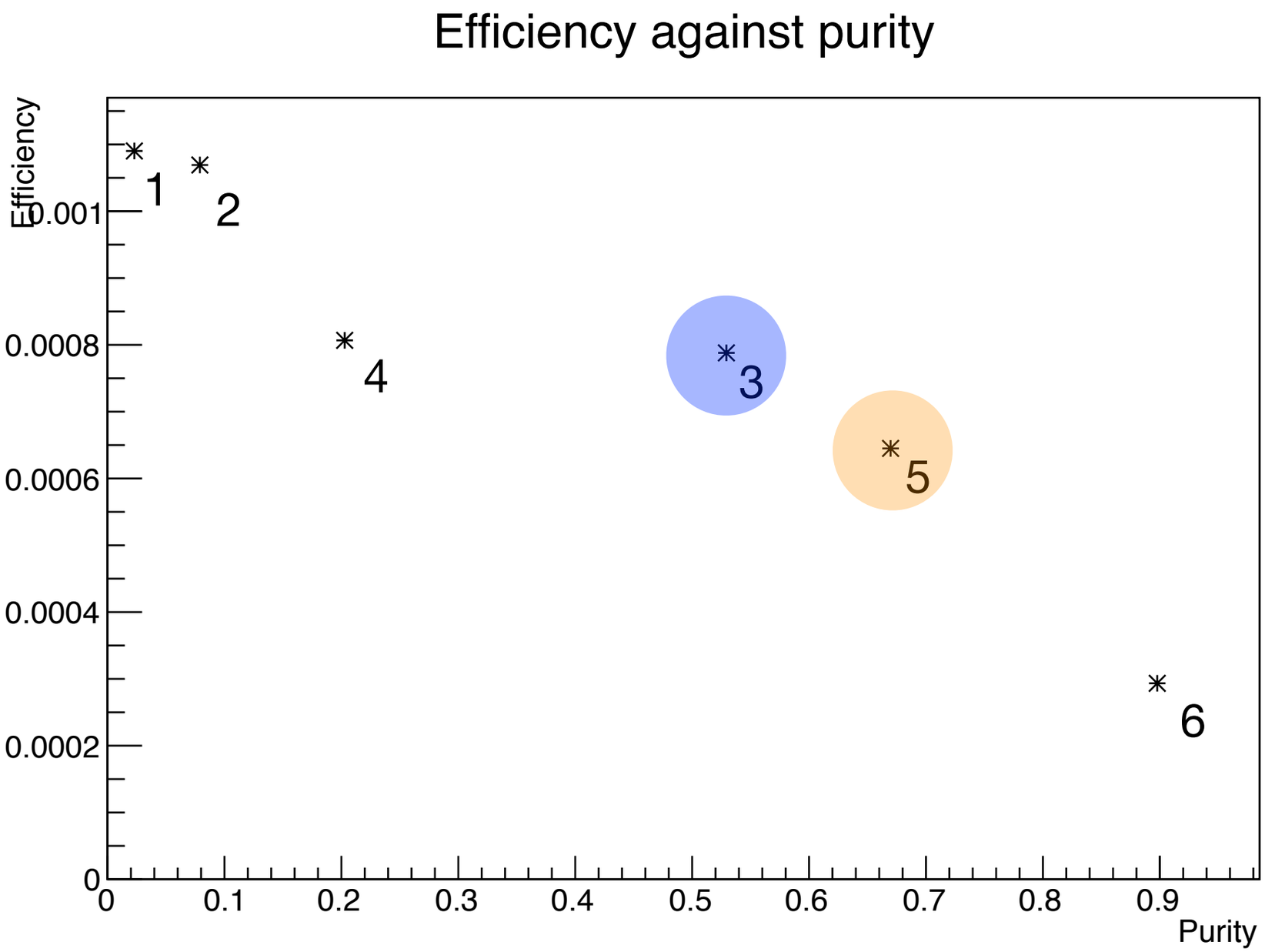
- Require jets and bjets → significant reduction in **ZZ background**

