Search for a Vector Like Quark T' decaying into quark top and Higgs boson in a dileptonic same sign final state with the CMS experiment at LHC

JRJC, 25 October 2022

Benjamin Blancon
Université Claude Bernard Lyon 1, Institut de Physique des 2 Infinis

Benjamin Blancon
JRJC BSM
10.25.22

Motivation

- In 2012: completion of the Standard Model (SM) with the discovery of Higgs boson.

- Mass of 125 GeV in natural units (n.u.) (~130 times the proton mass) problematic because the perturbative corrections make this mass divergent.

→ Hierarchy problem!

→ How do we fix this issue? Adding a new particle in the model!

- Vector-Like Quark (VLQ) T': particle (both quark and vector) whose interaction with the Higgs boson would cancel the corrections and solve the hierarchy problem.

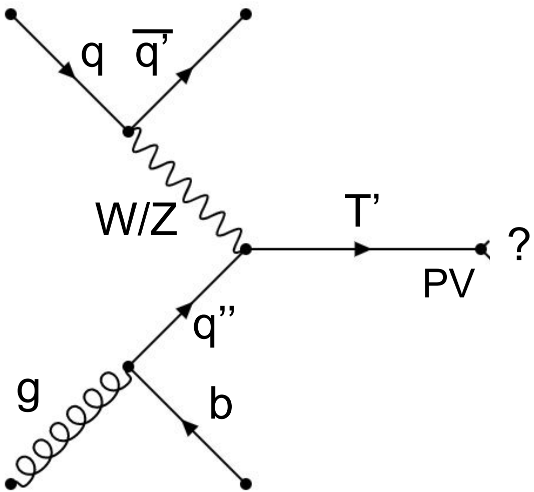
- Higgs boson mass at 125 GeV. → T' mass around 1 TeV (13 TeV in the center of mass of the LHC for 2016-2018). We assume that the T' mass is 700 GeV.

→ T' is highly unstable: how can we observe it?

Benjamin Blancon
JRJC BSM
10.25.22

T’ production

T’ single production –> ?



Single T’ production:

- quark q-antiquark $\overline{q}$’ interaction.
  ⟶ W/Z boson.
- gluon g-quark b interaction.
  ⟶ Quark q”.
- W/Z boson-quark q” interaction.
  ⟶ VLQ T’.

At primary vertex (PV), three modes for T’ decay:

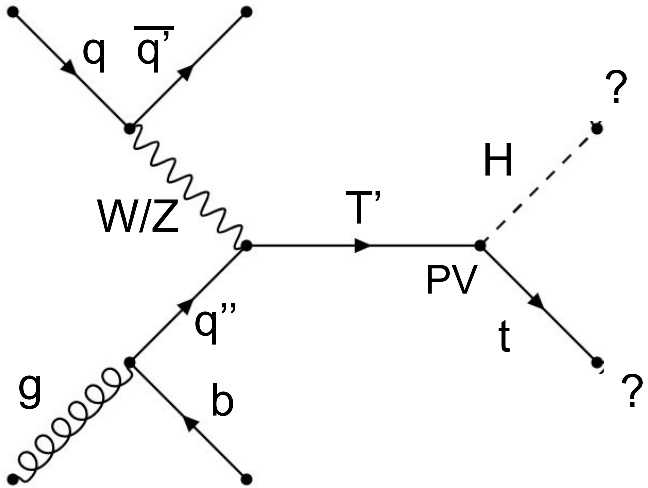
- T’ ⟶ W boson + top quark (50%).
- T’ ⟶ Z boson + top quark (25%).
- ✓ T’ ⟶ Higgs boson H + top quark t (25%): most interesting signal!

How about the decay of H and t?

Benjamin Blancon
JRJC BSM
10.25.22

T’ decay

T’ –> H + t –> ?



Analysis focused in the dileptonic (electron or muon, not tau) channel:

H ⟶ W^-W^+ bosons (21%).
⟶ Lepton l and antineutrino $\overline{\nu}$ (11% per lepton) and two quarks q’’’$\overline{q''''}$ (67%).

t ⟶ W^- boson and quark b (100%).
⟶ Lepton l, antineutrino $\overline{\nu}$ (11% per lepton) and quark b.

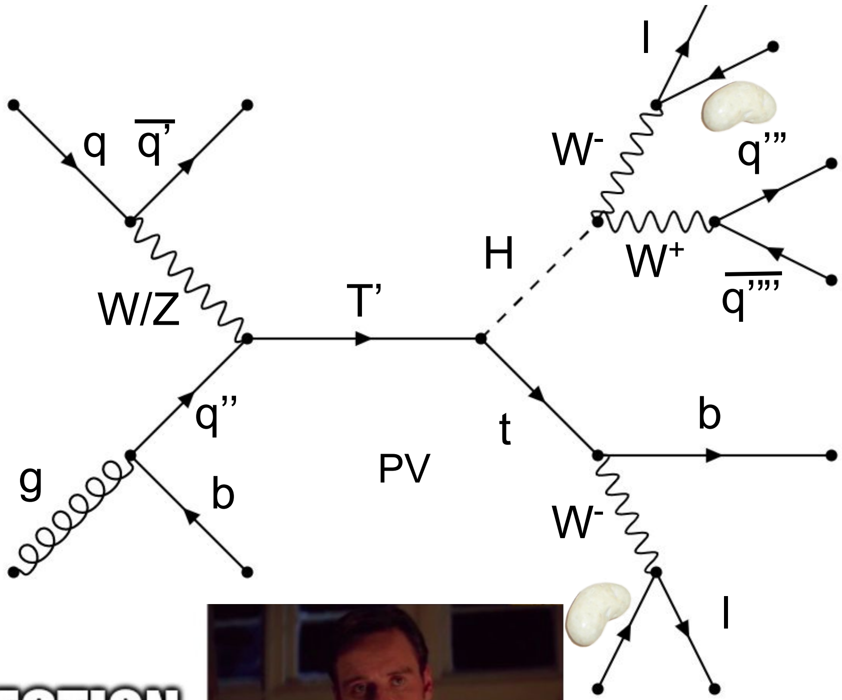
The leptons have the same sign (SS) in the final state. ⟶ New starting analysis!

(Ongoing analyses: H ⟶ bb all hadronic (B2G-18-003 / B2G-19-001), semileptonic (B2G-20-006) and H ⟶ γγ (B2G-21-007) channels.)

Benjamin Blancon
JRJC BSM
10.25.22

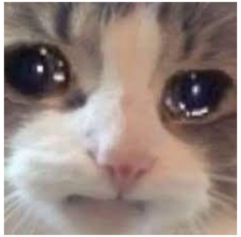
Signal final state

T' –> Dileptonic channel



Final state in our signal:

- 2 leptons SS.
- 3 jets coming from 3 quarks (see Jieun's talk) included 1 jet coming from quark b, e.g. 1 bjet.
- 2 mogettes that we don't detect directly in CMS: we will not consider them.



Three channels considered:

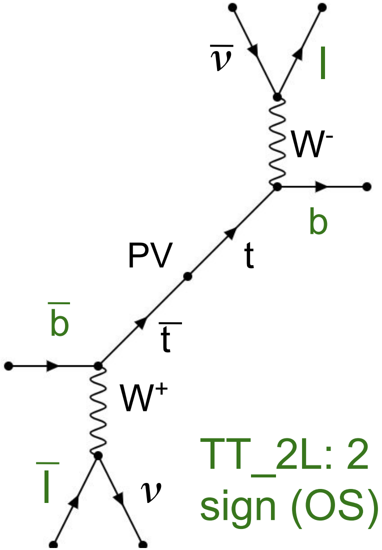
- 2 muons.
- 1 muon + 1 electron.
- 2 electrons.

So everything is good then…?

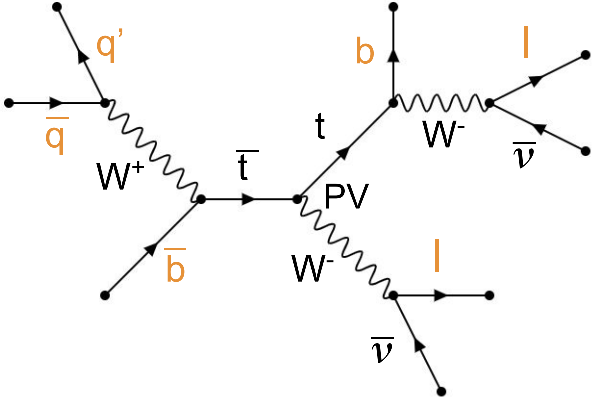
Benjamin Blancon
JRJC BSM
10.25.22

Signal vs backgrounds

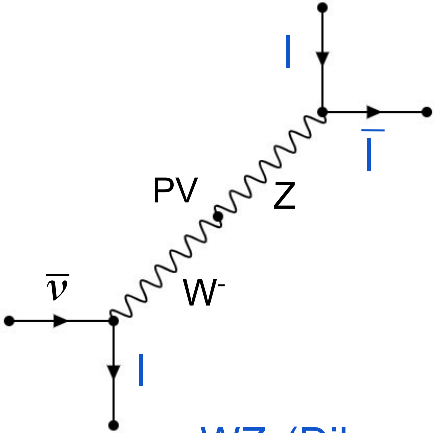
Of course not! Many other processes have (almost) the same final state!



TT_2L: 2 leptons opposite sign (OS) and 2 bjets.



ttW (ttX): 2 leptons SS and 4 jets with 2 bjets.



WZ (Diboson): 3 leptons.

A lot of backgrounds processes have to be considered (full list in backup) and we want to discriminate the signal over all of them.

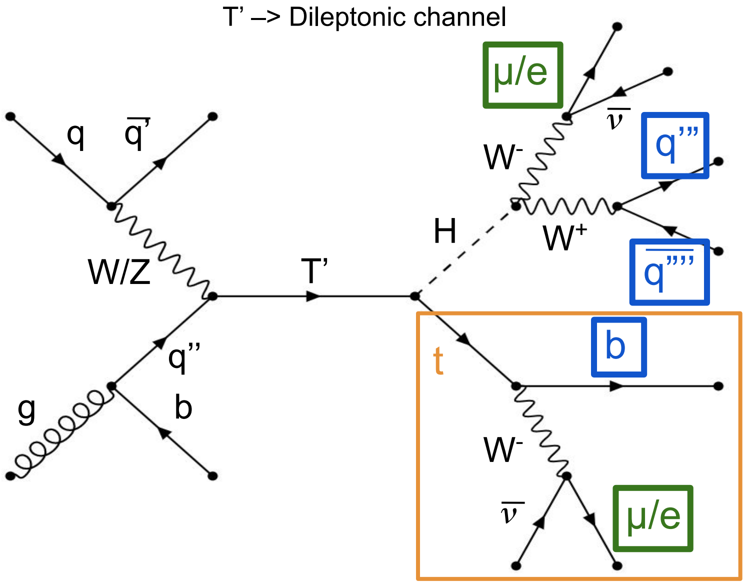
→ Required to design a brand new analysis strategy!

Benjamin Blancon
JRJC BSM
10.25.22

Analysis strategy

Goal ⟶ Get the main backgrounds under control!

- TT_2L: asking for SS leptons.
- Diboson: asking for (b)jets.
- ttX: asking for one non-hadronic top decay, e.g. one top decaying in one lepton, one neutrino and one bjet and not in 3 jets.



Determination of background shape thanks to combined fits of Signal Region and Control Regions and extraction of signal shape.

We are working on simulations where the T' ⟶ H+t decay has many final states.
⟶ How to make sure that the selection is efficient for the signal?

Generator level

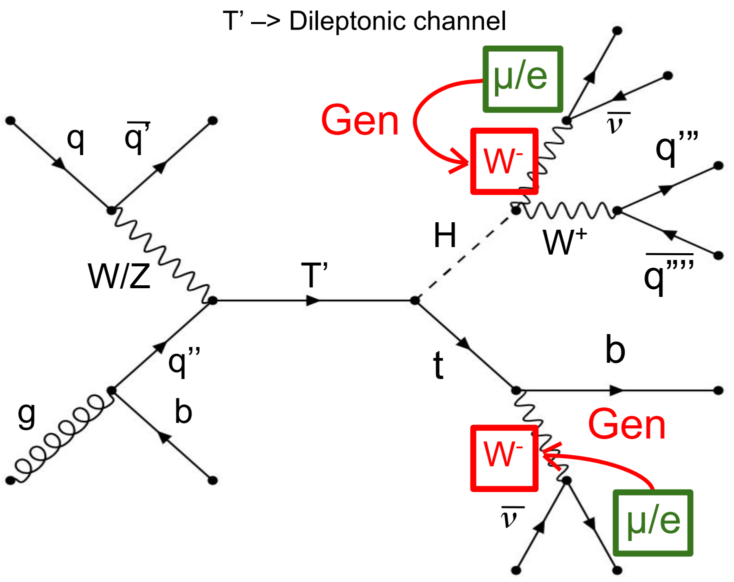
Working on simulated events. ⟶ Have access to all the intermediate decays!

We can ask the two leptons SS to come from W bosons. ⟶ Generator (Gen) selection (only for the signal!).

Variables of interest:

$$\text{Efficiency } \varepsilon = \frac{\text{Nb(Gen+Selection)}}{\text{Nb(Gen)}}$$: how many signal events are selected?

$$\text{Purity } P = \frac{\text{Nb(Selection+Gen)}}{\text{Nb(Selection)}}$$: how many selected events are signal events?



Let's start with lepton identification to remove opposite sign (e.g. TT_2L events)!

Lepton identification

Kinematic selection: Pt (transverse momentum) and η (pseudorapidity).

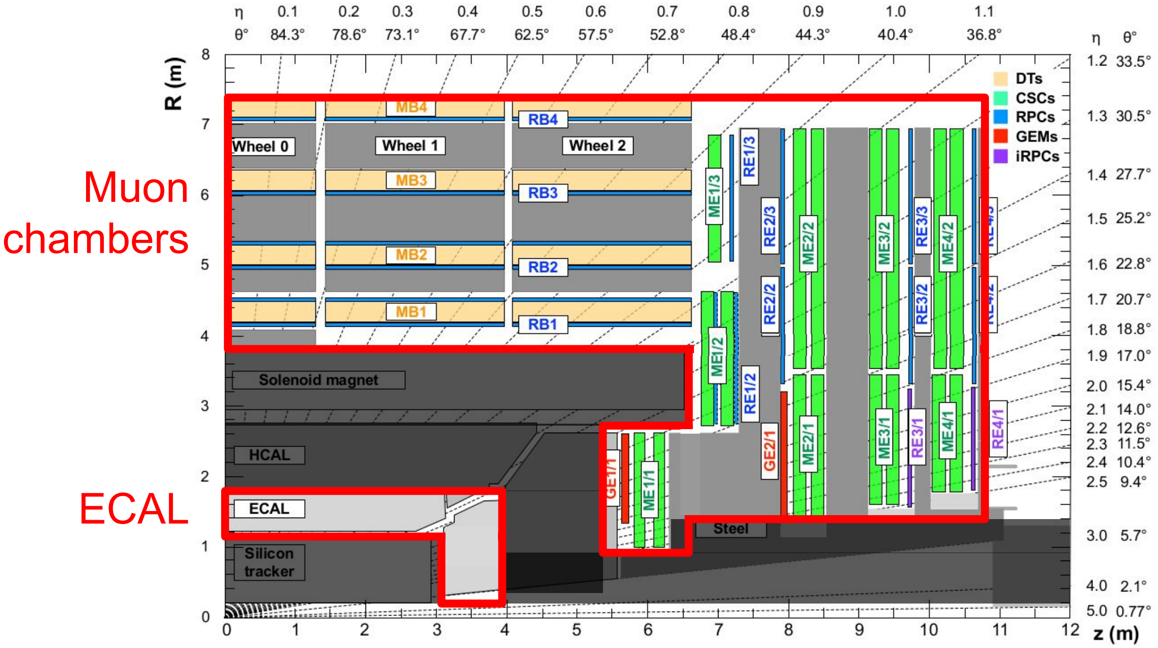
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

η = 0 for θ = 90°

η ⟶ ∞ for θ = 0°

Muon : Pt > 20 GeV
|η| < 2.4 (10.4°)

Electron : Pt > 25 GeV
|η| < 2.5 (9.4°)



CMS structure

Benjamin Blancon
JRJC BSM
10.25.22

Lepton identification

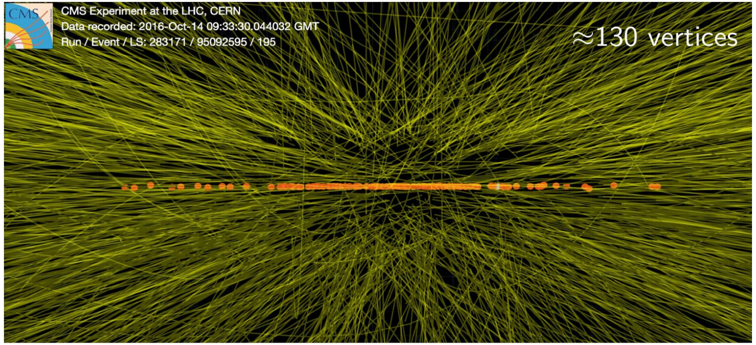
Variables on study (see backup for additional variables and studies):

- Identification (ID): based on a global algorithm (Particle Flow) that reconstructs all the particles thanks to the tracks, hits… Three possible values: loose, medium or tight. ✓

- Isolation: leptons must be outside of jets which can contain fake leptons.

$$\frac{\sum_{R_{iso}} Pt\ (\text{Particles-lepton})}{Pt\ (\text{lepton})} < 0.05\ (\text{tight})$$ where (R_{iso} = 10 GeV /Pt (lepton)) is the cone size[1].

