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

PhD Days, 25 April 2023

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Motivation

- Completion of the Standard Model (SM) in 2012 with the discovery of Higgs boson.

- Limits of the SM:
    - Dark matter?
    - Neutrino's mass?
    - Higgs boson measured mass $m_H \approx 125$ GeV. ⟶ Hierarchy problem!

⟶ Solution: add a new particle in the model! ✓

- Vector-Like Quark (VLQ) T':
    - Interaction with the Higgs boson solve the hierarchy problem.
    - Expected invariant mass $m_{T'} \approx 1$ TeV (13 TeV in the center of mass of the LHC for 2016-2018).

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

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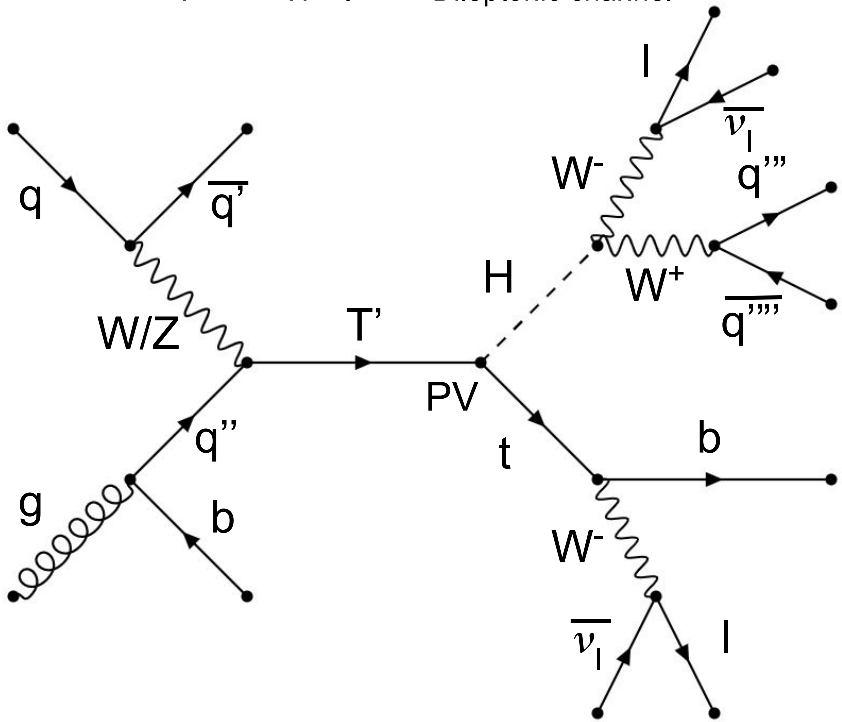
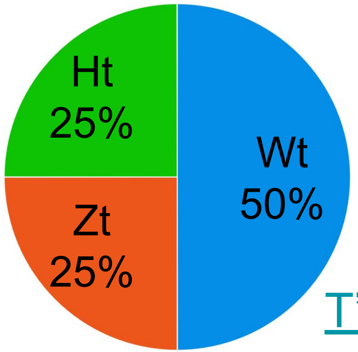
T’ production

T’ ⟶ H + t ⟶ Dileptonic channel

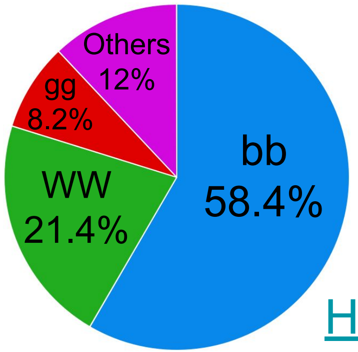


- Single T’ produced via electroweak process.



- W boson + top quark
- Z boson + top quark
- Higgs boson + top quark ✓

T’ decay

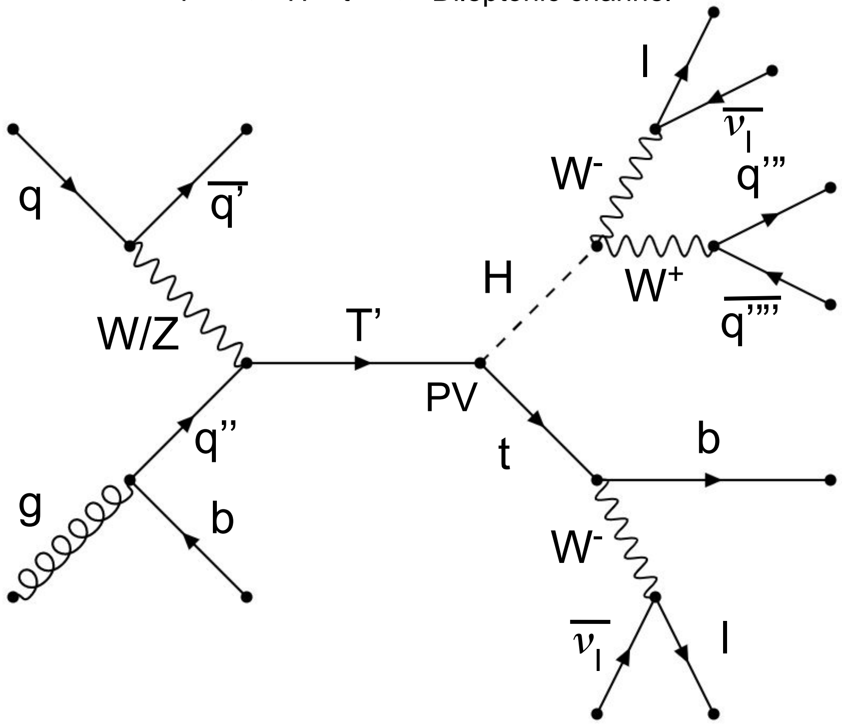


- Two b quarks
- Two W bosons ✓
- Two gluons
- Others (ττ, cc, ZZ, γγ…)