Event selection steps

Sample	4 leptons	1 jet	+ 1 btag	2 jets	+ 1 btag	+ 2 btags
ZZ(4ℓ)	185 ± 0.4	48.9 ± 0.2	2.54 ± 0.05	11.98 ± 0.10	1.10 ± 0.03	0.10 ± 0.01
WZ($3\ell\nu$)	0.40 ± 0.07	0.18 ± 0.05	0.00	0.09 ± 0.03	0.00	0.00
WWZ	1.40 ± 0.10	0.72 ± 0.07	0.13 ± 0.03	0.32 ± 0.05	0.08 ± 0.02	0.01 ± 0.008
ZZZ	1.38 ± 0.05	0.98 ± 0.04	0.16 ± 0.02	0.50 ± 0.03	0.10 ± 0.01	0.02 ± 0.006
$t\bar{t}W^+W^-$	0.03 ± 0.002	0.03 ± 0.002	0.02 ± 0.002	0.02 ± 0.002	0.02 ± 0.002	0.01 ± 0.001
$t\bar{t}Z^0$ signal	4.44 ± 0.30	4.35 ± 0.3	3.21 ± 0.26	3.28 ± 0.26	2.63 ± 0.24	1.19 ± 0.16
Sum MC	189.04	50.77	2.85	12.91	1.30	0.14
+ signal	193.48	55.12	6.06	16.19	3.92	1.33
Data	196 ± 14	42 ± 6.48	7 ± 2.65	13 ± 3.61	6 ± 2.45	2 ± 1.41
ttH	0.43 ± 0.03	0.41 ± 0.03	0.32 ± 0.03	0.34 ± 0.03	0.28 ± 0.03	0.10 ± 0.02

- Good data-to-MC agreement seen throughout
- 4 lepton: ZZ → 4ℓ is most dominant contribution
- 1 jet + 1 btag: reduces ZZ background substantially, ttZ signal now dominant
- 2 jets + 2 btags: very little background, but small statistics
- ttH non-negligible background contribution, not counted in MC prediction