- 3D Impact parameter significance sip3D: leptons must be close to the PV.
  Muon: sip3D < 3 cm.
  Electron: sip3D < 2 cm.



Event reconstruction is a real challenge considering all the tracks and the vertices!

[1]: mini-isolation (Section 4.4.1.)

Object identification - Summary

Muon	Pt > 20 GeV, $|\eta|$ < 2.4, tight ID, tight isolation, sip3D < 3
Electron	Pt > 25 GeV, $|\eta|$ < 2.5, tight ID, tight isolation, sip3D < 2
Jet	Pt > 30 GeV, $|\eta|$ < 4.5, tight ID
B-jet	Pt > 30 GeV, $|\eta|$ < 2.5, tight ID, medium DeepJet b-tag

Actually I do, Obi-Wan!

Algorithm to identify bjets.
Three values: loose, medium or tight.
✓

ID, Isolation and impact parameter significance are crucial for the identification of leptons.

We identify and ask for exactly 2 leptons SS, but we can go further!

Selection criteria - Signal

The T' has a large mass so we expect the 2 leptons to have high Pt.

→ $\sum_{\text{2 leptons}}$ Pt > 160 GeV to reduce all backgrounds.

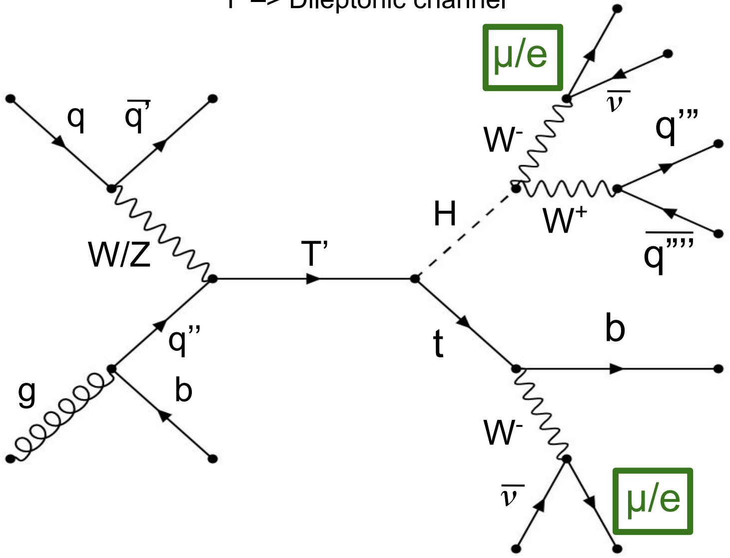
The 2 leptons must be back-to-back.

→ ΔR (leptons) > 1.8 to reduce all backgrounds.

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

ΔR ~ 0 for leptons next to each other
ΔR ≳ π for leptons back to back

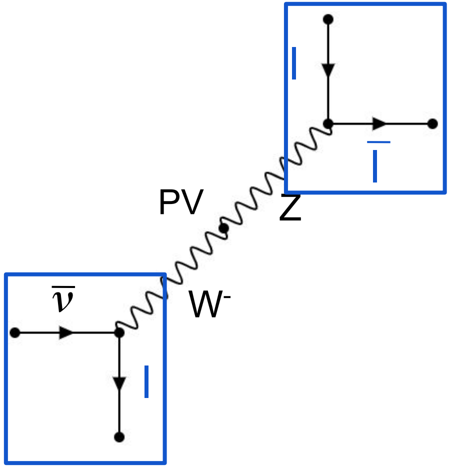
T' –> Dileptonic channel



How about the Diboson processes?

Selection criteria - Diboson

We expect 3 jets with 1 b-jet in the final state.
→ ≥ 3 jets and ≥ 1 b-jet with Pt > 50 GeV to reduce Diboson backgrounds.



WZ (Diboson): no jets.

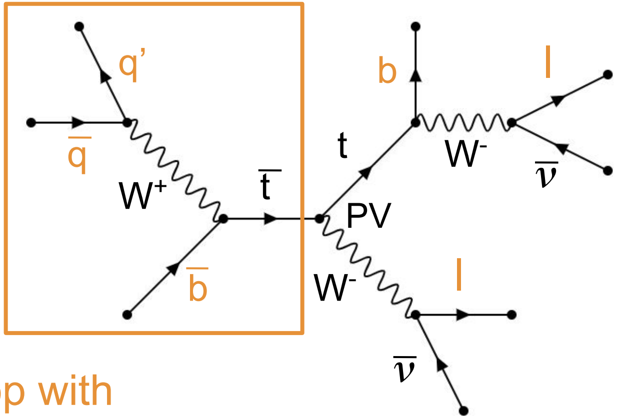
How about the ttX processes?

Benjamin Blancon
JRJC BSM
10.25.22

Selection criteria - ttX

The top must have a non-hadronic decay.

⟶ Min(3 jets invariant mass - top invariant mass) > 34 GeV (e.g. 3 jets invariant mass $\notin$ top invariant mass ± 2σ[1]) to reduce ttX backgrounds.



ttW (ttX): one hadronic top with $\sum_{3\ \text{jets}}$ invariant mass = top invariant mass

[1]: B2G-19-001, section 3.2.2

⟶ Let's see the results of this selection!

Selection criteria - Results

Process	Signal	TT_2L	ttW	ZH	Sum of Bkgs	S/B
No Cut	1.3E4	1.3E7	9.2E4	6.6E5	1.3E10	0.0001%
Cut 0 : Sum of Pt of 2 leptons > 160 GeV	19.9	161.1	370.7	2216.0	4620.9	0.43%
Cut 1 : ≥ 3 jets and ≥ 1 bjet with Pt > 50 GeV	12.4	60.1	248.1	31.7	709.5	1.75%
Cut 2: Min(3 jets mass - top mass) > 34 GeV	9.6	43.9	127.5	25.6	384.8	2.49%
Cut 3: ΔR (leptons) > 1.8	9.3	34.1	95.4	14.1	280.1	3.32%

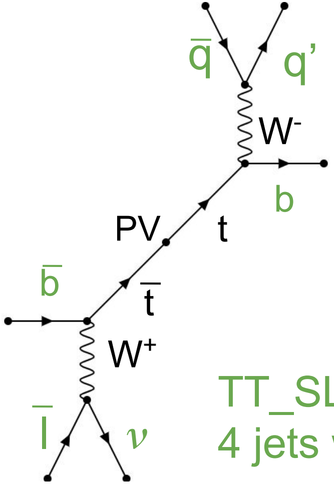
- 99.999% (TT_2L, No Cut → Cut 0)
- 98.6% (ZH, Cut 0 → Cut 1)
- 48.6% (ttW, Cut 1 → Cut 2)

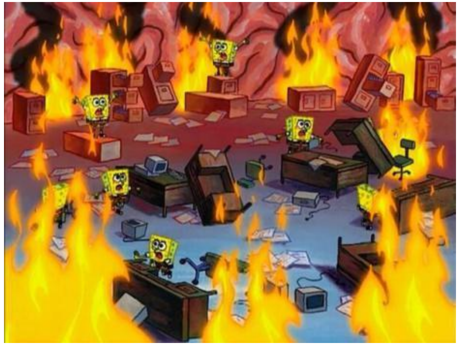
All the channels are considered. The first cut removes the most background events, etc… The selection is effective (good S/B) but ttW (ttX) remain as the main background.

Main goal: discriminate the signal over the background.
⟶ Need to find a specific variable!

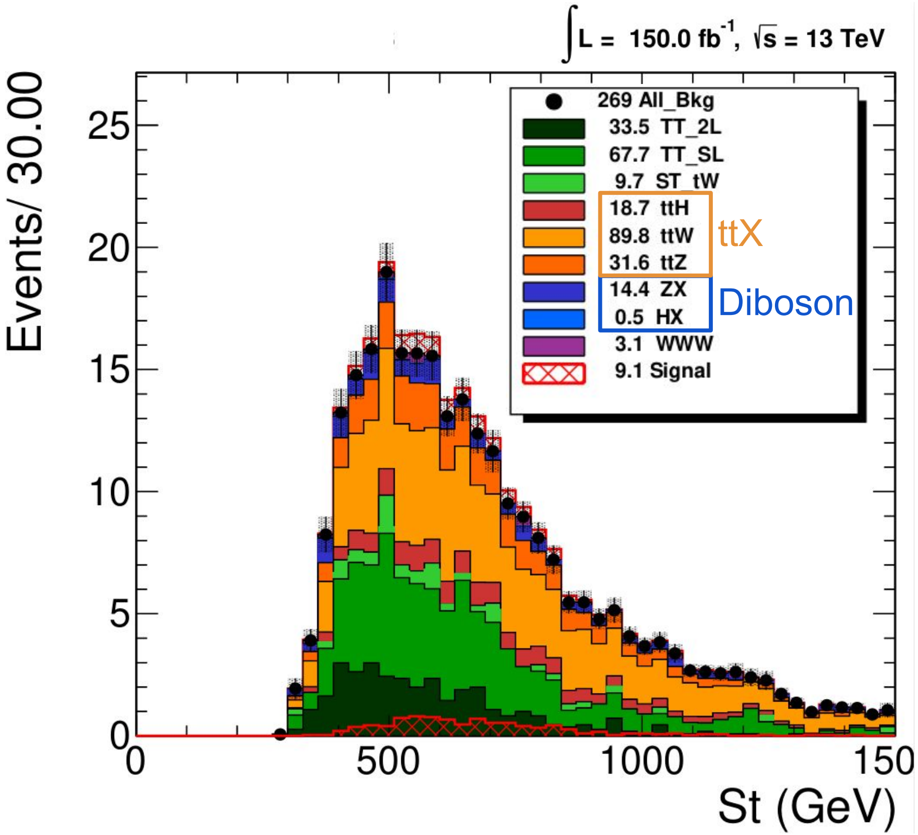
Main variable

The main variable is the
St = Sum of Pt of leptons and jets.
ttX (53%), TT_SL (25%) and TT_2L (12%) are main backgrounds and the signal is barely visible. ⟶ Study is ongoing.





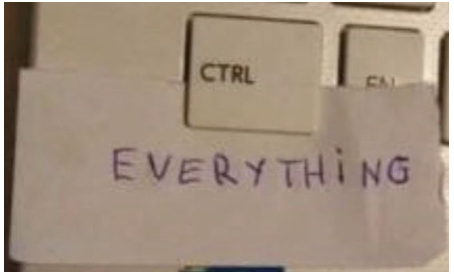
TT_SL: 1 lepton and
4 jets with 2 bjets.



How can we extract the signal?

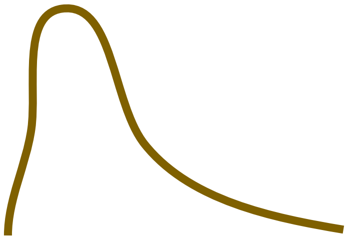
Benjamin Blancon
JRJC BSM
10.25.22

Control regions

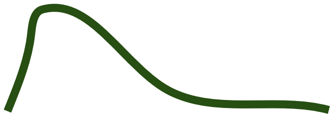


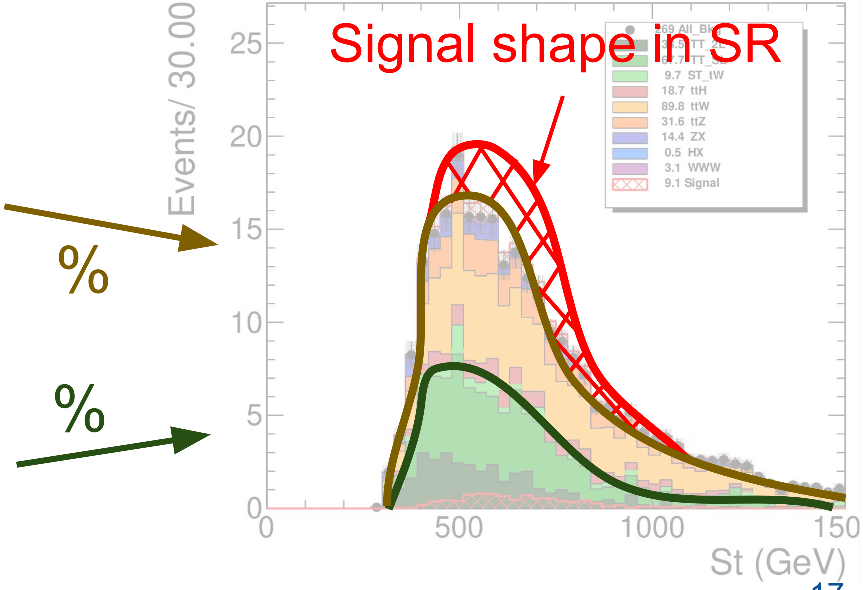
Goal ⟶ Define background shape thanks to Control regions (CRs) where backgrounds are pure and apply it to the Signal Region (SR) to extract signal shape.

CR 1: first background shape



CR 2: second background shape





…

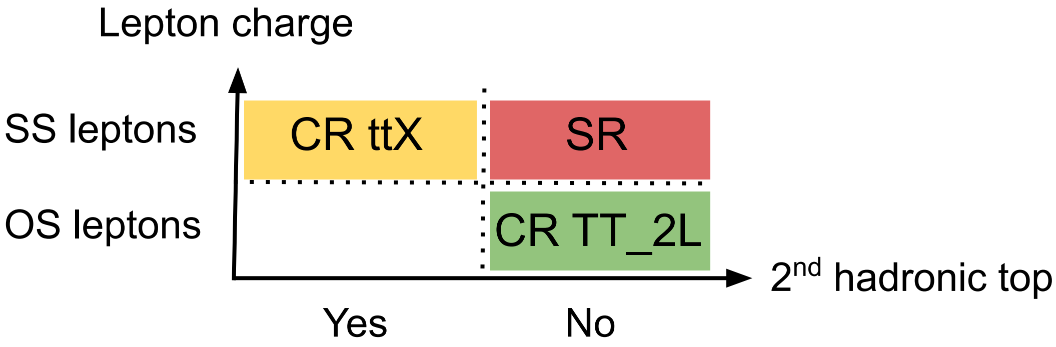
Benjamin Blancon
JRJC BSM
10.25.22

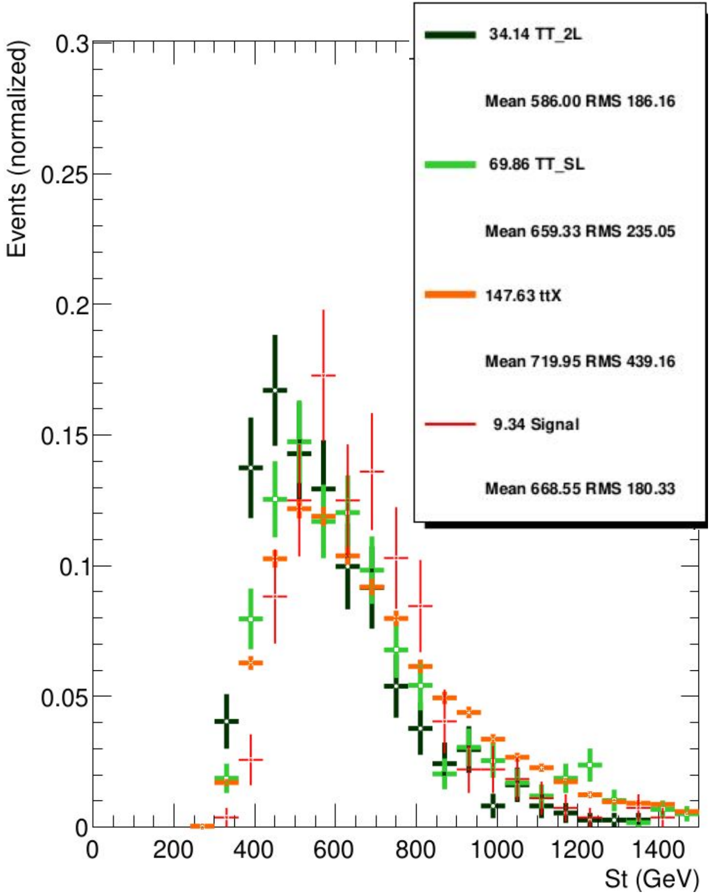
Control regions

Three different shapes for St for ttX, TT_SL and TT_2L in the SR.