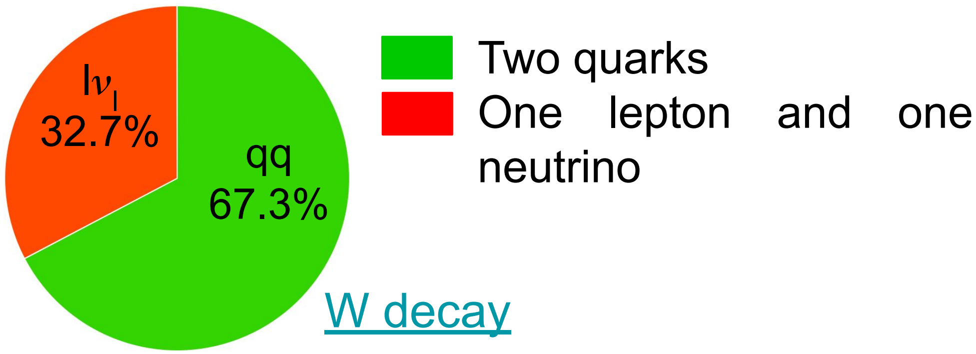
Higgs decay

T’ production

T’ → H + t → Dileptonic channel



- W leptonic or hadronic decay.

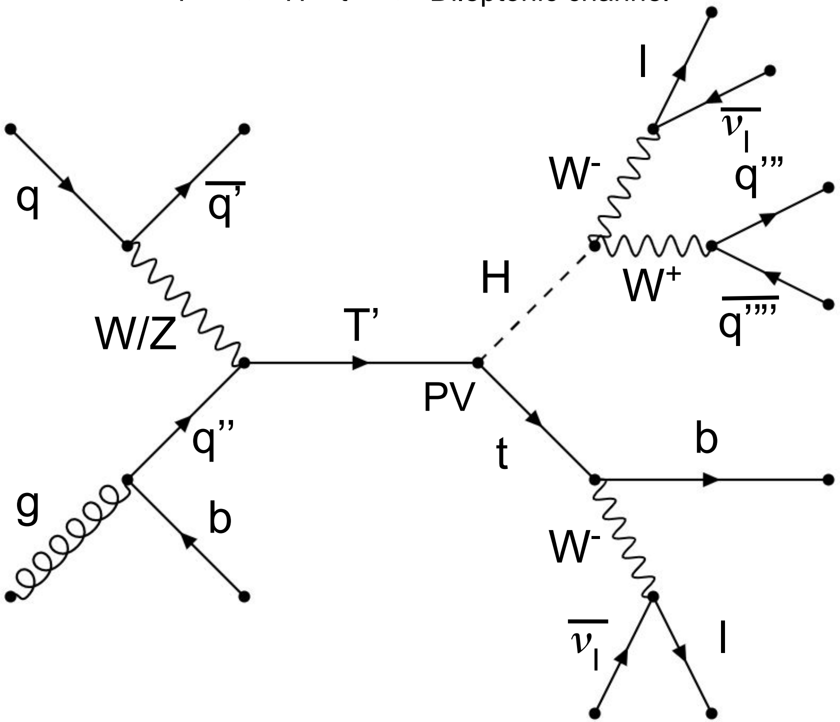


W decay

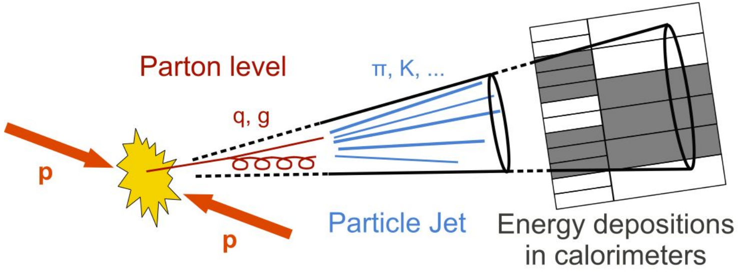
- Two leptons same sign (SS) in the finale state. → New analysis!
- NB: Excess published in the all-hadronic channel with 2016 data for $m_{T'}$ = 680 GeV.

Signal final state

T’ → H + t → Dileptonic channel



- Final state:
  - Two leptons SS.
  - Three jets with one b-jet.
  - Two neutrinos (not considered).



Creation of a jet

- Three channels:
  - Two muons.
  - One muon + one electron.
  - Two electrons.

What about the backgrounds?

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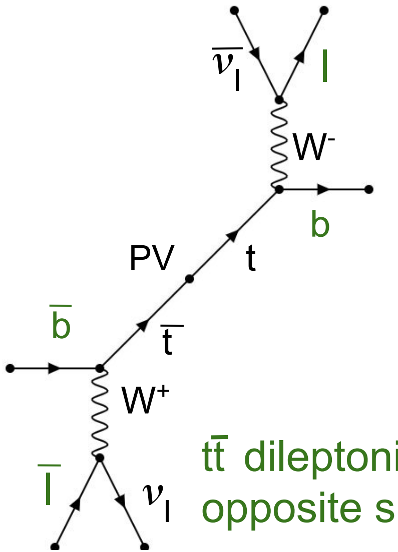
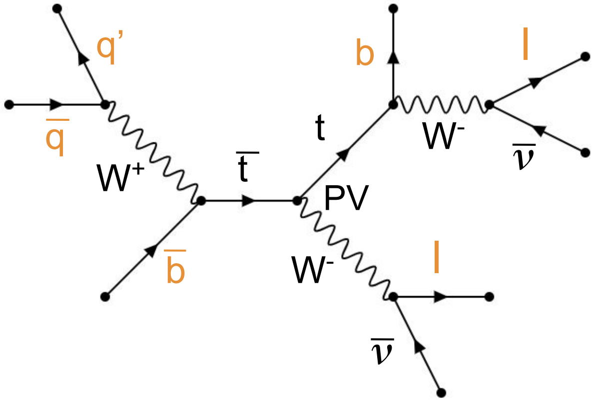
Signal vs backgrounds

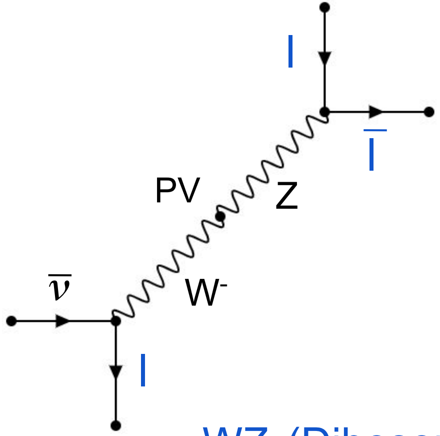
- Many processes with (almost) the same final state.