Selection optimisation

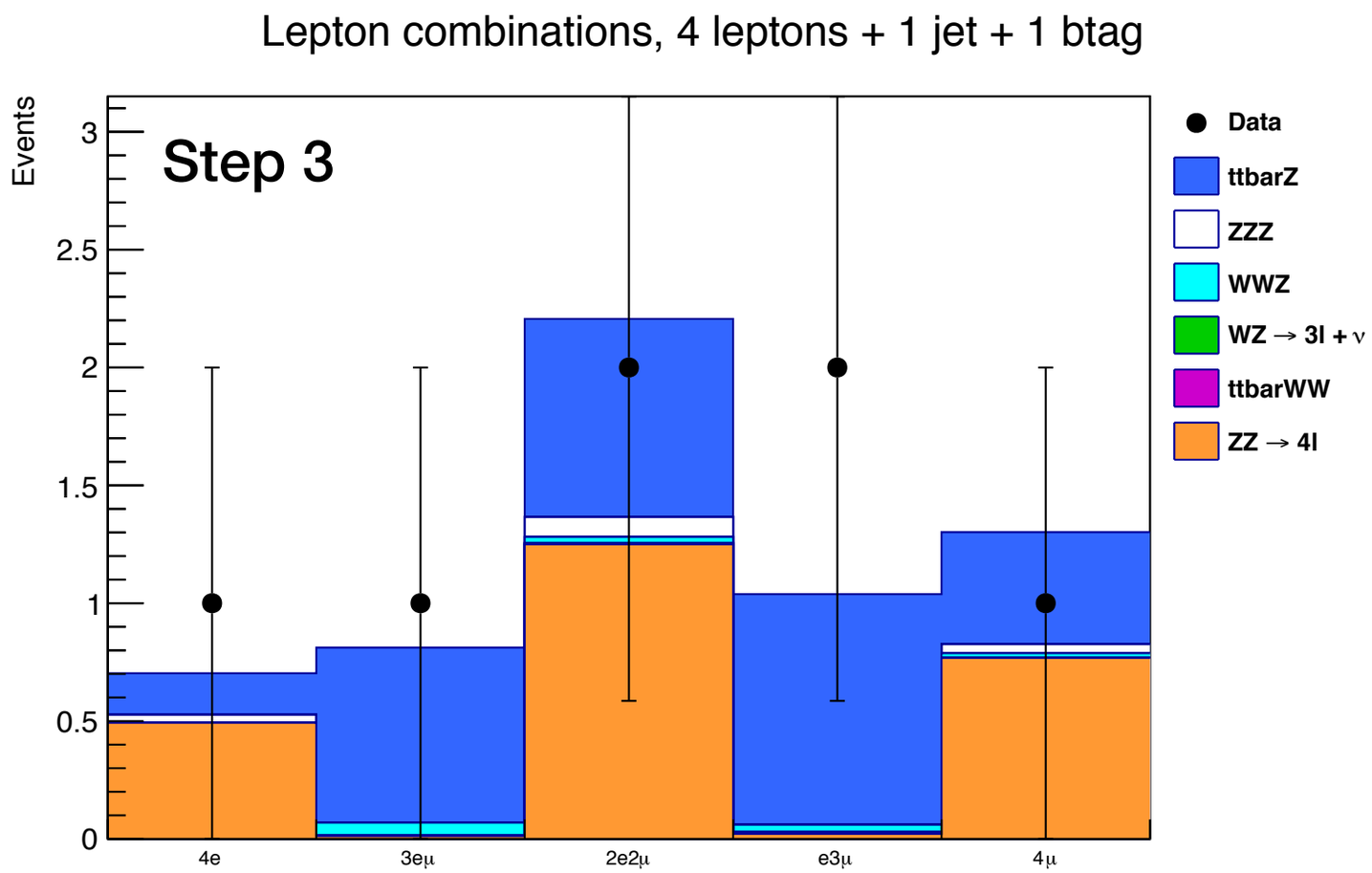


1. 4 leptons
2. 4 leptons + 1 jet
3. 4 leptons + 1 jet + 1 btag
4. 4 leptons + 2 jets
5. 4 leptons + 2 jets + 1 btag
6. 4 leptons + 2 jets + 2 btags