⟶ Three CRs by inverting one cut:

- ttX: at least one hadronic top decay.
- TT_2L: two leptons opposite sign.
- TT_SL: ? Study is ongoing. It is not considered.



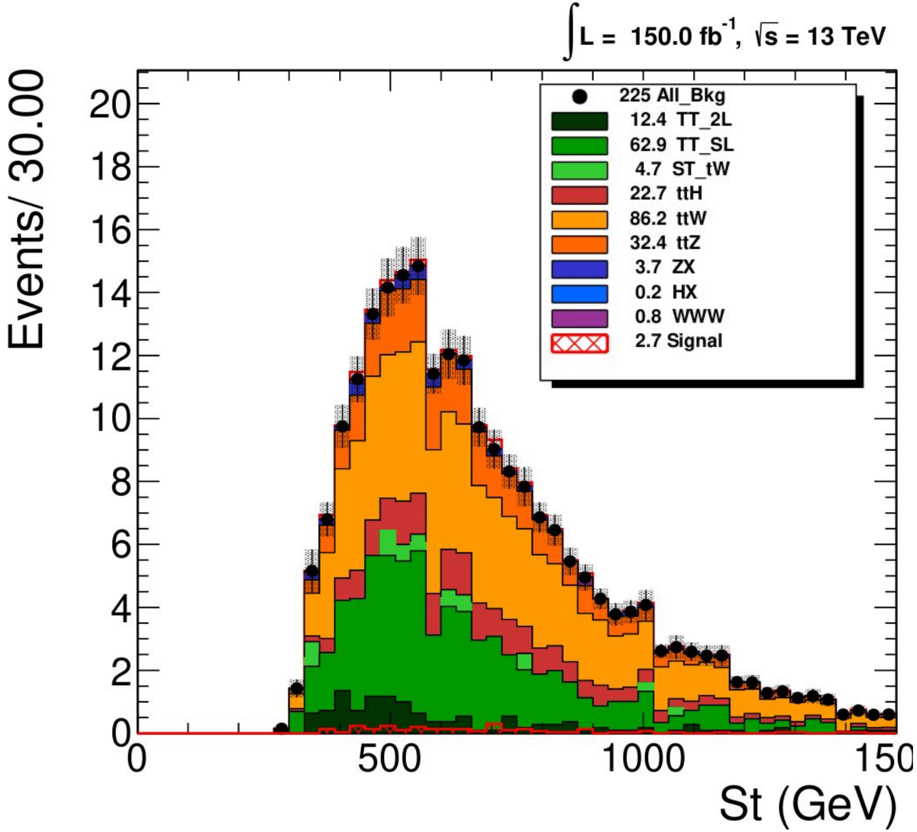


Let's start with the ttX CR!

Control regions - ttX

ttX is the largest background in its CR (63.0%). TT_SL is not negligible (27.6%) but we will not consider it. TT_2L and the signal contamination are negligible.

⟶ OK!

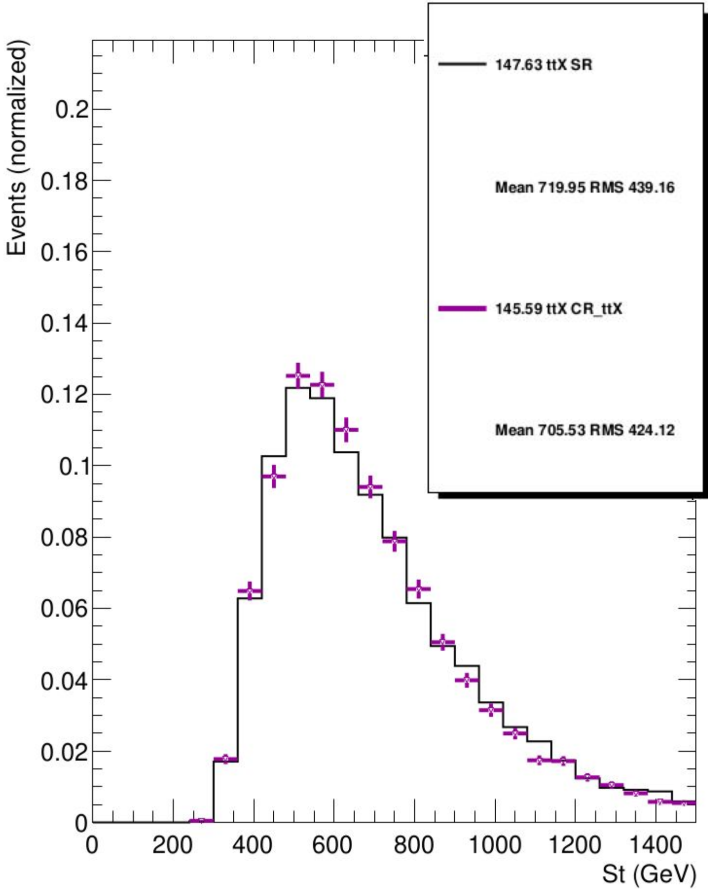


Let's compare the shape with SR!

Control regions - ttX (Validation)

Same shape for ttX in SR and its CR (see separated channels in backup).

⟶ Valid method for ttX!

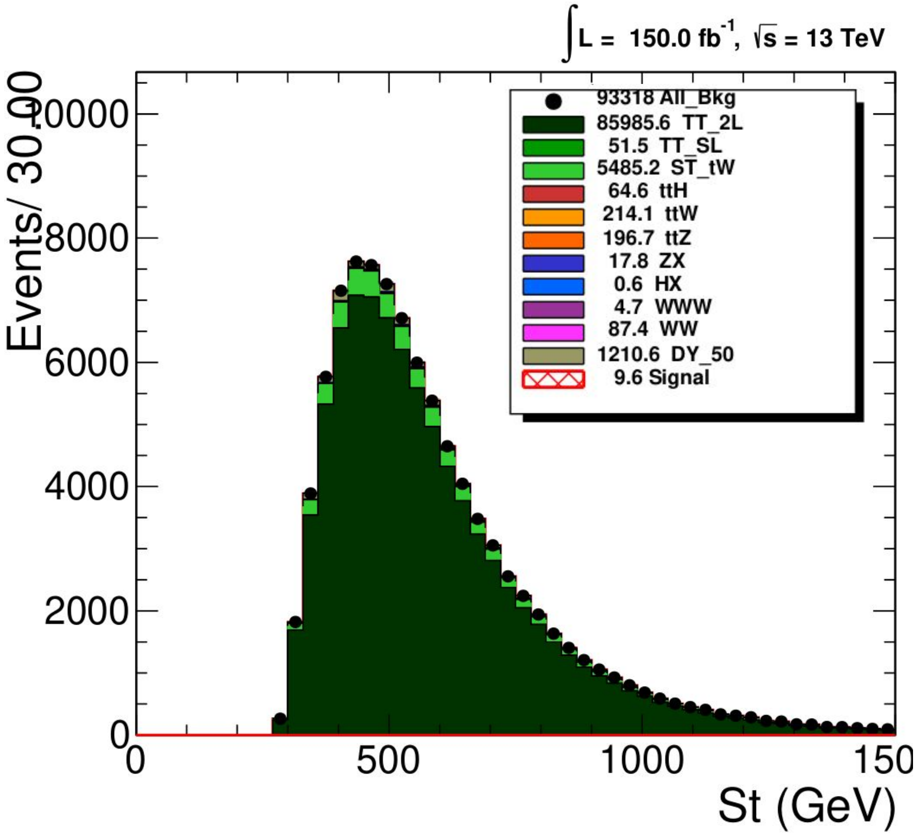


How about the TT_2L CR?

Benjamin Blancon
JRJC BSM
10.25.22

Control regions - TT_2L

TT_2L is the largest background in its CR (92,1%). ttX, TT_SL and the signal contamination are negligible.
⟶ OK!

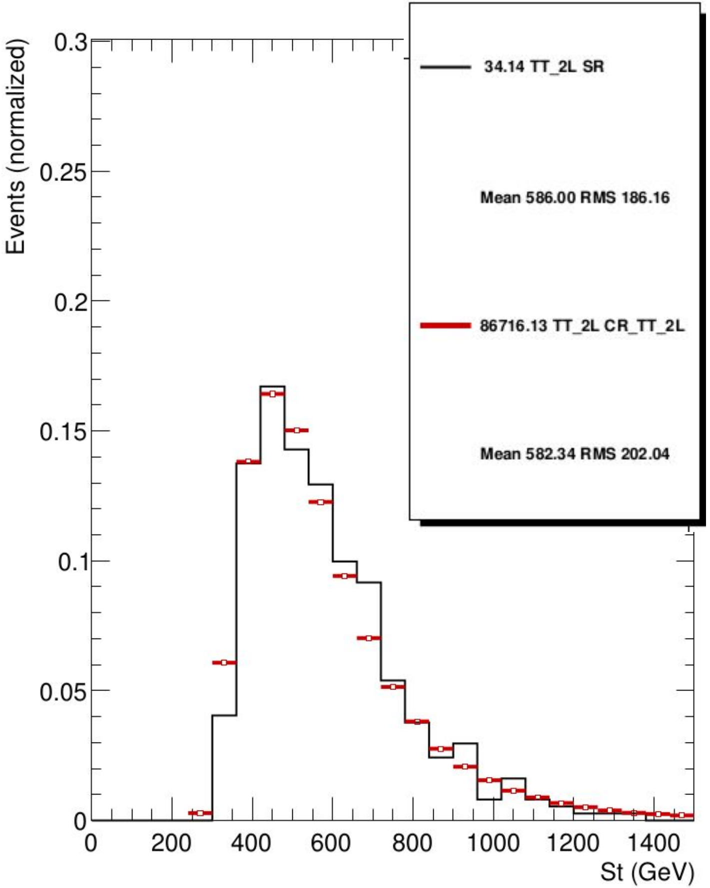


Let's compare the shape with SR!

Control regions - TT_2L (Validation)

Global same shape for TT_2L in the SR and its CR, need more statistics to confirm (see separated channels in backup).

⟶ Valid method for TT_2L?!



Summary

We focused on T' ⟶ top+H dileptonic SS final state analysis.

Analysis strategy designed: multiple studies (lepton identification, cut selection).

Defined CRs for the background estimation method.

Still a lot of things to do (get TT_SL under control, Scale Factors, apply the fit strategy for the background, comparison with the data, paper)!

That's all Folks!

Back-up

Datasets (UL18, Luminosity = 150 fb^{-1})

The backgrounds are ranked as major backgrounds.

Process	Cross-section (fb)	Number of events	Dataset name
Signal ($M_{T'}$ = 700 GeV)	89	400,000	/TprimeBToTH_M-700_LH_TuneCP5_13TeV-madgraph_pythia8/*-v1/NANOAODSIM
ttbar	87,315	145,020,000	/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/*-v1/NANOAODSIM
ttW	610.5	27,686,862	/ttWJets_TuneCP5_13TeV_madgraphMLM_pythia8/*-v2/NANOAODSIM
ttZ	770	32,793,815	/ttZJets_TuneCP5_13TeV_madgraphMLM_pythia8/*-v2/NANOAODSIM
Single top (tW)	19,467	22,220,050	/ST_tW_antitop_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/*-v1/NANOAODSIM /ST_tW_top_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/*-v1/NANOAODSIM
ttH	271	7,328,993	/ttHToNonbb_M125_TuneCP5_13TeV-powheg-pythia8/*-v2/NANOAODSIM
WZ	4,429.7	9,821,283	/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/*-v2/NANOAODSIM

* = RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1

Datasets (UL18, Luminosity = 150 fb^{-1})

Process	Cross-section (fb)	Number of events	Dataset name
ZZ	1,256	98,488,000	/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/*-v2/NANOAODSIM
WWW	208.6	240,000	/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8/*-v1/NANOAODSIM
WH	31.3	19,916,695	/HWminusJ_HToWWTo2L2Nu_WTo2L_M-125_TuneCP5_13TeV-powheg-pythia8/*-v2/NANOAODSIM /HWplusJ_HToWWTo2L2Nu_WTo2L_M-125_TuneCP5_13TeV-powheg-pythia8/*-v2/NANOAODSIM
ZH	185.8	9,899,256	/HZJ_HToWW_M-125_TuneCP5_13TeV-powheg-jhugen727-pythia8/*-v2/NANOAODSIM
WW	12,178	9,994,000	/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/*-v2/NANOAODSIM
Drell-Yan	18,610,000 (10-50 GeV) 6,020,850 (50 GeV)	94,452,816 96,233,328	/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/NANOAODSIM /DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/NANOAODSIM
W+Jets	61,334,900	81,051,269	/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/NANOAODSIM

* = RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1

Events number scaling

Interaction probability for a given particle for a given reaction (fb)

$$\text{Number of scaled events} = \frac{\text{Number of raw events after selection}}{\text{Number of raw events before selection}} * \text{Cross section} * \text{Luminosity}$$

Number of collisions detected by CMS (fb^{-1}, 137 fb^{-1} between 2016 and 2018)

Acceptance and efficiency are set to 1 (for the moment!).

Benjamin Blancon
JRJC BSM
10.25.22

Muon identification

List of additional studied variables:

- Phi.
- 3D impact parameter ip3d.
- Mini PF relative charged isolation = Pt of muon/ / $\sum_{\mathrm{R_{iso}}}$ (Pt of all charged particles): loose < 0.10, tight < 0.05[1].
- PF relative 0.3 isolation = $\sum_{\mathrm{R}\,=\,0.3}$ (Pt of charged hadrons - Max(0, Pt of neutral hadrons and photons - PU/2)) / Pt of muon: loose < 0.10, tight < 0.05[2].
- PF relative 0.3 charged isolation = $\sum_{\mathrm{R}\,=\,0.3}$ (Pt of charged hadrons) / Pt of muon: loose < 0.10, tight < 0.05[2].
- PF relative 0.4 isolation = $\sum_{\mathrm{R}\,=\,0.4}$ (Pt of charged hadrons - Max(0, Pt of neutral hadrons and photons - PU/2)) / Pt of muon: loose < 0.25, tight < 0.15[2].

[1]: mini-isolation (Section II.A.), [2]: isolation (Section 3.5.)