$t\bar{t}$ dileptonic ($t\bar{t}$): 1 or 2 leptons opposite sign (OS) and 2 b-jets.



ttW (ttX): 2 leptons SS and ⩾ 4 jets with 2 b-jets.



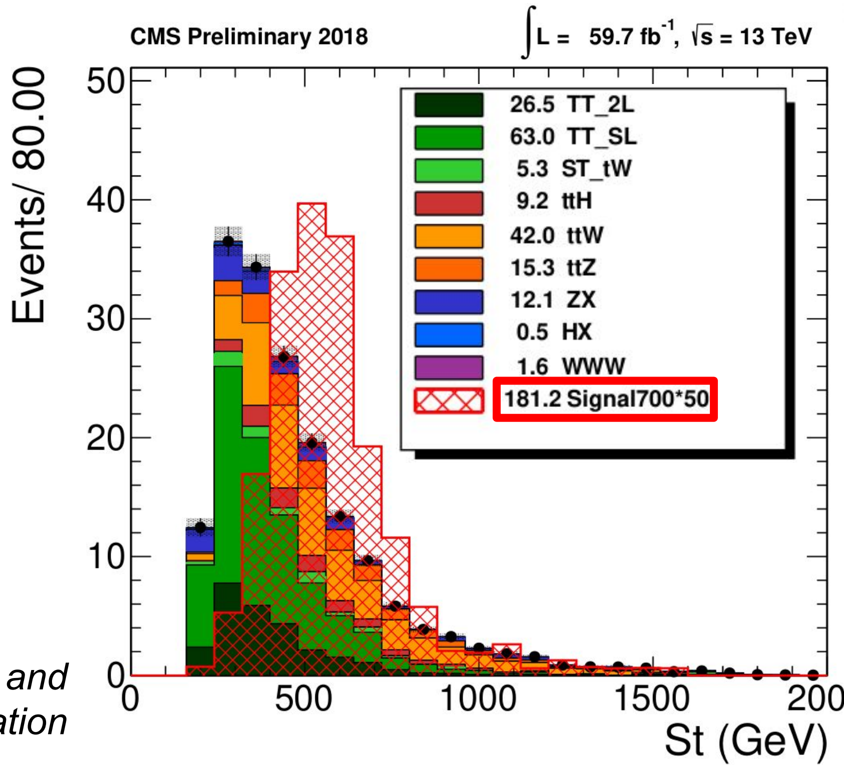
WZ (Diboson): ⩾ 2 leptons.

- Goal: get the main backgrounds under control.

→ New analysis strategy!

Analysis strategy

- Reducing $t\bar{t}$/Diboson/ttX.
- Looking for a resonance in the St = $\sum_{\text{leptons+jets}} Pt$ spectrum (Pt = transverse momentum).
- Estimation of the background:
  - Data-driven technique.
  - Fit of the smoothly falling St distribution.
- Optimized for $m_{T'}$ = 700 GeV.



St distribution for backgrounds and signal after object identification

Let's start with the object identification to reduce $t\bar{t}$ and diboson events!

Object identification

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

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

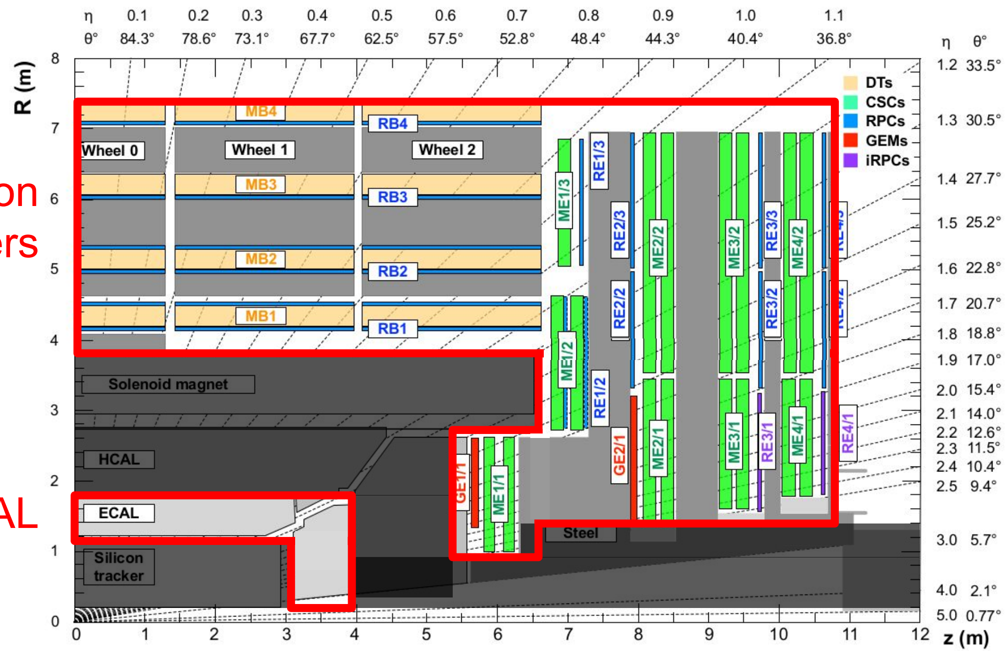
η = 0 for θ = 90°

η ⟶ ∞ for θ = 0°

- ○ Muon: Pt > 20 GeV, |η| < 2.4.
- ○ Electron: Pt > 25 GeV, |η| < 2.5.
- ○ Jet: Pt > 30 GeV, |η| < 4.5.
- ○ B-jet: Pt > 30 GeV, |η| < 2.5.