- Optimal step 5; choose 3 to retain statistics but impose further requirements

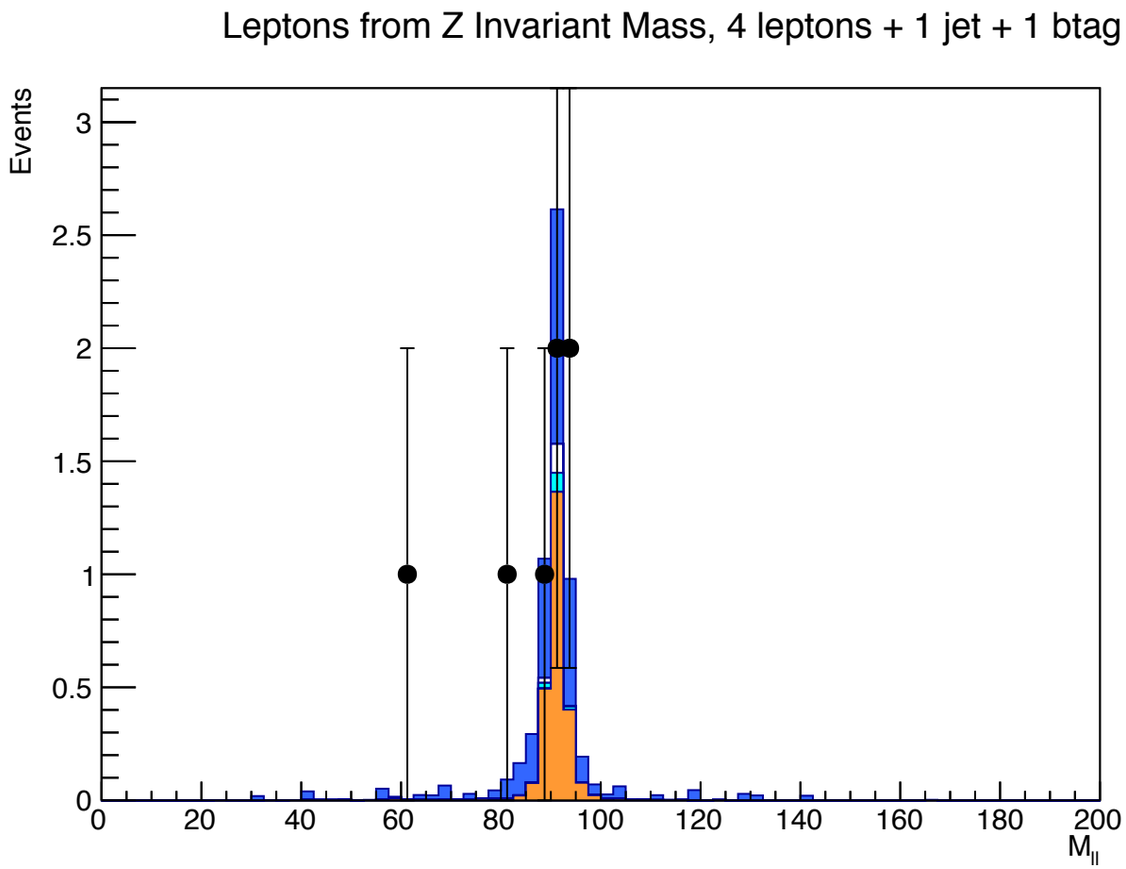
Step 3 vs Step 5

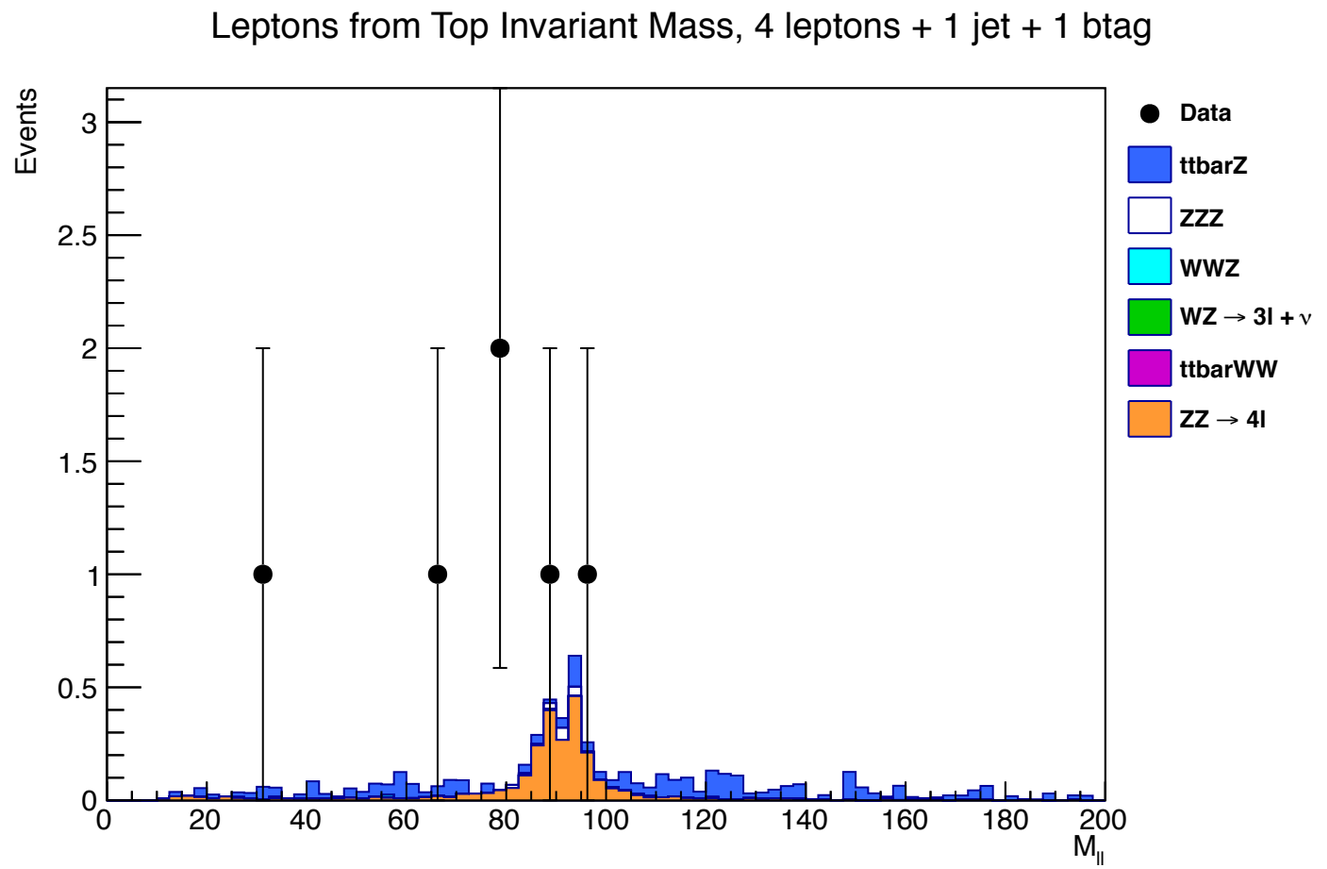
- Step 5: 2 jets + 1 btag → reduces ttZ signal to 2.63, background of 1.10
- Step 3: 1 jet + 1 btag → ttZ signal of 3.21 but background of 2.85



- But background is mostly ZZ and mainly same flavour leptons
  - Attempt to suppress this background

Further event selection cuts





- After 4 lepton + 1 jet + 1 btag Z window imposed to suppress ttH background ☺
  - Z window requires 76 < M$\ell\ell$ < 106 GeV
- Veto on 2nd Z (if same flavour pair) introduced to suppress ZZ → 4ℓ process

Calculating cross section

- Cross section for ttZ calculated at optimal cut stage - final selection:

  4 leptons + 1 jet + 1 btag + Z window + 2nd Z veto

$$\sigma = \frac{N_{sig}}{\epsilon_{tot} \cdot \int \mathcal{L} dt} = \frac{N_{obs} - N_{bkg}}{\epsilon_{tot} \cdot \int \mathcal{L} dt}$$

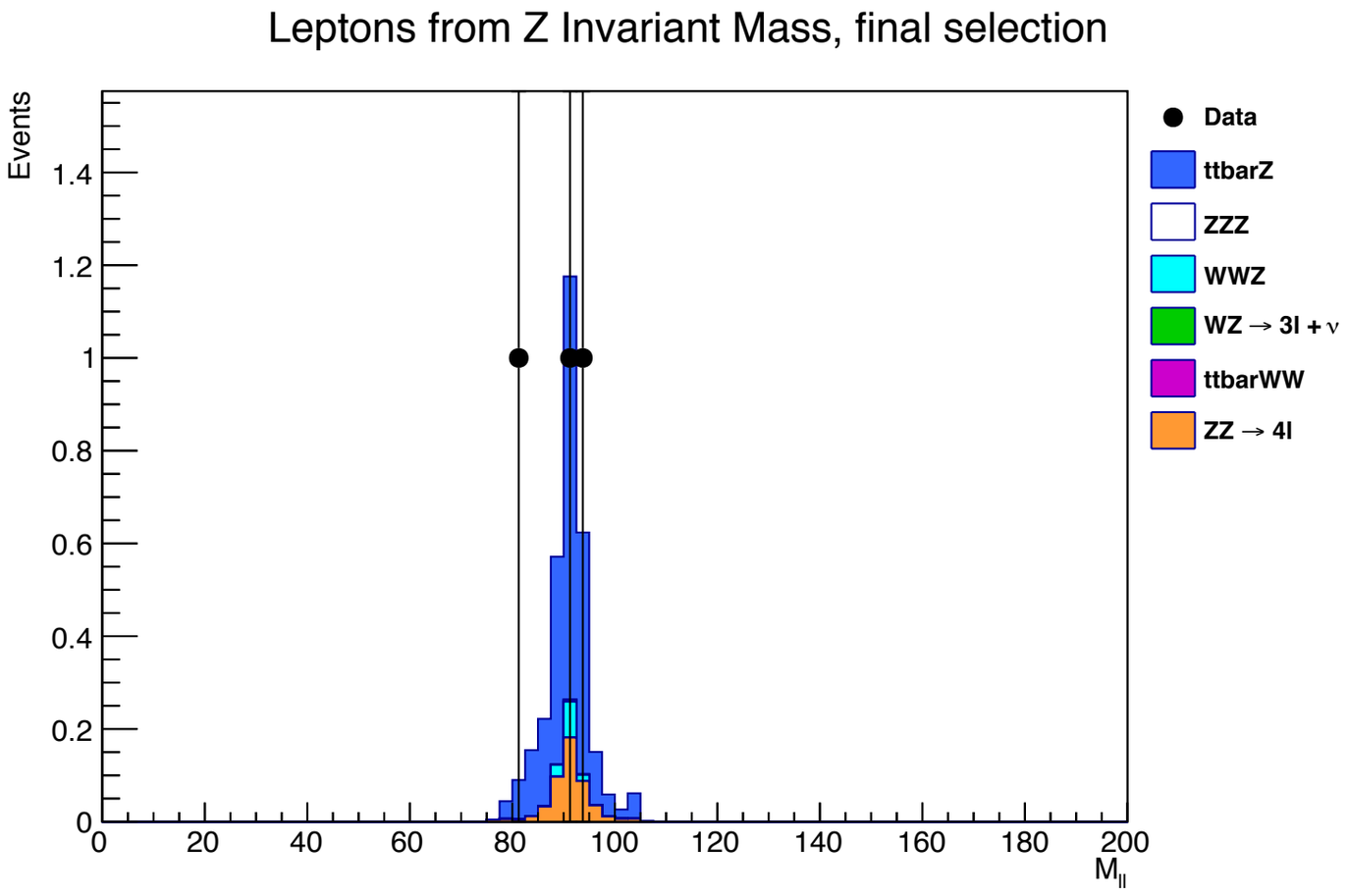
- $N_{obs} = 3$, $N_{bkg} = 0.61$
- $\epsilon_{tot} = 0.00063$
- $N_{sig} = N_{obs} - N_{bkg} = 2.39$
- Luminosity = 19.8 fb^{-1}

- N_{bkg} taken from MC, 50% uncertainty assigned
- ϵ_{tot} produced using the ttZ MC corrected for data efficiencies (stat. uncertainty 9%)