Muon identification - 2μ channel

ID	Isolation	Sip3D	Signal	ε Signal (%)	P Signal (%)	ttbar	ttW	WZ	S/B
Loose	Nothing	Nothing	41.0	60.9	35.7	26632.0	728.4	4484.1	0.13%
	Loose	Nothing	27.0	52.0	46.5	6550.1	584.9	4168.7	0.24%
	Tight	Nothing	23.6	47.4	48.7	4139.4	520.1	3712.3	0.28%
Medium	Nothing	Nothing	38.7	60.4	37.5	24082.3	705.5	4344.5	0.13%
	Loose	Nothing	25.4	51.6	49.1	4575.9	566.9	4043.7	0.28%
	Tight	Nothing	22.1	47.0	51.4	2432.3	504.5	3603.1	0.34%
Tight	Nothing	Nothing	37.2	58.1	37.8	23025.9	681.1	4205.5	0.13%
	Loose	Nothing	24.3	49.3	49.3	4291.6	548.0	3919.0	0.28%
	Tight	Nothing	21.2	45.3	52.1	2250.2	487.8	3494.3	0.34%
		<10	19.6	45.2	56.1	1310.2	475.9	3419.9	0.38%
		<5	17.7	44.1	62.2	790.4	454.9	3219.9	0.40%
		<3	15.7	42.2	70.9	484.0	417.1	2891.8	0.41%

✓

Electron identification

List of additional studied variables:

- Same variables as for muons.
- Δη between SuperCluster and electron.
- Non-PF 0.3 ECAL isolation.
- Non-PF 0.3 HCAL isolation.
- Non-PF 0.3 track isolation.
- Non-PF 0.3 track isolation with HEEP ID.
- WP 80 MVA isolation ID.
- TTH MVA lepton ID.

Electron identification - 1μ+1e channel

ID	Isolation	Sip3D	Signal	ε Signal (%)	P Signal (%)	ttbar	ttW	WZ	S/B
Tight	Tight	<3	20.6	27.1	64.1	2373.5	566.3	6724.2	0.21%
		<2	17.5	23.7	66.0	1623.8	494.4	6227.3	0.21%
HEEP		<3	20.3	25.2	64.6	3151.1	527.4	6149.2	0.21%
		<2	17.0	22.2	66.7	2148.8	458.1	5614.0	0.21%

✓

Electron identification - 1μ+1e channel

List of variables for ttH AN:

- $P_t > 25$ GeV, $|\eta| < 2.5$, loose ID, isolation < 0.40, sip3D < 8.
- Transverse impact parameter d_{xy} of electron < 0.05.
- Longitudinal impact parameter d_z of electron < 0.1.
- $\sigma_{i\eta i\eta}$ of electron < 0.011 in barrel ($|\eta| < 1.479$) and < 0.03 in endcap ($|\eta| > 1.479$).
- $\dfrac{\text{Electron energy}_{HCAL}}{\text{Electron energy}_{ECAL}} < 0.1.$
- $\dfrac{1}{\text{Electron energy}_{ECAL}} - \dfrac{1}{Pt_{tracker}} < -0.04.$
- Number of missing hits = 0.
- Loose MVA isolation ID.

	Signal	ε Signal (%)	P Signal (%)	ttbar	ttW	WZ	S/B
Study ttH AN	2.7	2.9	53.7	1668.2	64.8	835.3	0.11%

Selection criteria

List of additional studied variables:

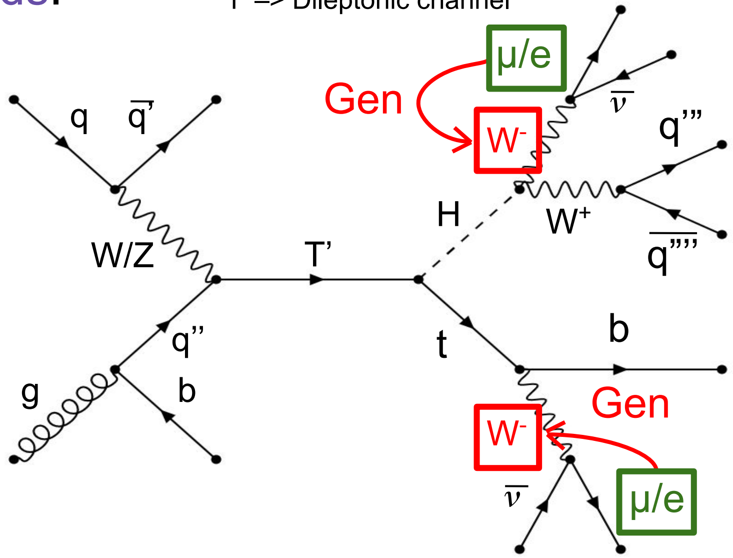
- Pt of 1st and 2nd lepton.
- Pt of sum of the two leptons.
- Δφ between the two leptons.
- Mass of sum of the two leptons.
- Pt of 1st, 2nd and 3rd jet and 1st b-jet.
- Ht = Sum of Pt of the jets.

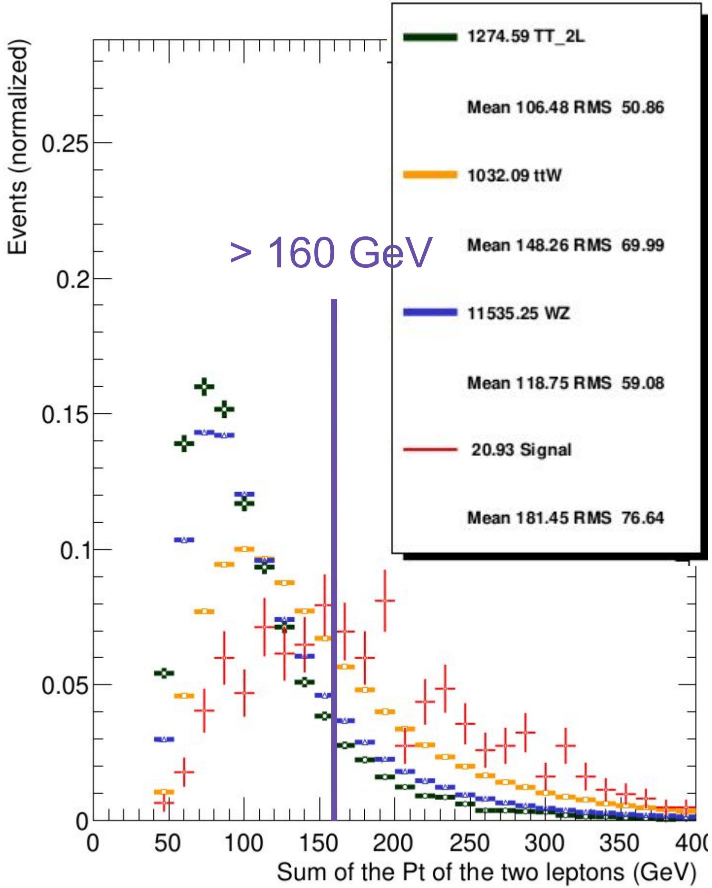
Selection criteria - Signal

The T' has a large mass so we expect the 2 leptons to have high Pt (Gen selection for the signal).

⟶ Cut 0: $\sum_{\text{2 leptons}} Pt > 160$ GeV to reduce all the backgrounds.

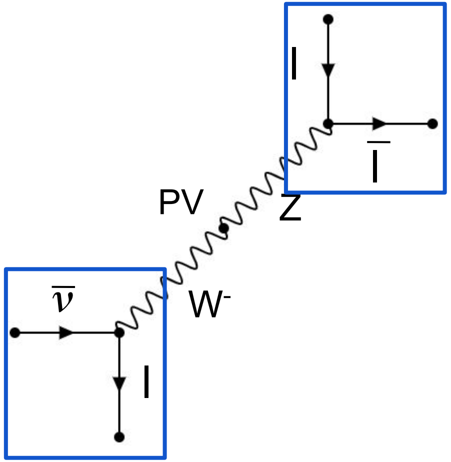
T' –> Dileptonic channel



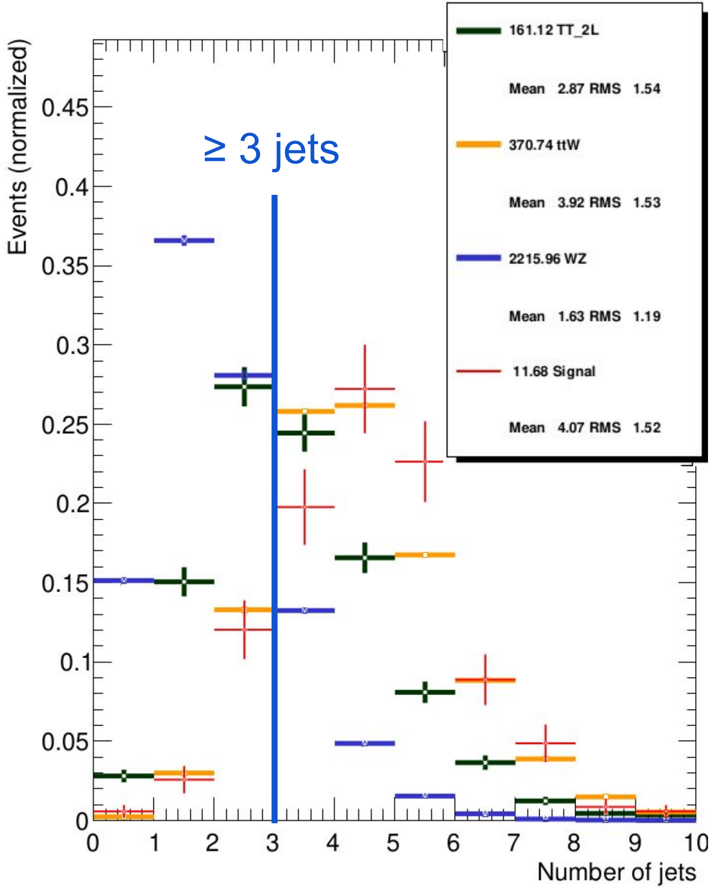


Selection criteria - Diboson

We expect 3 jets with 1 b-jet in the final state.
⟶ Cut 1: ≥ 3 jets and ≥ 1 b-jet with Pt > 50 GeV to reduce Diboson backgrounds.

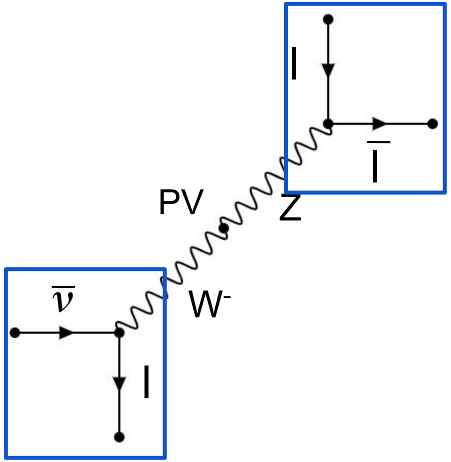


WZ (Dibosons): no jets.

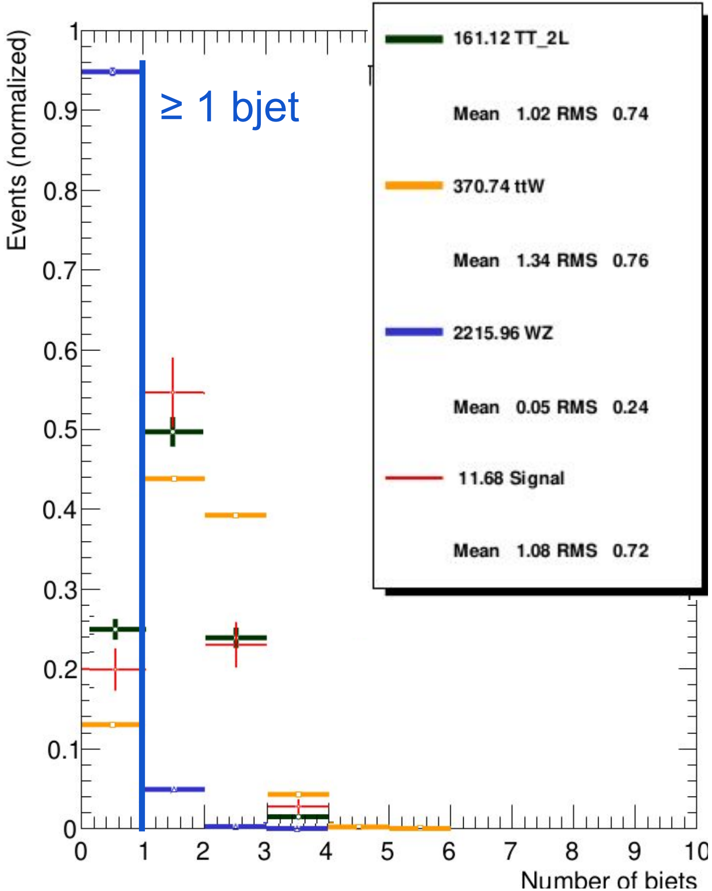


Selection criteria - Diboson

We expect 3 jets with 1 b-jet in the final state.
⟶ Cut 1: ≥ 3 jets and ≥ 1 b-jet with Pt > 50 GeV to reduce Diboson backgrounds.



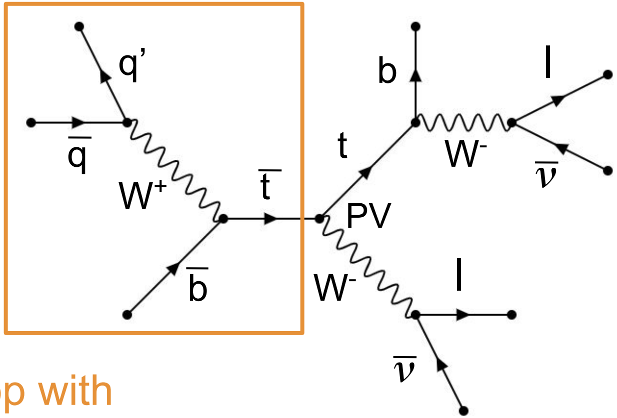
WZ (Dibosons): no jets.



Selection criteria - ttX

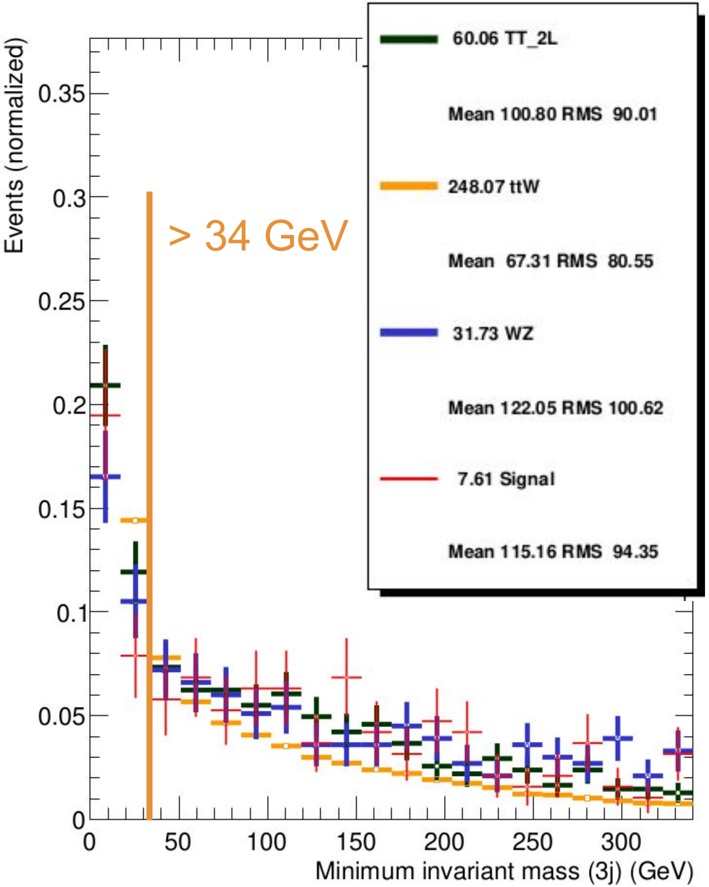
The top must have a non-hadronic decay.

⟶ Cut 2: Min(3 jets invariant mass - top invariant mass) > 34 GeV (i.e. 3 jets invariant mass ∉ top invariant mass ± 2σ[1]) to reduce ttX backgrounds.