Muon chambers

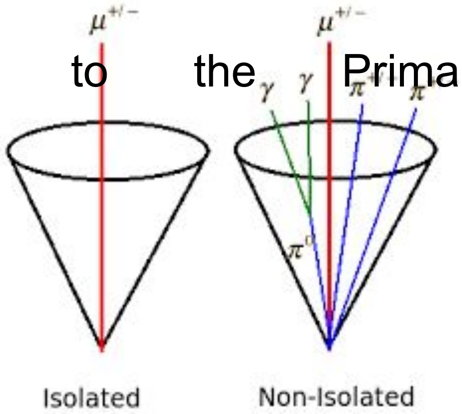
ECAL



[CMS structure](#)

Object identification

- Variables on study:
  - Identification (ID): based on a global algorithm (Particle Flow) that reconstructs all the particles thanks to the tracks, hits…
  - Isolation: leptons must be distant from other particles.
  - Impact parameter: leptons must be close to the Primary Vertex (PV).
  - Charge: leptons must have the correct electric charge.
  - Jet flavor: b-jets must be correctly identified.



Nature of a muon's isolation

We identify and ask for 2 leptons SS and ≥ 3 jets with ≥ 1 b-jet but we can go further!

Selection criteria

- The two leptons must be back-to-back.

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

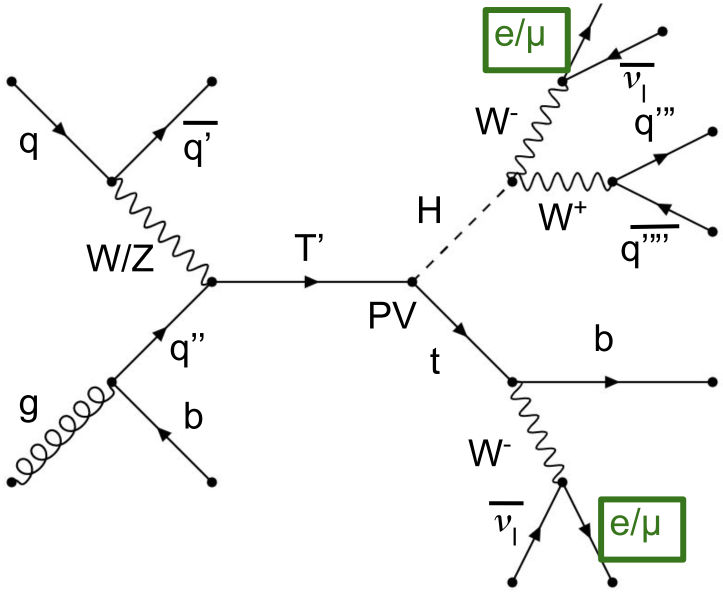
$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

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

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

→ $\sum_{\text{2 leptons}} Pt > f(St)$ where f is a function optimized to reduce all backgrounds (see next slide).

T' → H + t → Dileptonic channel

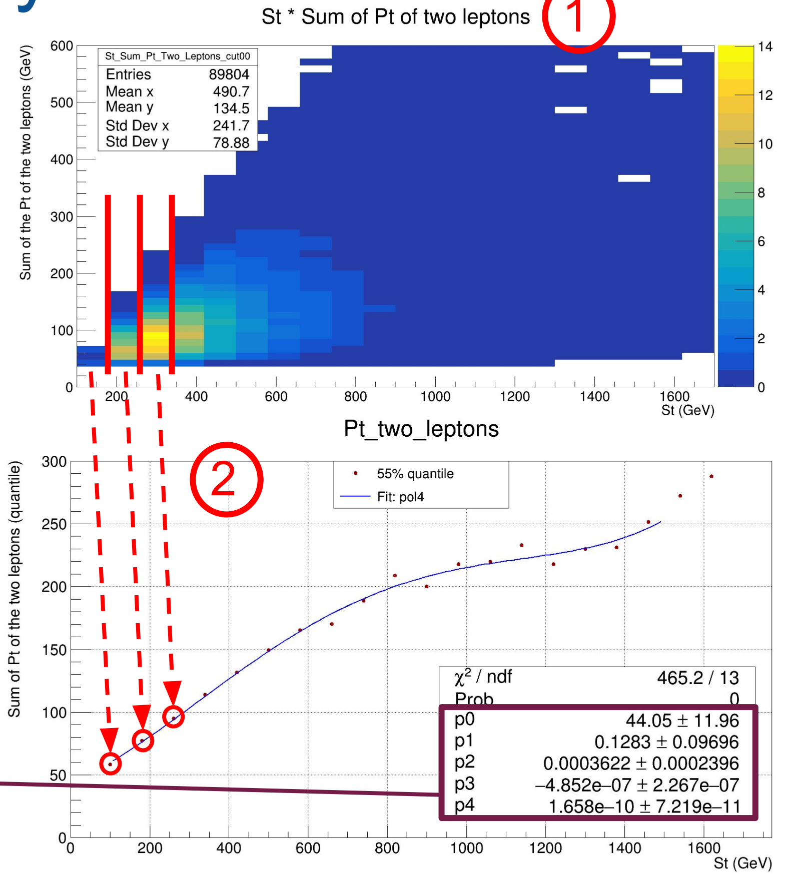


Optimization using quantiles of background yield

- Goal: optimize the cut value as a function of St to preserve the efficiency in each St bins.

- Pt of the two leptons (y-axis) vs St (x-axis) plotted in a 2D histogram for the background.
- Percentage of the background yield kept in each bin to plot the related 1D graph.
- Fit of the 1D graph thanks to a polynomial function.