Systematic	Assigned uncertainty (%)
Pile up	1
Lepton efficiencies	9
Jet energy resolution	1
Jet energy scale	1
Btagging efficiencies	5
Mistagging efficiencies	1
All combined	11

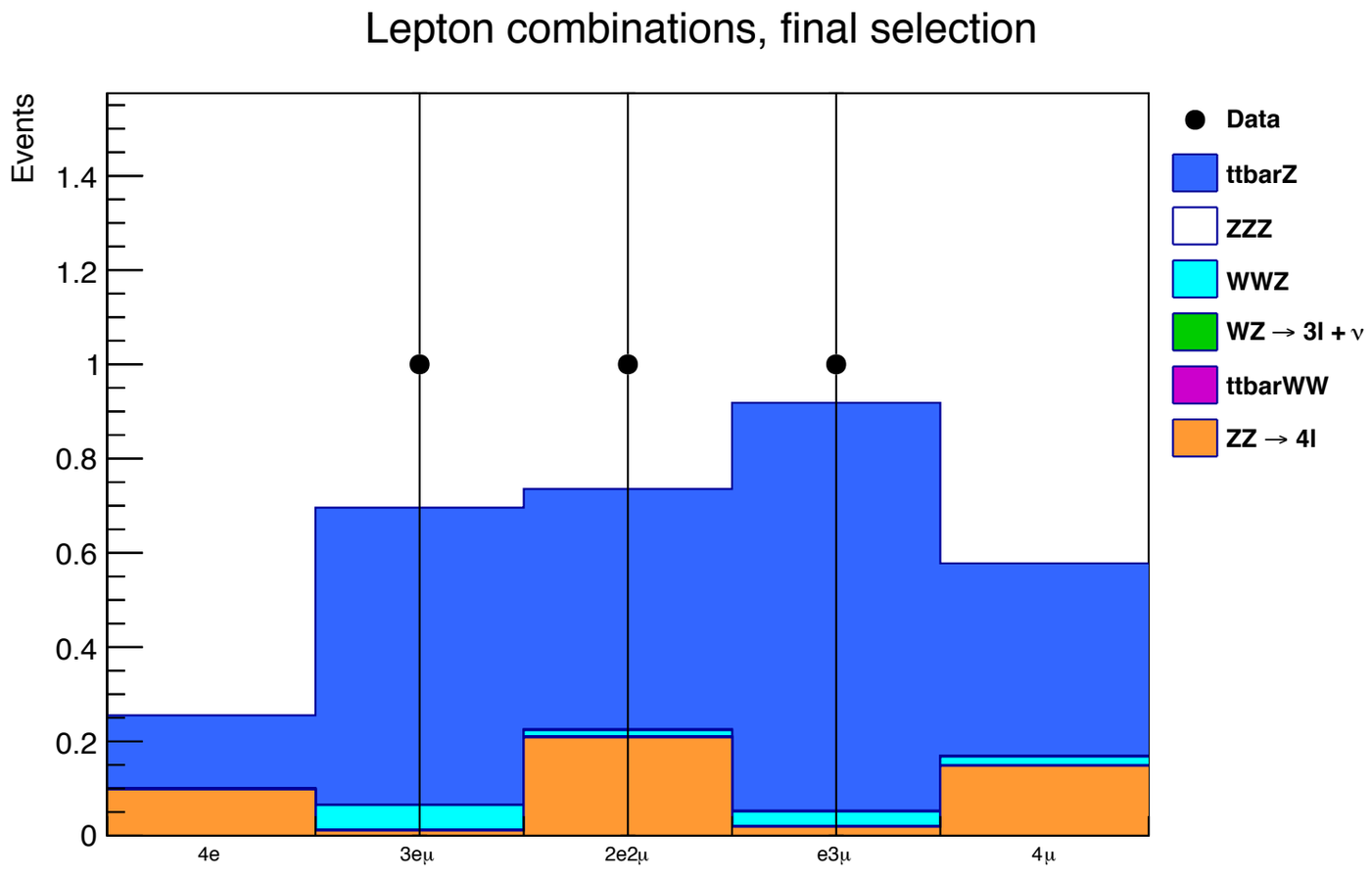
Results

- Using CMS 2012 data at 8 TeV
- Measured cross section:
  191 ± 138 (stat.) ± 37 (syst.) fb
- Theory calculation:
  206 + 19 - 24 fb
- Uncertainty of measurement is large - 72% stat error
- In agreement with SM predictions & MC simulations
- Injected ttH signal would change results minimally