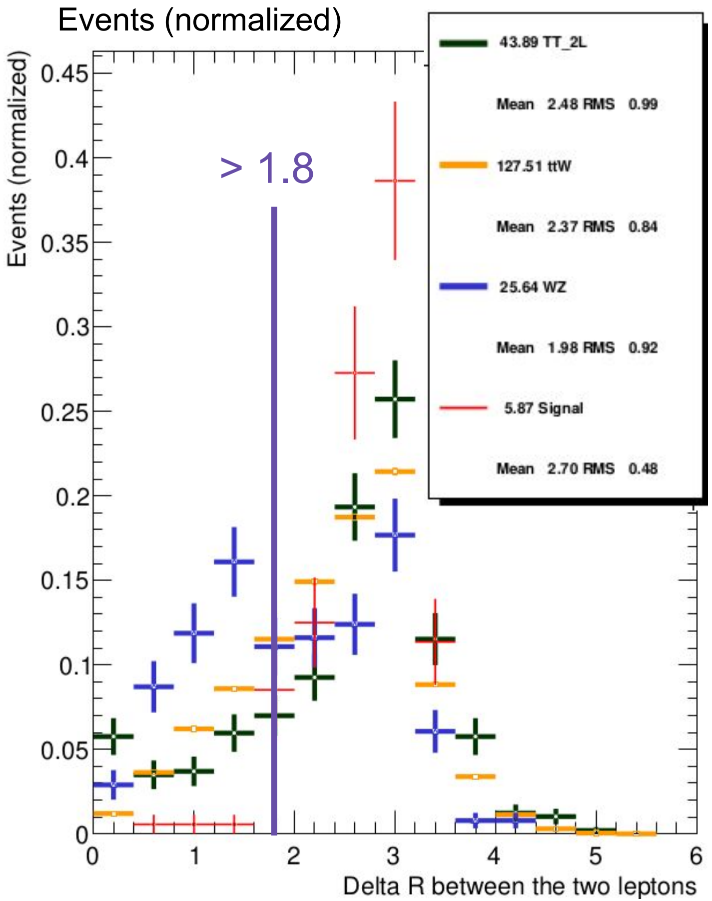
ttW (ttX): one hadronic top with

$\sum_{3\ jets}$ invariant mass = top invariant mass



[1]: B2G-19-001, section 3.2.2

Selection criteria - Signal



The 2 leptons must be back-to-back.

⟶ Cut 3: ΔR (leptons) > 1.8 to reduce all the backgrounds.

Selection criteria - All channels results

Process	Signal	ε signal (%)	P signal (%)	TT_2L	ttW	WZ	S/B
Cut 0	19.9	14.4	65.2	161.1	370.7	2216.0	0.72%
Cut 1	12.4	9.4	68.9	60.1	248.1	31.7	3.65%
Cut 2	9.6	7.3	67.4	43.9	127.5	25.6	4.87%
Cut 3	9.3	7.1	66.9	34.1	95.4	14.1	6.47%

Selection criteria - All channels results

Process	Signal	ttW	TT_SL	TT_2L	ttZ	ttH	ZX*	Single top (tW)	WWW	HX*	Others*	Sum of Bkgs	S/B
Cut 0	19.9	370.7	336.6	161.1	132.8	86.8	2341.6	58.1	91.0	89.3	952.8	4620.9	0.43%
Cut 1	12.4	248.1	181.6	60.1	92.6	63.8	33.2	24.7	4.3	1.0	0.2	709.5	1.75%
Cut 2	9.6	127.5	91.0	43.9	45.6	29.1	26.7	16.5	3.5	0.8	0.2	384.8	2.49%
Cut 3	9.3	95.4	69.9	34.1	32.6	19.6	14.9	10.0	3.1	0.5	0.0	280.1	3.32%

* ZX = ZW + ZZ
HX = HW + HZ
Others = WW, Drell-Yan and W+Jets

Selection criteria - 2μ channel results

Process	Signal	ε signal (%)	P signal (%)	TT_2L	ttW	WZ	S/B
Cut 0	8.2	22.5	65.4	36.7	145.0	412.9	1.38%
Cut 1	5.1	14.7	69.1	14.3	98.2	6.2	4.30%
Cut 2	4.1	12.3	72.1	10.7	50.9	5.1	6.15%
Cut 3	4.0	12.1	72.5	8.7	38.4	2.4	8.08%

Selection criteria - 2μ channel results

Process	Signal	ttW	TT_SL	TT_2L	ttZ	ttH	ZX*	Single top (tW)	WWW	HX*	Others*	Sum of Bkgs	S/B
Cut 0	8.2	145.0	138.2	36.7	22.6	35.8	425.5	16.6	33.5	32.3	236.4	1122.6	0.73%
Cut 1	5.1	98.2	71.8	14.3	15.9	26.6	6.3	5.8	1.6	0.4	0.0	240.8	2.12%
Cut 2	4.1	50.9	35.0	10.7	7.9	12.0	5.2	3.1	1.3	0.3	0.0	126.4	3.24%
Cut 3	4.0	38.4	30.9	8.7	5.6	8.1	2.4	2.3	1.3	0.2	0.0	97.9	4.09%

* ZX = ZW + ZZ
HX = HW + HZ
Others = WW, Drell-Yan and W+Jets

Selection criteria - 1μ+1e channel results

Process	Signal	ε signal (%)	P signal (%)	TT_2L	ttW	WZ	S/B
Cut 0	9.2	13.9	70.0	83.6	174.1	1194.6	0.63%
Cut 1	5.8	9.2	73.0	31.3	116.0	16.4	3.54%
Cut 2	4.4	6.7	70.5	22.7	59.5	13.2	4.61%
Cut 3	4.2	6.3	70.1	17.1	44.4	7.2	6.11%

Selection criteria - 1μ+1e channel results

Process	Signal	ttW	TT_SL	TT_2L	ttZ	ttH	ZX*	Single top (tW)	WWW	HX*	Others*	Sum of Bkgs	S/B
Cut 0	9.2	174.1	156.4	83.6	74.6	40.2	1247.2	31.3	44.3	43.2	271.1	2166.1	0.43%
Cut 1	5.8	116.0	84.8	31.3	52.0	29.4	17.0	13.7	2.1	0.5	0.2	347.0	1.67%
Cut 2	4.4	59.5	43.6	22.7	25.5	13.6	13.6	9.5	1.7	0.4	0.2	190.0	2.32%
Cut 3	4.2	44.4	30.5	17.1	18.4	9.2	7.5	5.8	1.3	0.3	0.0	134.5	3.12%

* ZX = ZW + ZZ
HX = HW + HZ
Others = WW, Drell-Yan and W+Jets

Selection criteria - 2e channel results

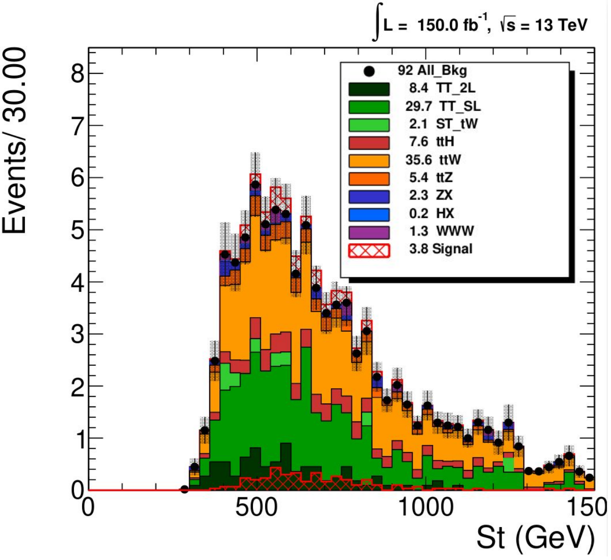
Process	Signal	ε signal (%)	P signal (%)	TT_2L	ttW	WZ	S/B
Cut 0	2.5	6.8	60.2	40.8	51.7	608.5	0.35%
Cut 1	1.6	4.3	64.6	14.5	33.8	9.2	2.78%
Cut 2	1.1	2.9	59.7	10.5	17.2	7.4	3.13%
Cut 3	1.1	2.8	58.0	8.4	12.6	4.5	4.31%

Selection criteria - 2e channel results

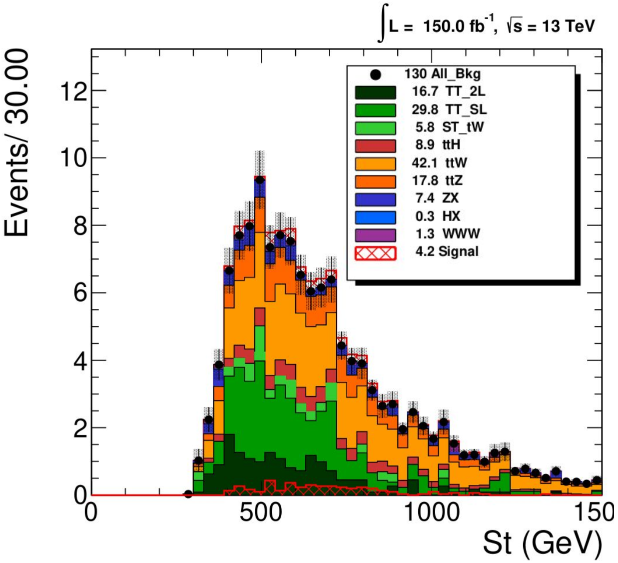
Process	Signal	ttW	TT_SL	TT_2L	ttZ	ttH	ZX*	Single top (tW)	WWW	HX*	Others*	Sum of Bkgs	S/B
Cut 0	2.5	51.7	42.0	40.8	35.6	10.8	668.8	10.2	13.2	13.8	445.3	1332.2	0.19%
Cut 1	1.6	33.8	25.0	14.5	24.7	7.8	9.9	5.3	0.7	0.1	0.0	121.7	1.31%
Cut 2	1.1	17.2	12.4	10.5	12.2	3.5	7.9	3.9	0.5	0.1	0.0	68.1	1.62%
Cut 3	1.1	12.6	8.5	8.4	8.6	2.3	4.9	1.8	0.5	0.1	0.0	47.7	2.31%