⟶ New Cut that preserves the background shape!



$$\sum_{2\ \text{leptons}} Pt > f(St).$$

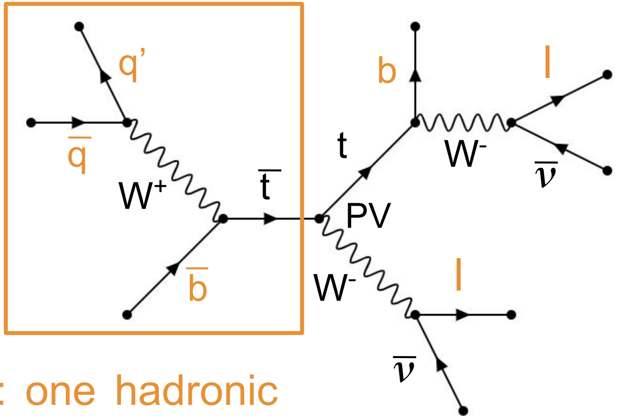
3

Selection criteria - ttX

- The top quark must have a non-hadronic decay.

→ $\mathrm{Min}(m_{bqq'} - m_{top}) > 34$ GeV (e.g. $m_{bqq'} \notin m_{top} \pm 2\sigma$[1])

to reduce ttX backgrounds.



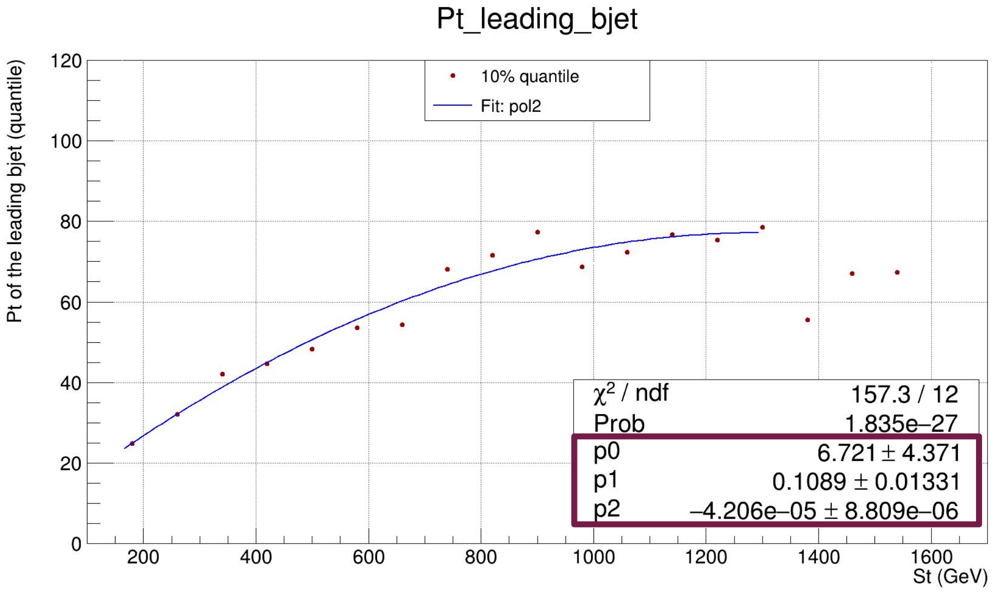
ttW (ttX): one hadronic top with $m_{bqq'} = m_{top}$

[1]: Internal analysis value.

Selection criteria

- We expect one b-jet with high Pt in the final state.

→ Pt of leading b-jet > f'(St) where f' is a function optimized to reduce all backgrounds.



Let's see the results with this selection!

Selection criteria - Results

Process	Signal	$t\bar{t}$	ttX	Diboson	Sum of Bkgs	S/B
No Cut	5.3E3	2.7E7	1.0E5	4.3E5	1.9E9	0.0003%
Cut 0: 2 leptons SS and ≥ 3 jets with ≥ 1 b-jet	9.9	872.3	508.4	59.6	1.5E3	0.65%
Cut 1: ΔR (leptons) > 1.8	9.2	597.7	341.7	37.7	1.0E3	0.89%
Cut 2: Sum of Pt of the two leptons > f(St)	5.3	175.1	155.8	22.5	377.3	1.40%
Cut 3: $Min(m_{bqq'} - m_{top})$ > 34 GeV	4.1	101.7	73.2	17.1	207.5	1.98%
Cut 4: Pt of leading b-jet > f'(St)	3.6	89.5	66.5	12.6	182.5	1.98%

- 99.997% ($t\bar{t}$, No Cut → Cut 0)
- 99.986% (Diboson, No Cut → Cut 0)
- 53.0% (ttX, Cut 2 → Cut 3)

- All channels with 2018 simulation considered.
- $t\bar{t}$ and ttX processes highly suppressed (S/B ≃ 2%) but remain the main backgrounds (49.0% and 36.4% respectively).

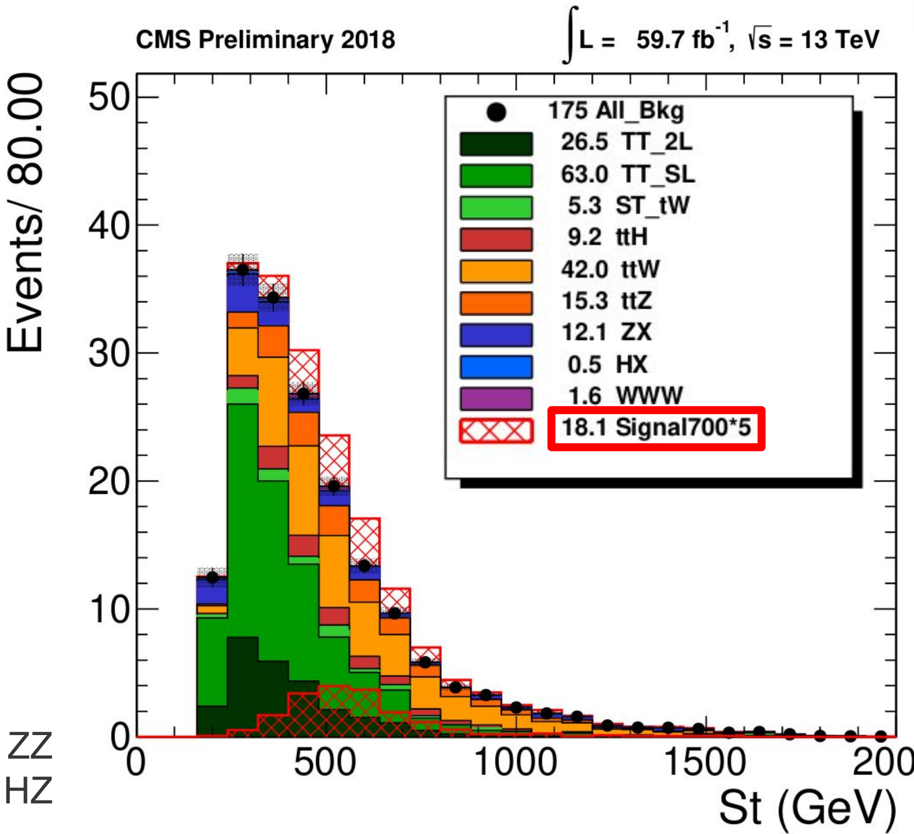
How about the St distribution?