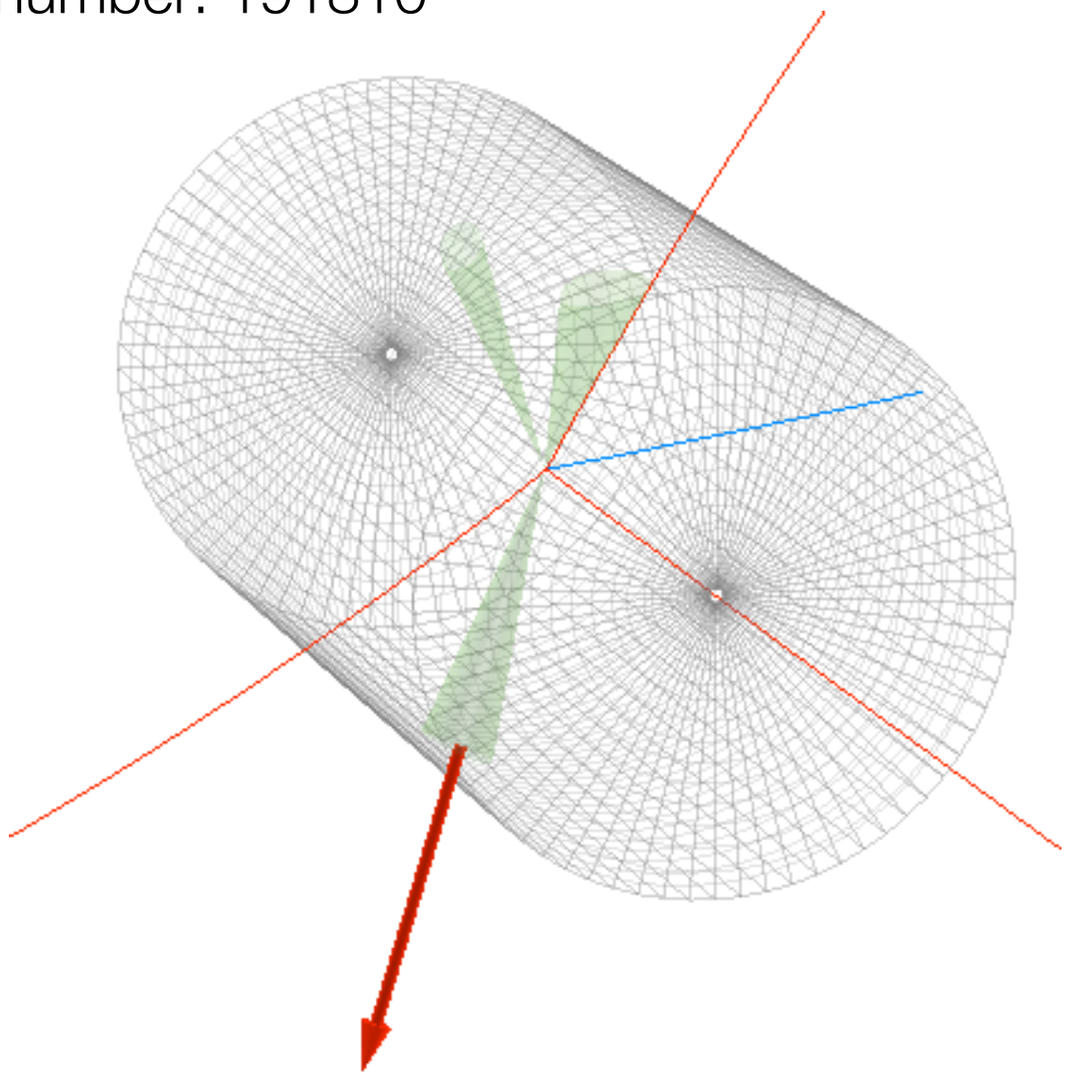
Combined cross section

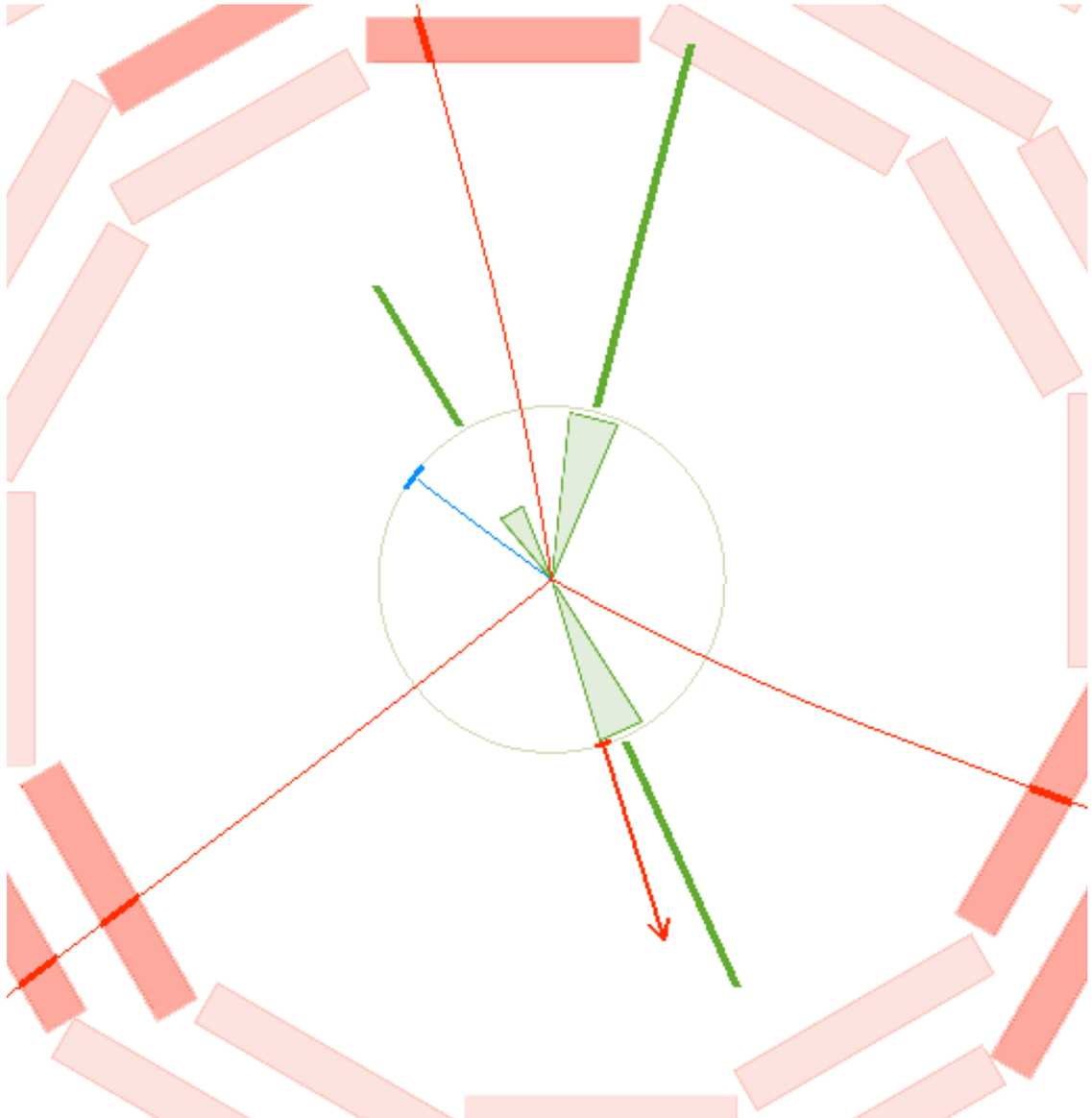
- Use lepton categories to calculate cross section
- Combine using maximum likelihood
- Cross section determined as:
  205 ± 136 (stat.) ± 23.5 (syst.) fb
- 66% statistical error
- Systematic error reduced



ttZ candidate event

Event number: 123865322
Lumi block: 78
Run number: 191810





Dilepton mass of Z system: 93.27
Lepton 1 - p_T: 120.2; η: -0.956
Lepton 2 - p_T: 23.28; η: -0.383

Dilepton mass of Top system: 30.94
Lepton 1 - p_T: 38.17; η: -1.384
Lepton 2 - p_T: 29.86; η: -0.903

2 b-tagged jets:
Jet 1 - p_T: 162.48; η: -1.249; **btag**: 0.884
Jet 2 - p_T: 124.14; η: -0.319; **btag**: 0.830
3rd non-b-tagged jet:
Jet 3 - p_T: 59.00; η: 2.246

Summary

- Study of 4-lepton final states in ttZ production
- Optimised event selection requirements
- Cross section determined with very large statistical errors
  - Investigated combination method of calculation
- Found candidate ttZ event in very pure selection category

Back up

Lowering p_T cuts

- Initially required $p_T > 20$ GeV
- Statistics gained with $p_T > 10$ GeV
  - Mostly from 4th lepton, some from 3rd
  - Some fakes introduces
- Further gained from $p_T > 5$ GeV
  - All from 4th lepton
  - Mostly fakes