* ZX = ZW + ZZ
HX = HW + HZ
Others = WW, Drell-Yan and W+Jets

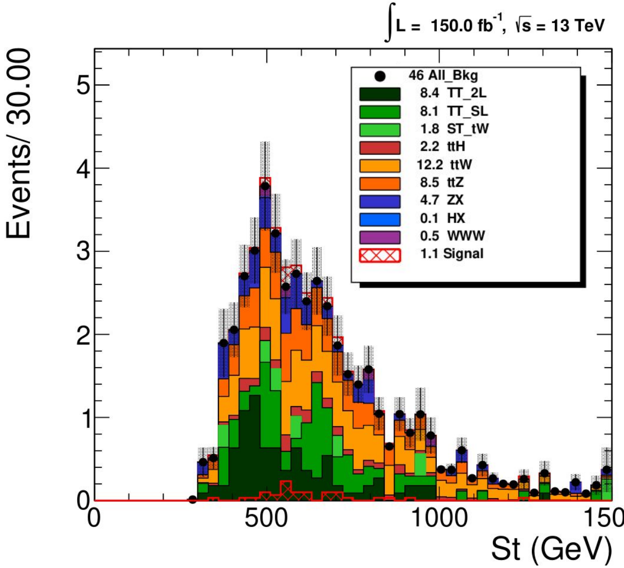
Main variable - Separated channels



2μ channel

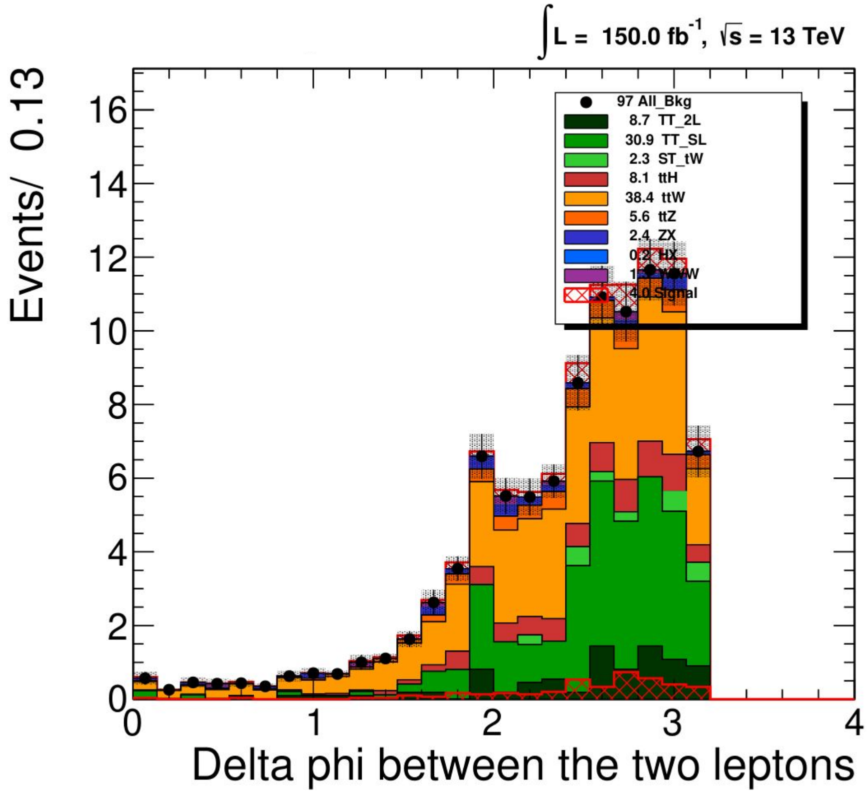


1μ+1e channel

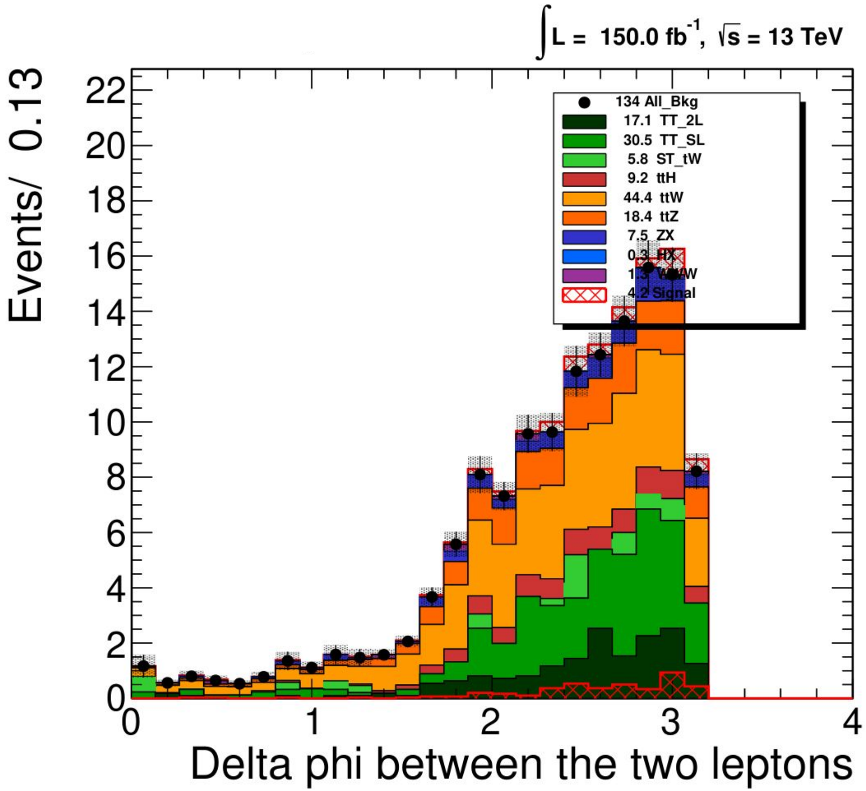


2e channel

Main variable - Δφ



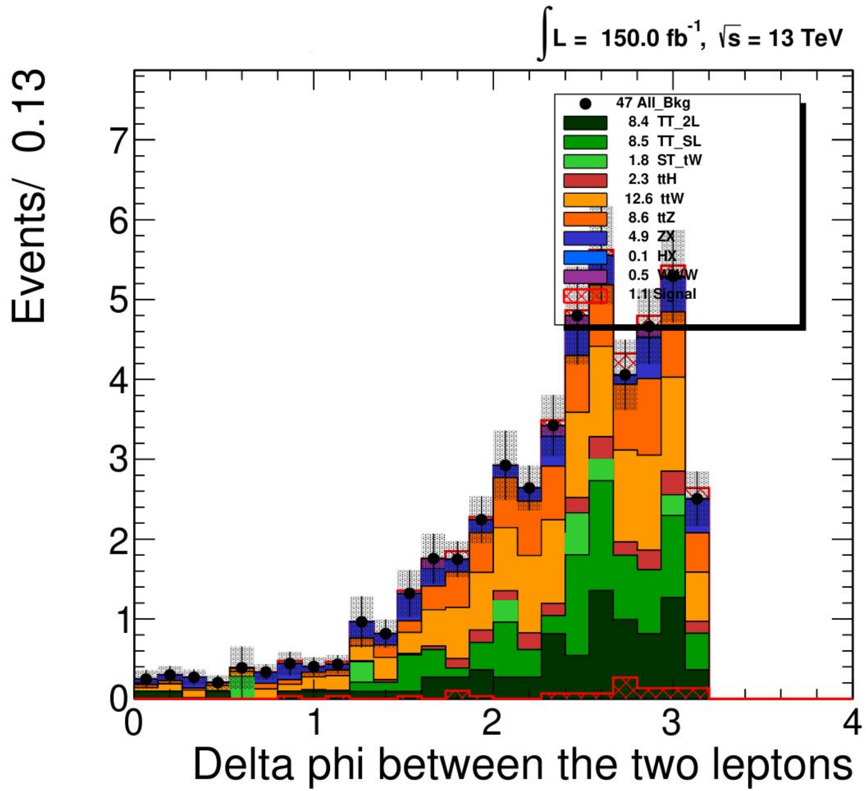
2μ channel



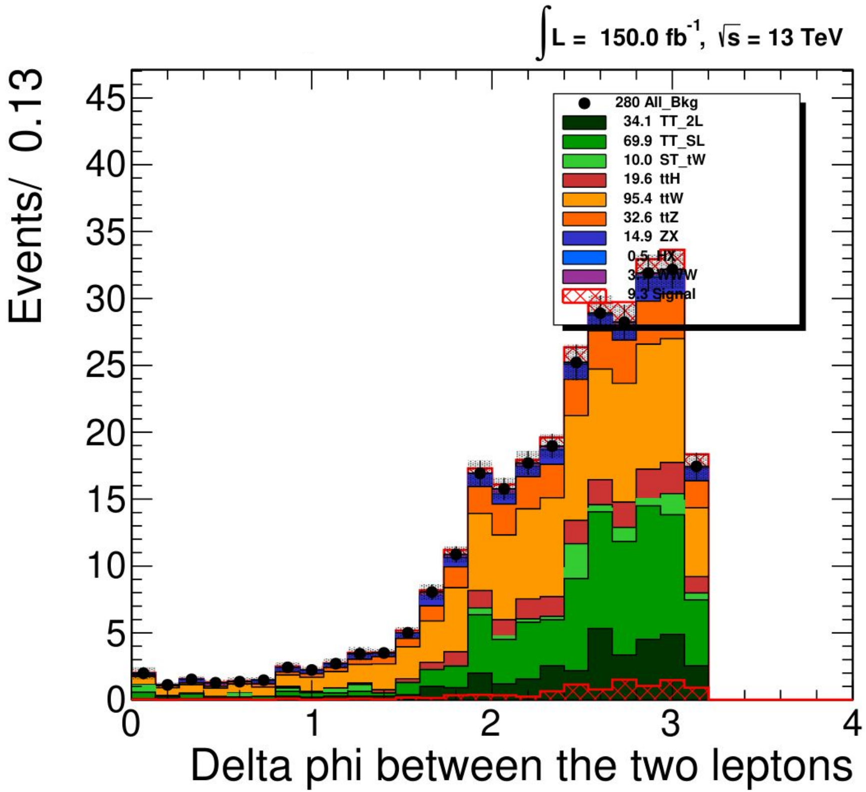
1μ+1e channel

Benjamin Blancon
JRJC BSM
10.25.22

Main variable - Δφ

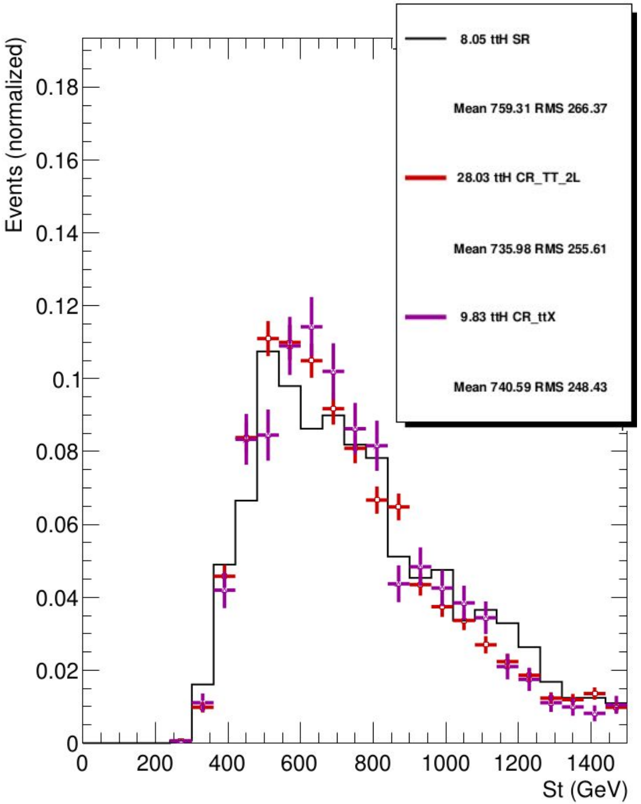


2e channel

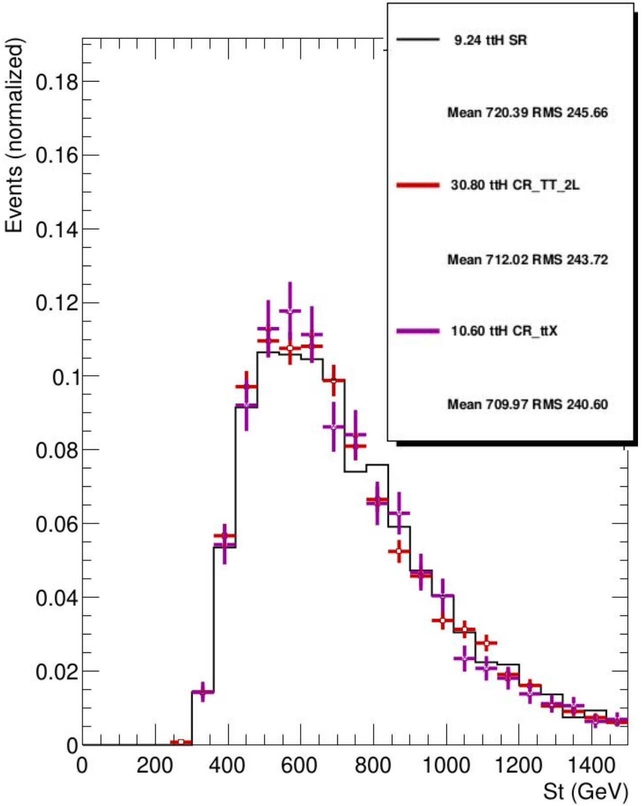


Total

Control regions vs Signal region (ttH)

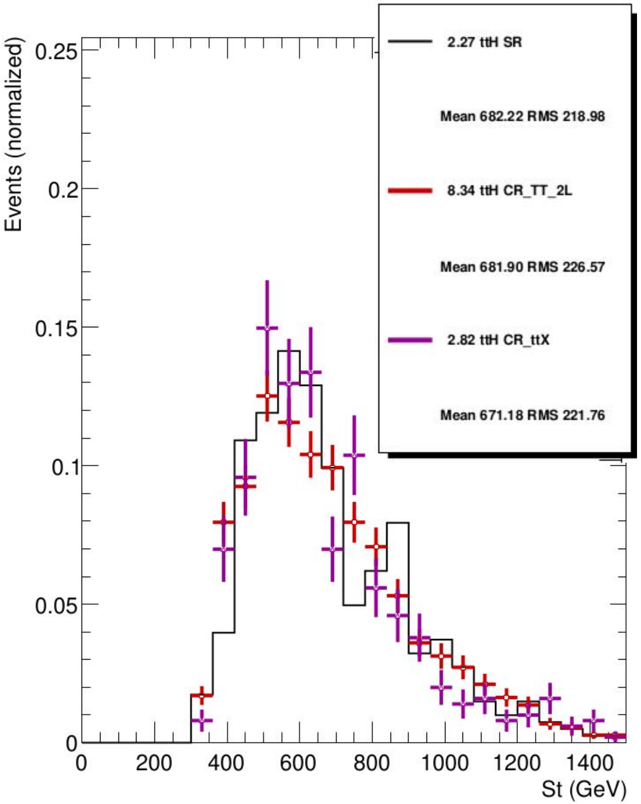


2μ channel

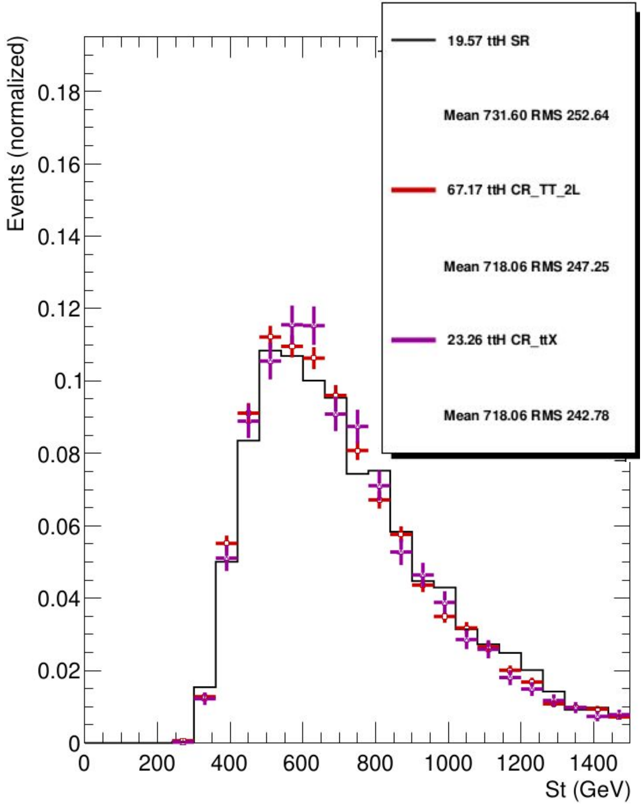


1μ+1e channel

Control regions vs Signal region (ttH)

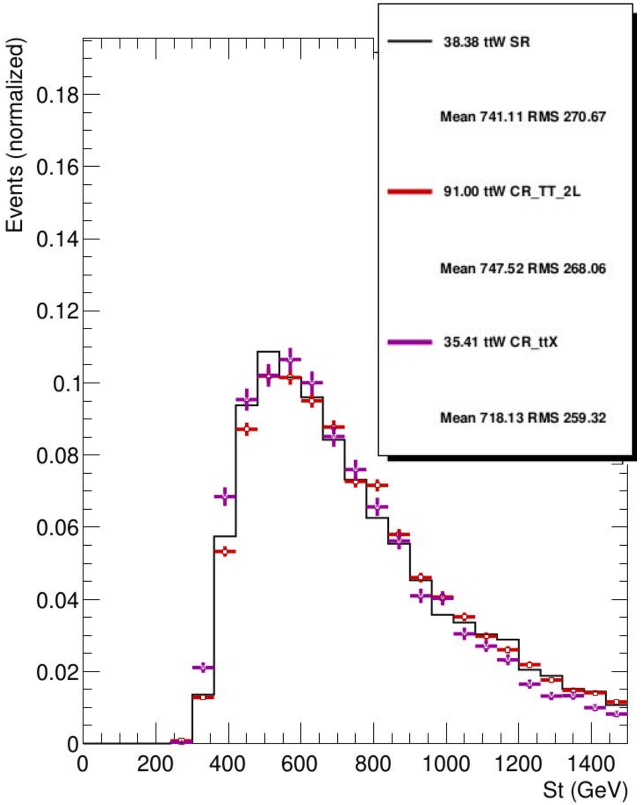


2e channel

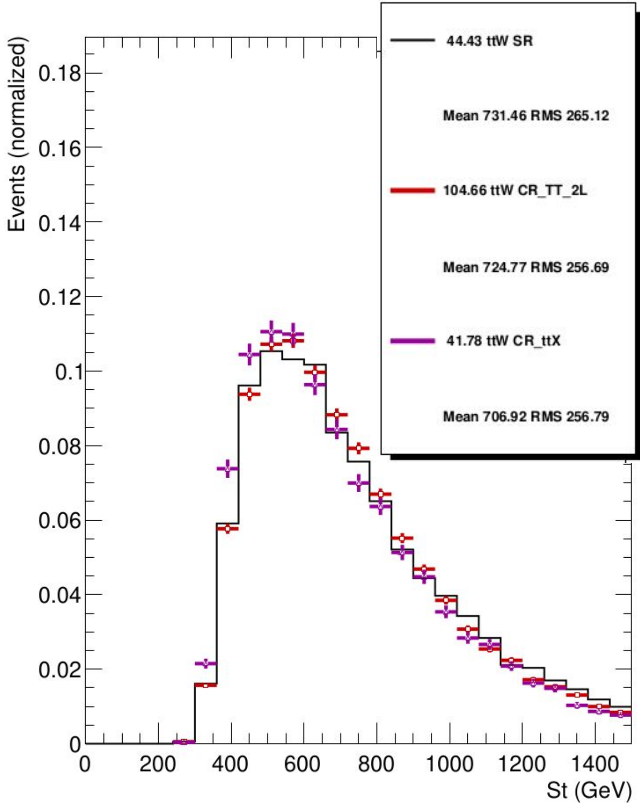


Total

Control regions vs Signal region (ttW)

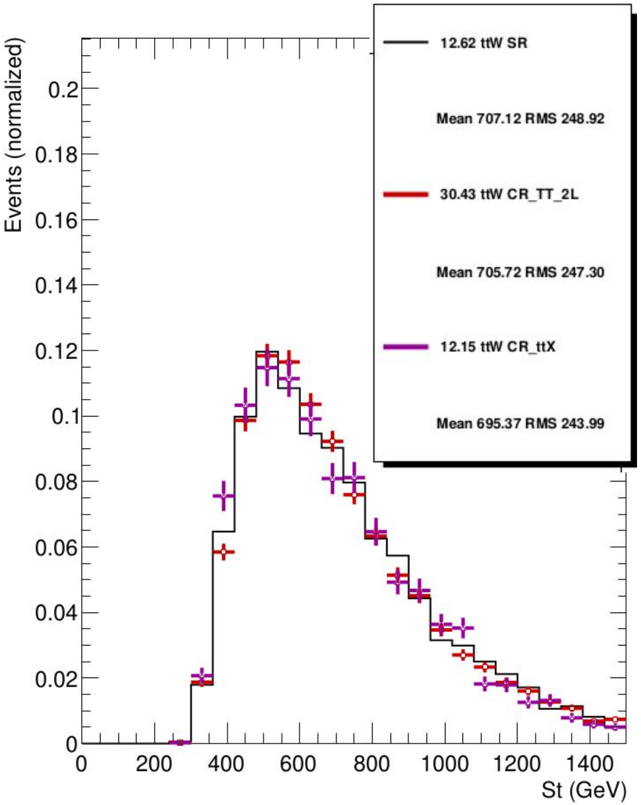


2μ channel

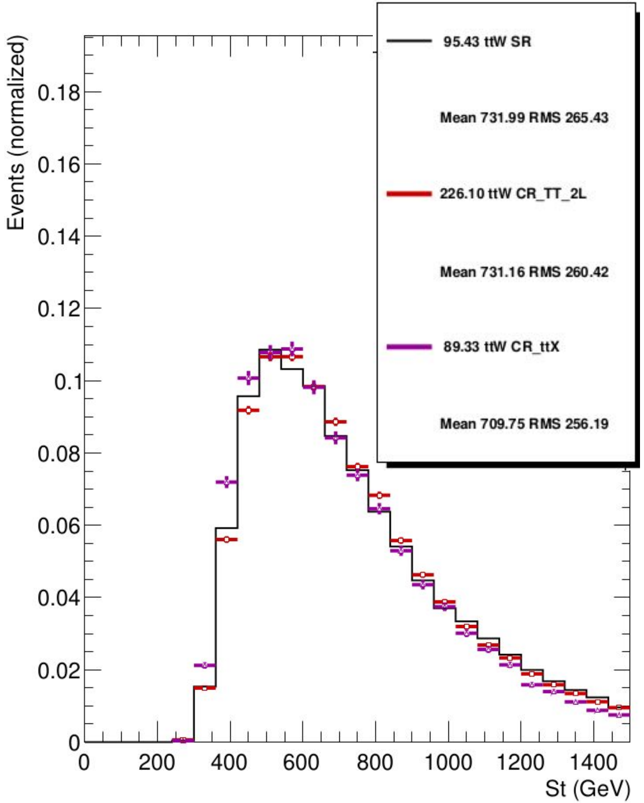


1μ+1e channel

Control regions vs Signal region (ttW)