St distribution

- Reminder: $St = \sum_{\text{leptons+jets}} Pt.$

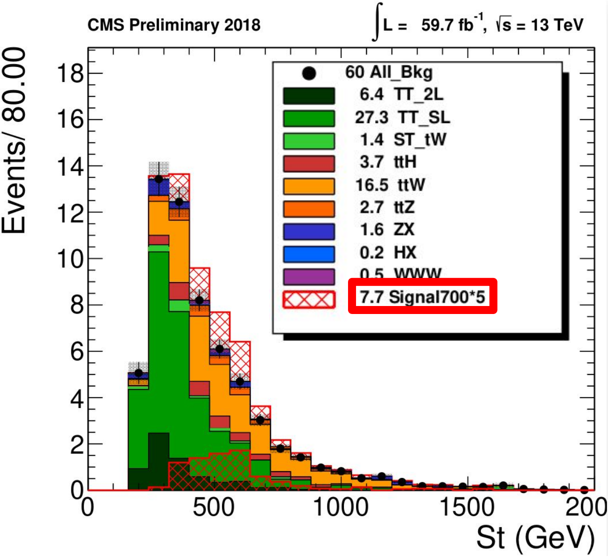
- Background shape smooth after the full selection and can be fitted.
- Signal spread over a too large range of momentum.

→ Investigate other variables.

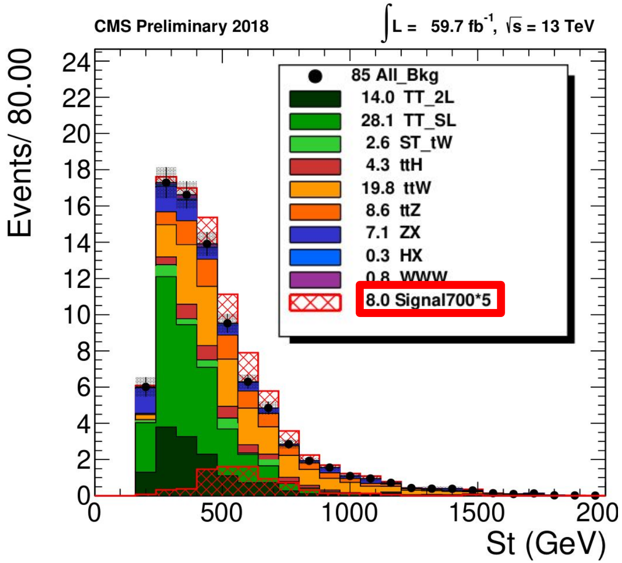


ZX = ZW + ZZ
HX = HW + HZ

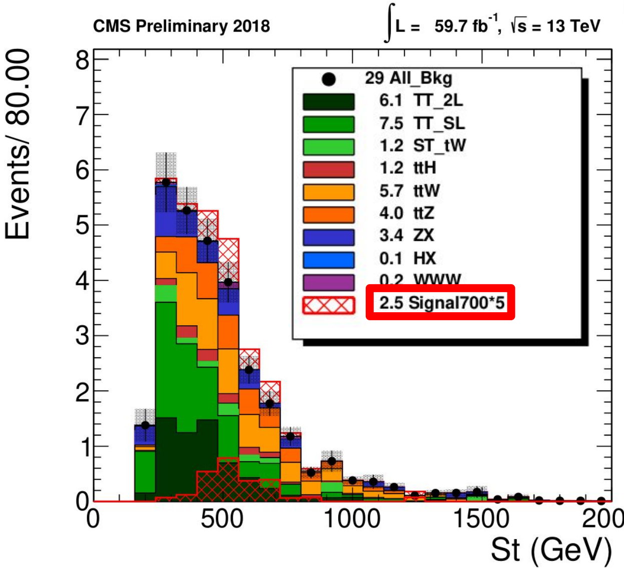
St distribution by lepton channels



2μ channel



1μ+1e channel



2e channel

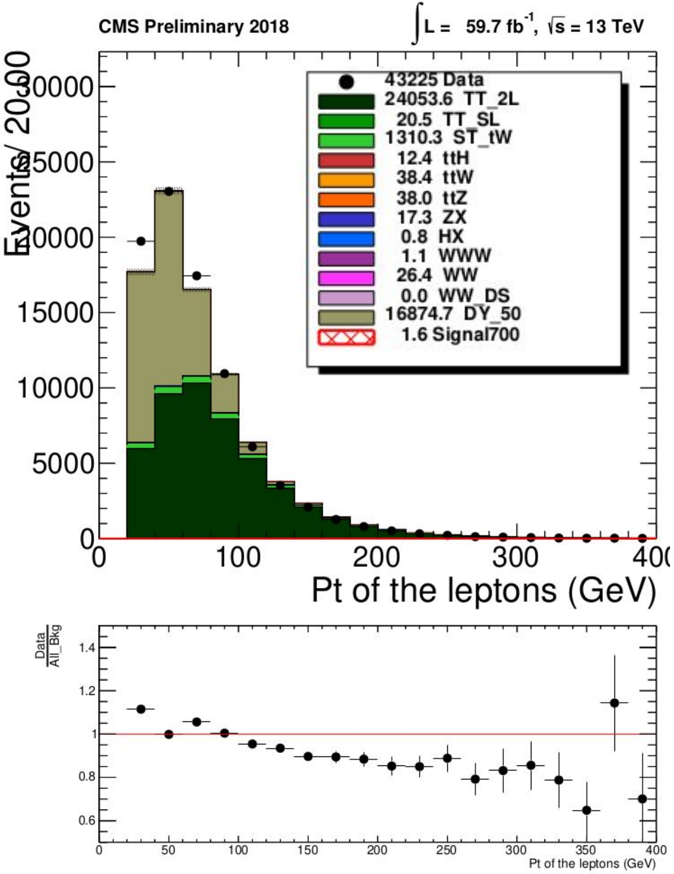
- Same conclusion for separated channels.
- Signal not visible in the dielectronic channel.

Let’s have a first look with real data!

Comparing data with simulation

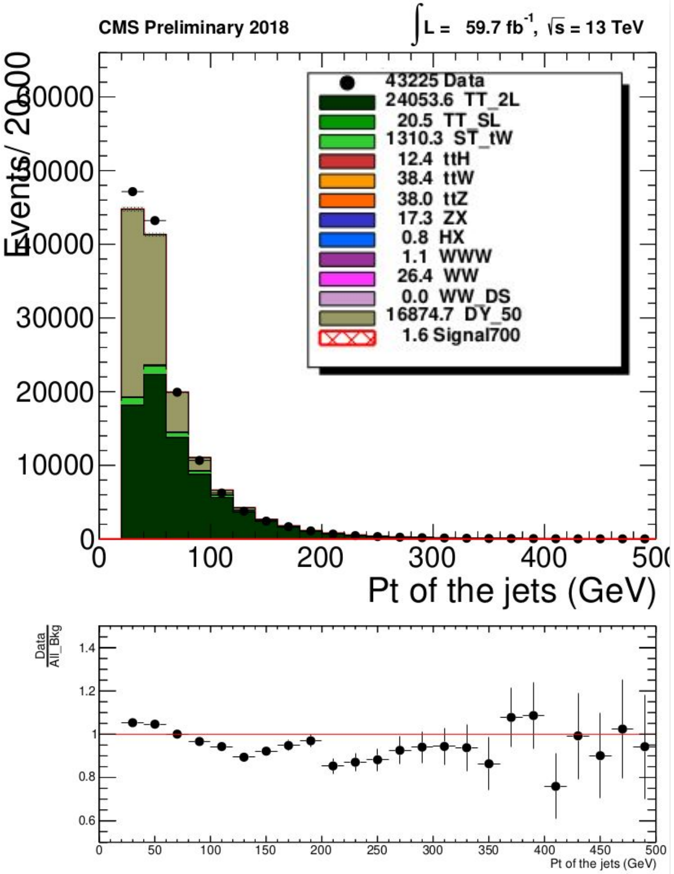
- First comparison between data and MC has been done for the dimuonic channel in the $t\bar{t}$ dileptonic control region (two leptons opposite sign).
- St variable 'blinded' for the moment.
- Data/MC agreement within 20% for the Pt of the leptons.

→ To be improved!



Comparing data with simulation

- Similar level of data/MC agreement for other variables studied (except St!).



Next steps

- Add the one muon + one electron and dielectronic channels for data/MC agreement.
- Add latest calibration corrections to improve the data/MC agreement.
- Estimate the expected sensitivity in the signal region.
- Perform the analysis by adding 2016 and 2017 samples.

Summary

- We focused on T’ $\longrightarrow$ top+H dileptonic SS final state analysis.
- Analysis strategy designed: multiple studies (object identification, cut selection and optimization by using percentages of the background yield).
- First data over MC comparison.
- We expect a finalized analysis strategy by the summer!


That's all Folks!

Back-up

VLQ production

- Several extensions of the Standard Model (SM) predict the existence of VLQs:
  - Spin ½ fermions.
  - Left-handed and right-handed components behave in the same way under the SM symmetry group.
  - Vector current couplings to the weak gauge bosons.
  - Non-Yukawa coupling mass-terms for VLQs are allowed.

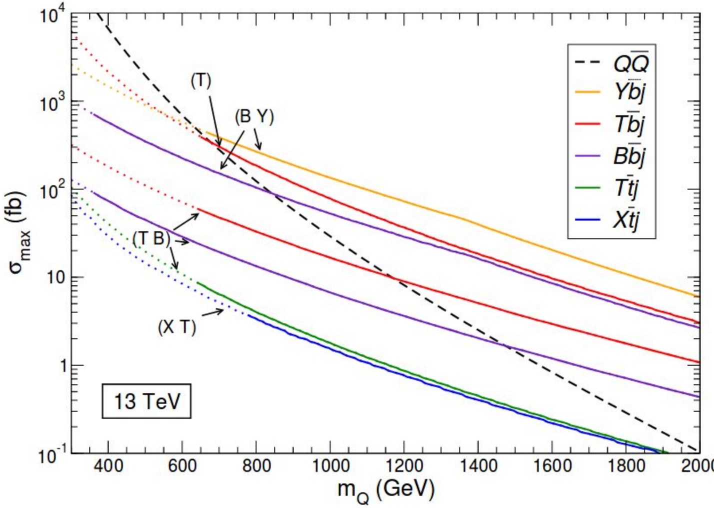
Type	Charge
X	+5/3
T	+2/3
B	-1/3
Y	-4/3

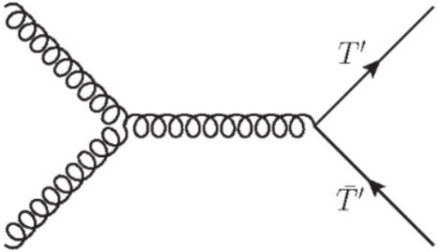
SU(2) Multiplets	
Singlets	T,B
Doublets	(T,B),(X,T),(B,Y)
Triplets	(X,T,B),(T,B,Y)

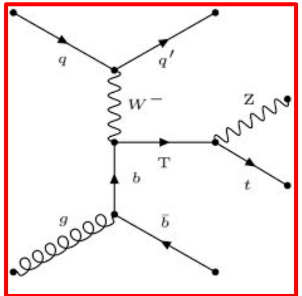
Slides from Francesco

VLQ production

- VLQs could be produced both singly and in pair:
  - Pair production:
    - Strong interaction processes.
    - Model independent cross section, suppressed for large VLQ mass.
  - Single production:
    - Electroweak processes.
    - Cross section depending on VLQ mass and coupling to SM particles.
    - Models foresee preferential mixing with 3rd generation SM quarks.