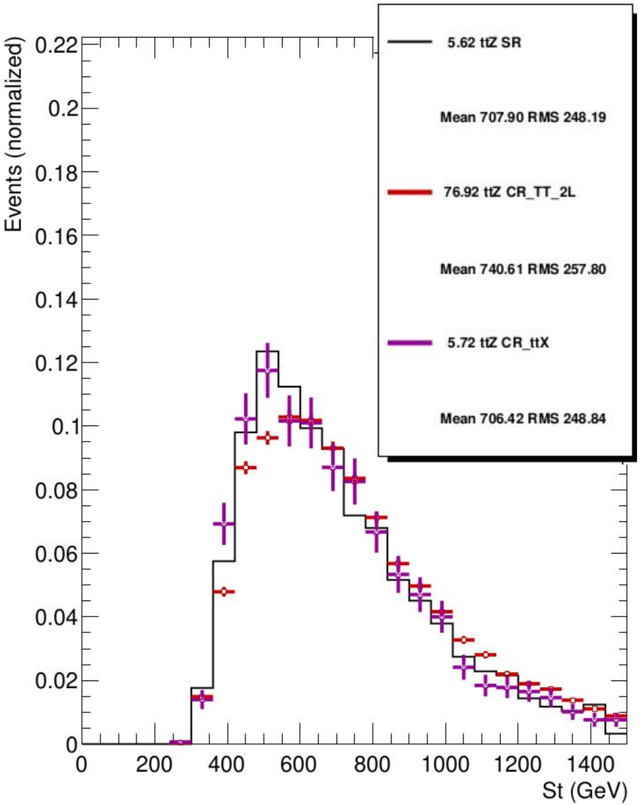


2e channel

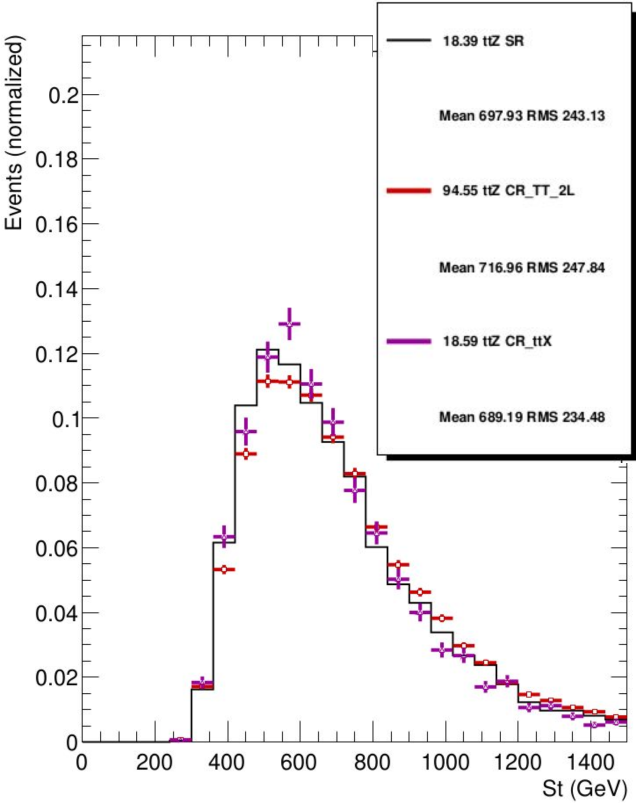


Total

Control regions vs Signal region (ttZ)

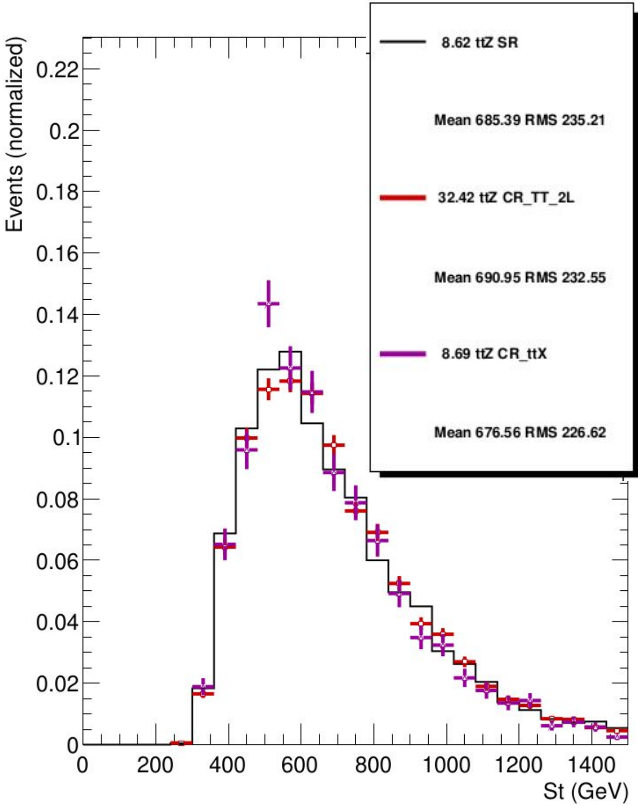


2μ channel

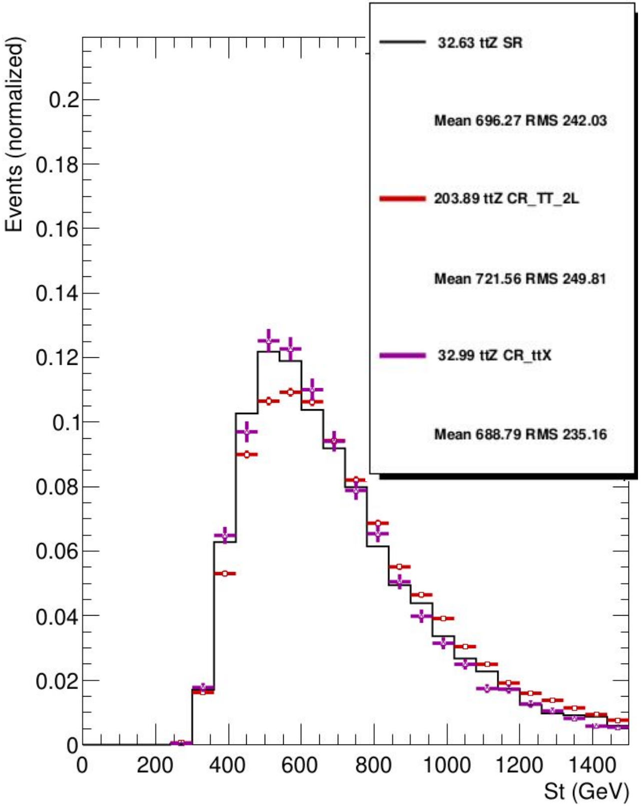


1μ+1e channel

Control regions vs Signal region (ttZ)

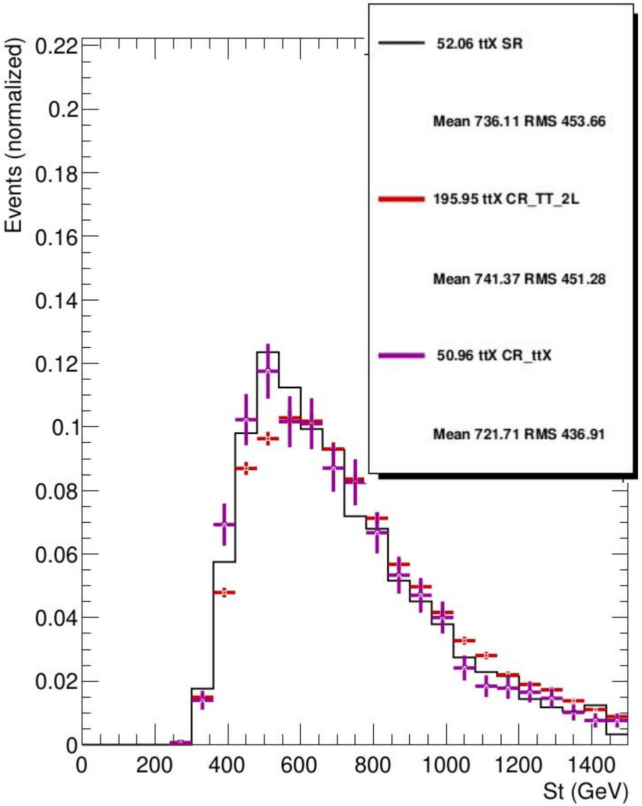


2e channel

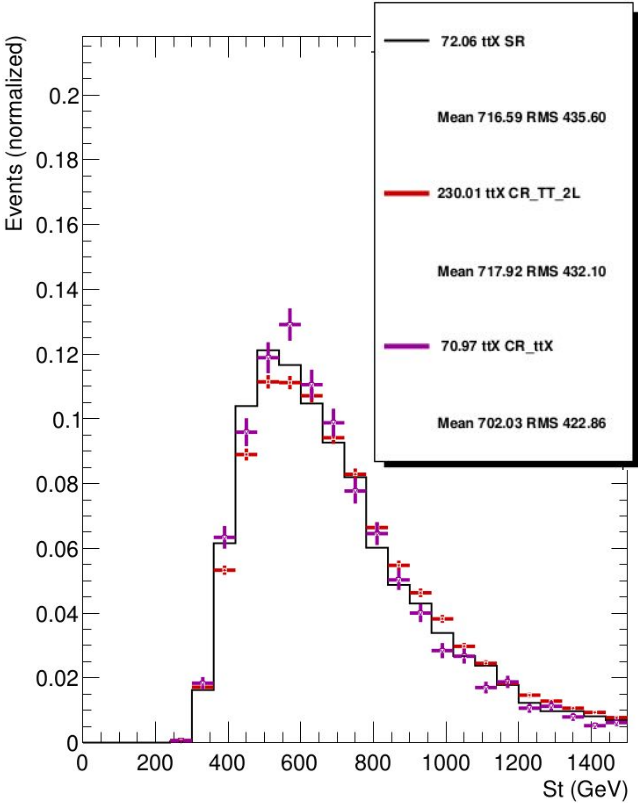


Total

Control regions vs Signal region (ttX)

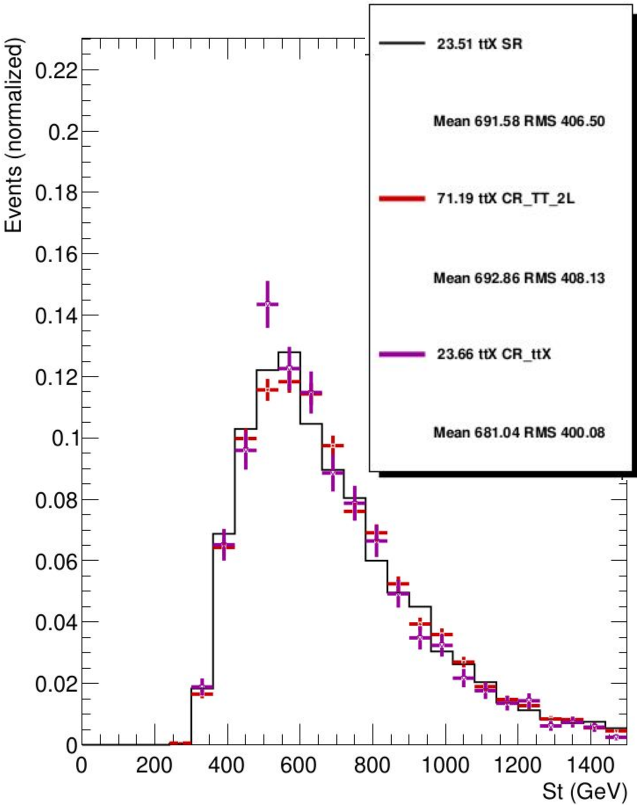


2μ channel

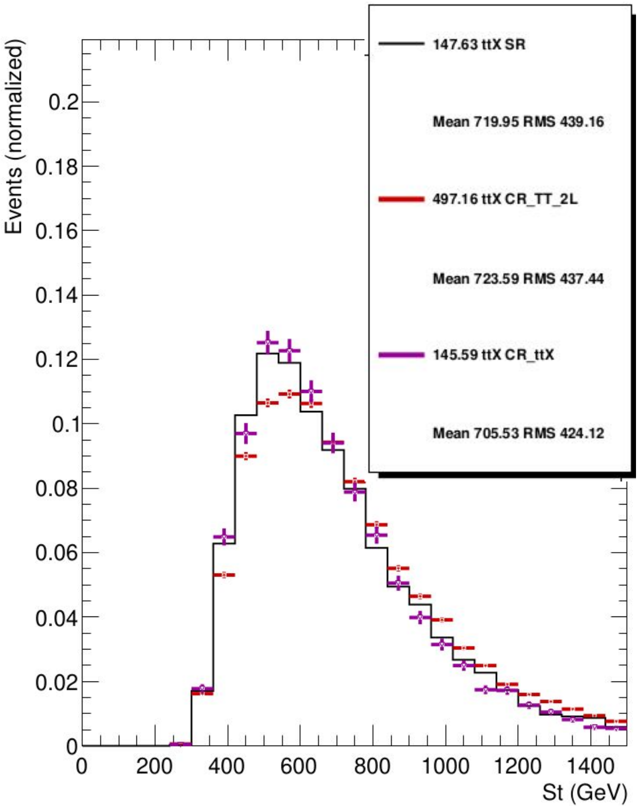


1μ+1e channel

Control regions vs Signal region (ttX)

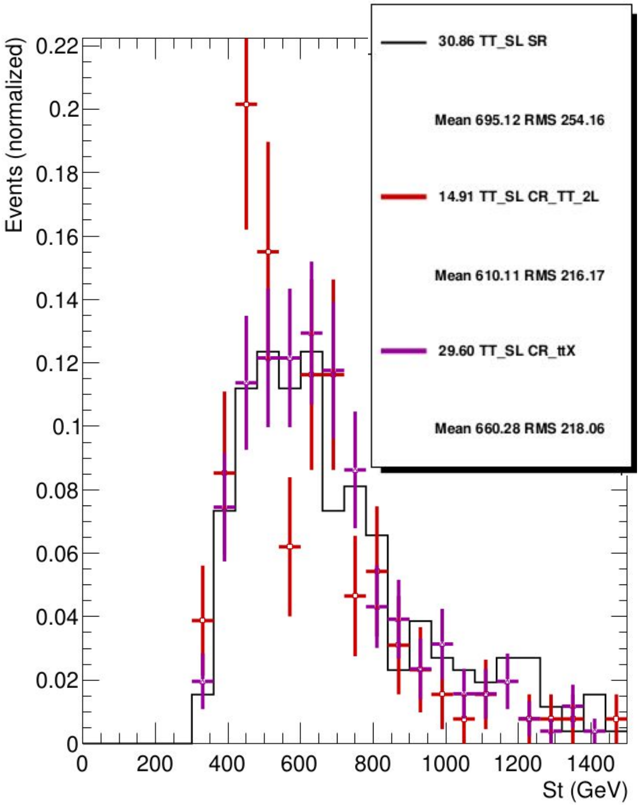


2e channel

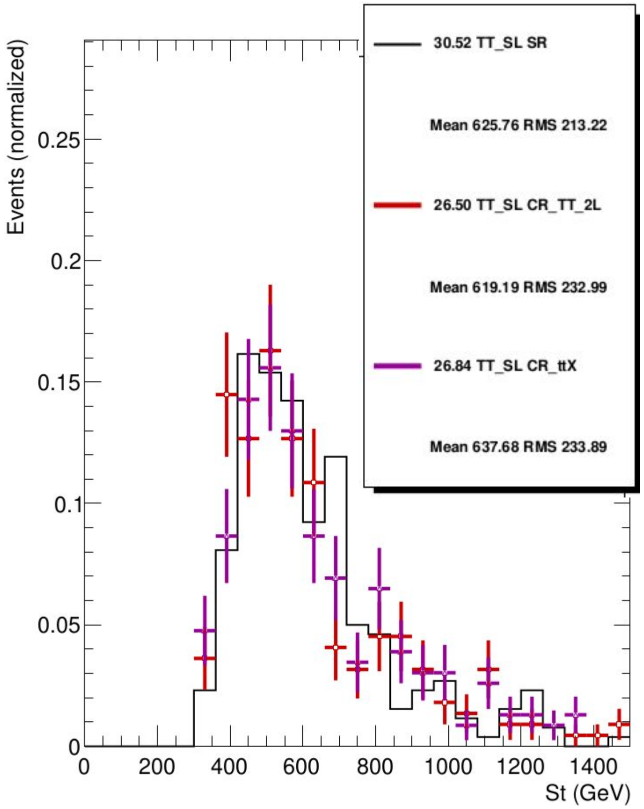


Total

Control regions vs Signal region (TT_SL)

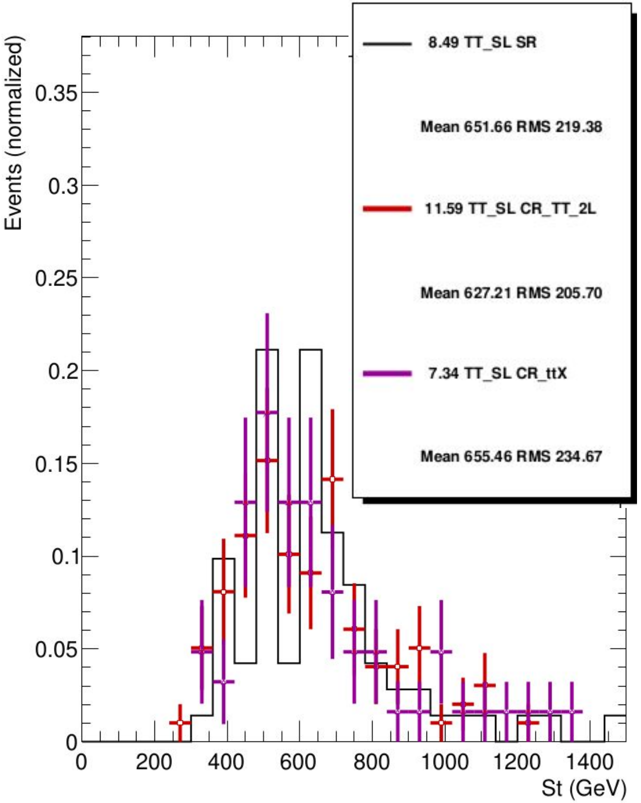


2μ channel

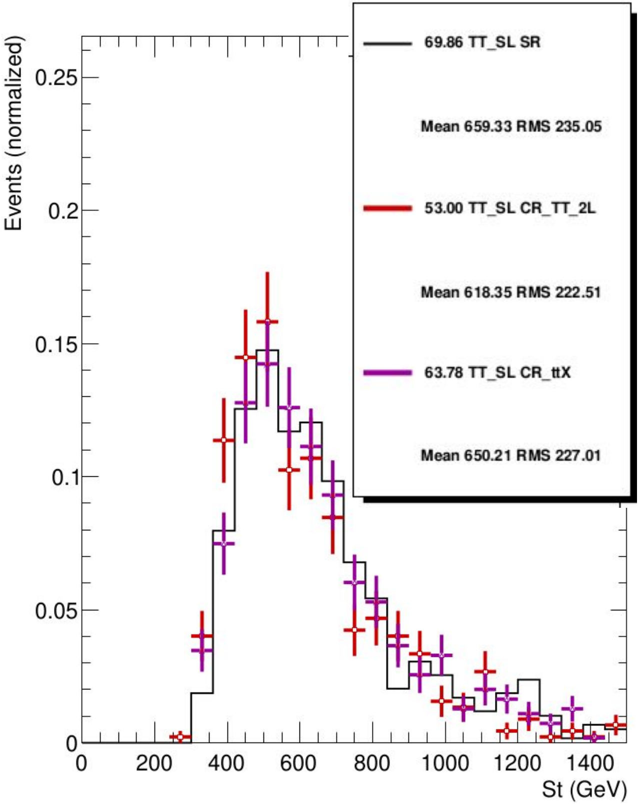


1μ+1e channel

Control regions vs Signal region (TT_SL)

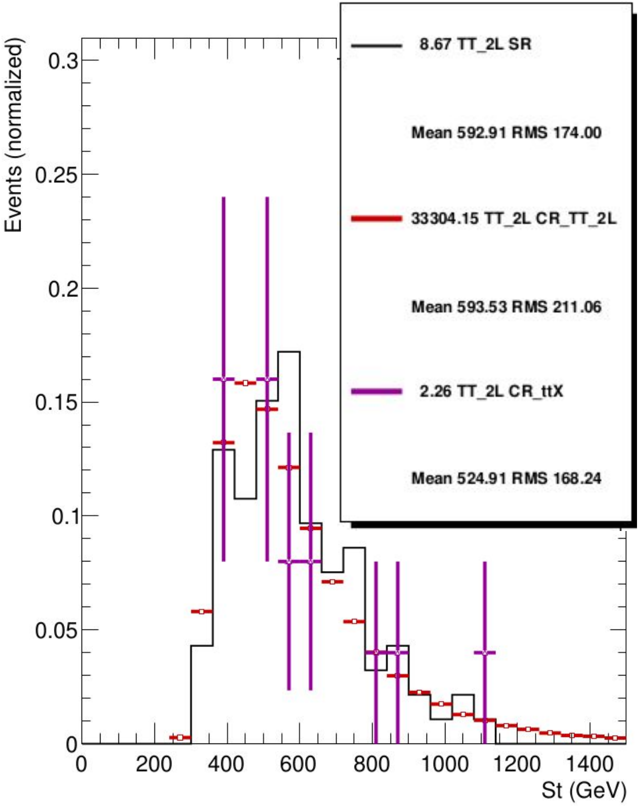


2e channel

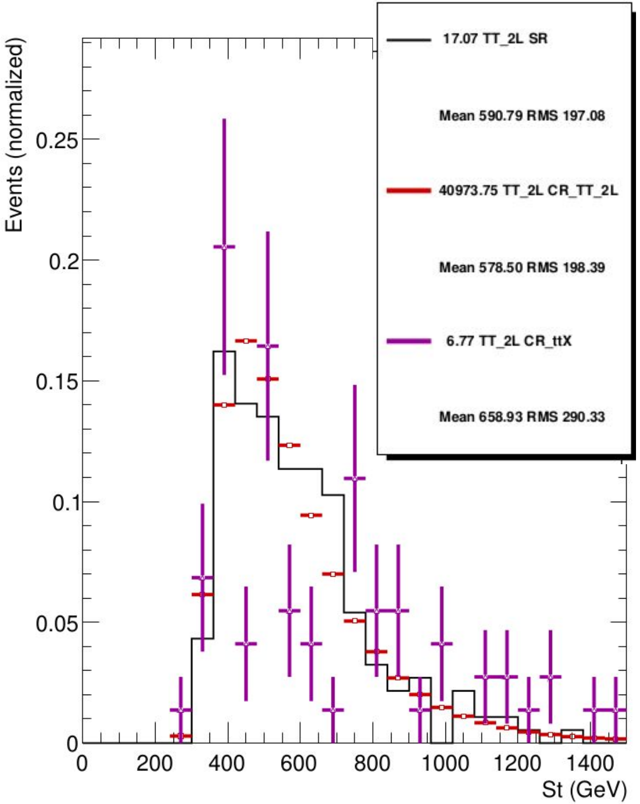


Total

Control regions vs Signal region (TT_2L)

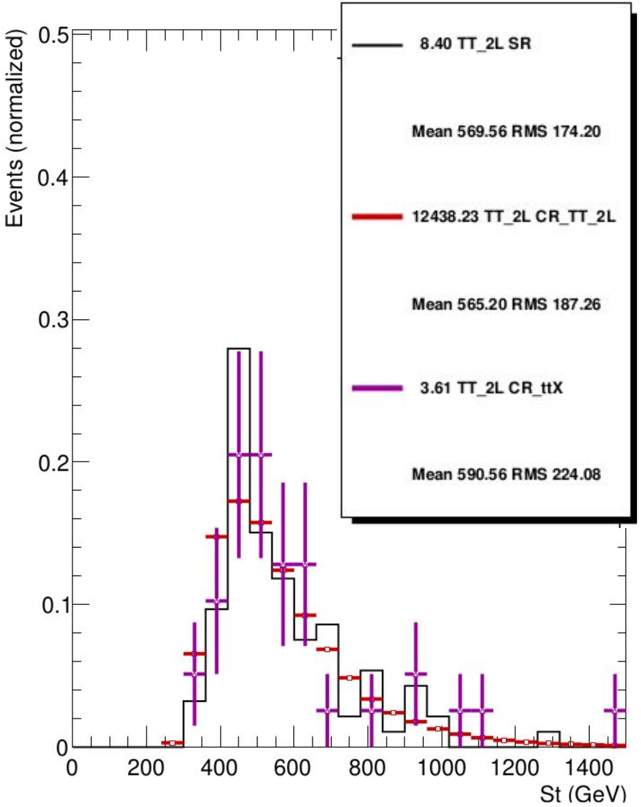


2μ channel

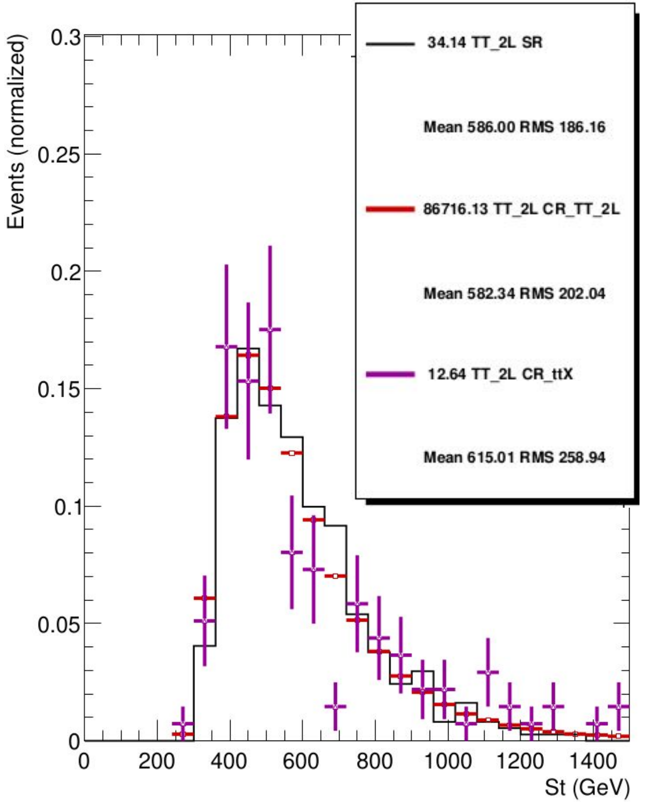


1μ+1e channel

Control regions vs Signal region (TT_2L)

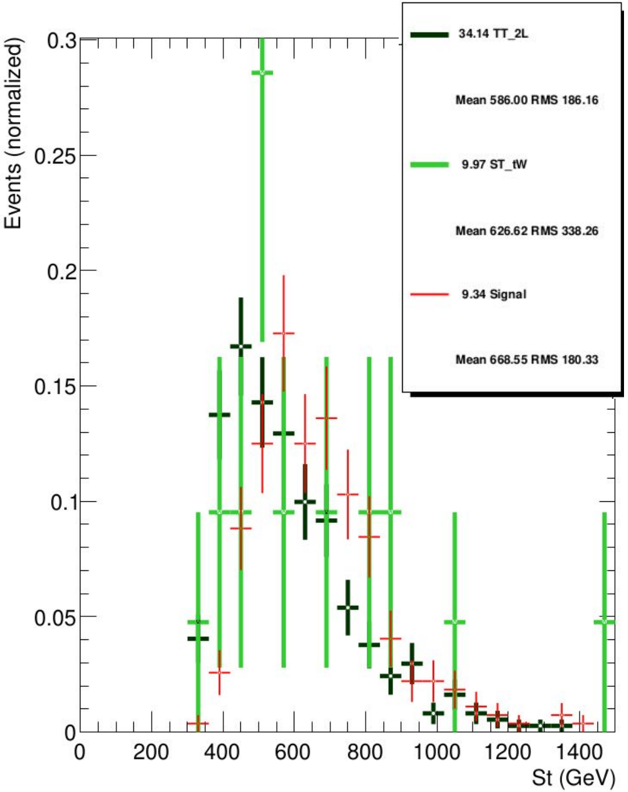


2e channel

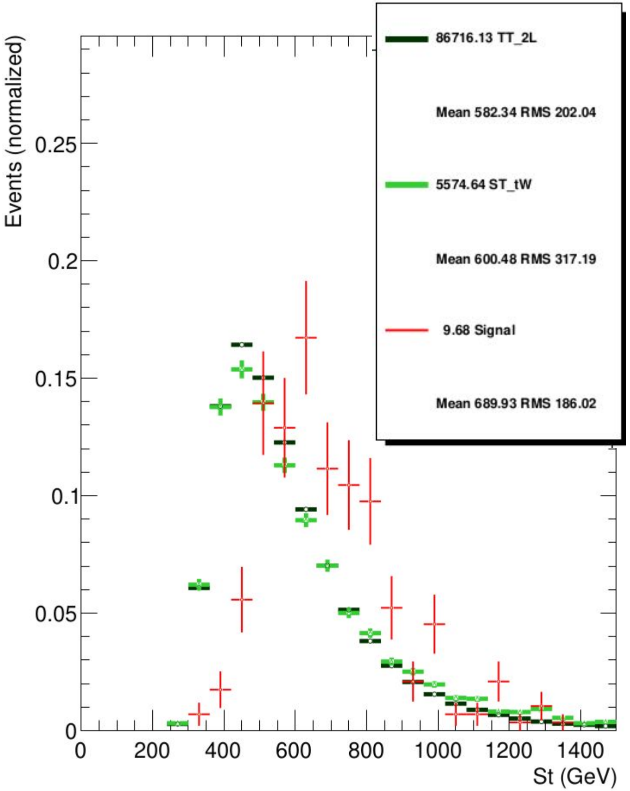


Total

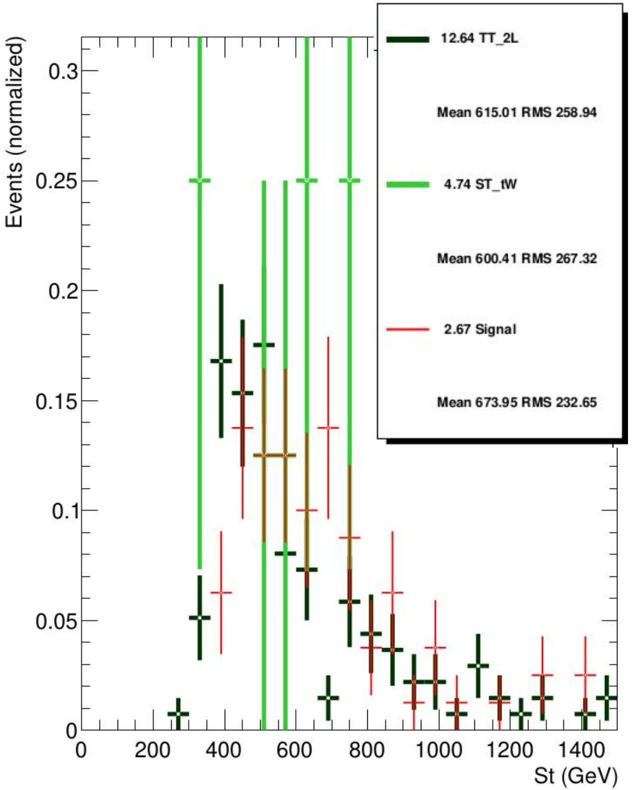
Control regions - TT_2L vs Single top



SR



CR TT_2L



CR ttX