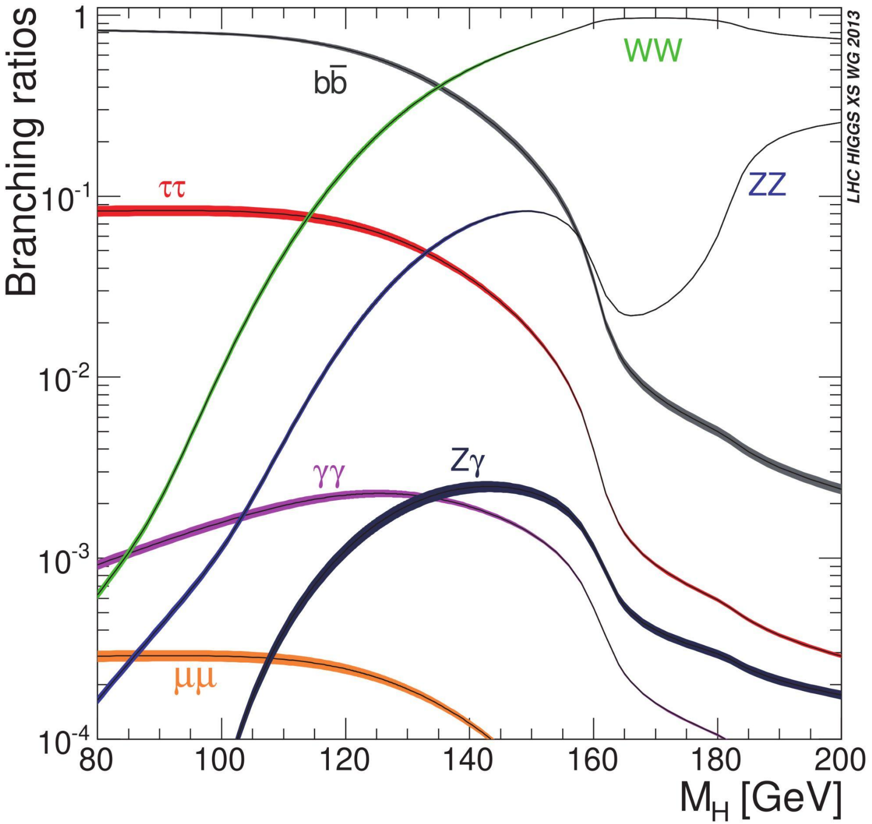






Type	Decay channel
X	tW
T	tZ,tH,tA,bW
B	bZ,bH,tW
Y	bW

Higgs boson branching ratio decay



Reference

Datasets (UL18, Luminosity = 59.7 fb^{-1})

Process	Cross-section (fb)	Number of events	Dataset name
Signal ($M_{T'}$ = 600 GeV)	176.4[1]	400,000	/TprimeBToTH_M-600*
Signal ($M_{T'}$ = 625 GeV)	148.9	400,000	/TprimeBToTH_M-625*
Signal ($M_{T'}$ = 650 GeV)	121.3	276,000	/TprimeBToTH_M-650*
Signal ($M_{T'}$ = 675 GeV)	105.0	400,000	/TprimeBToTH_M-675*
Signal ($M_{T'}$ = 700 GeV)	88.6	400,000	/TprimeBToTH_M-700*
Signal ($M_{T'}$ = 800 GeV)	45.9	397,000	/TprimeBToTH_M-800*
Signal ($M_{T'}$ = 900 GeV)	25.1	400,000	/TprimeBToTH_M-900*
Signal ($M_{T'}$ = 1000 GeV)	14.5	400,000	/TprimeBToTH_M-1000*

[1]: Github for the computation of the theoretical cross-sections (NWA)

* = _LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM

Datasets (UL18, Luminosity = 59.7 fb^{-1})

Process	Cross-section (fb)	Number of events	Dataset name
Signal ($M_{T'}$ = 1100 GeV)	8.67	400,000	/TprimeBToTH_M-1100*
Signal ($M_{T'}$ = 1300 GeV)	3.39	394,000	/TprimeBToTH_M-1300*
Signal ($M_{T'}$ = 1400 GeV)	2.19	400,000	/TprimeBToTH_M-1400*
Signal ($M_{T'}$ = 1500 GeV)	1.45	400,000	/TprimeBToTH_M-1500*
Signal ($M_{T'}$ = 1600 GeV)	0.974	367,000	/TprimeBToTH_M-1600*
Signal ($M_{T'}$ = 1700 GeV)	0.663	400,000	/TprimeBToTH_M-1700*
Signal ($M_{T'}$ = 1800 GeV)	0.458	400,000	/TprimeBToTH_M-1800*

No 1200 GeV mass point dataset for UL18.

* = _LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM

Datasets (UL18, Luminosity = 59.7 fb^{-1})

Process	Cross-section (fb)	Number of events	Dataset name
ttbar semileptonic	364,351	476,408,000	/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/*-v1/NANOAODSIM
ttbar dileptonic	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
ttH	271	7,328,993	/ttHToNonbb_M125_TuneCP5_13TeV-powheg-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
WZ	4,429.7	9,821,283	/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8/*-v2/NANOAODSIM
ZZ	1,256	98,488,000	/ZZTo4L_TuneCP5_13TeV_powheg_pythia8/*-v2/NANOAODSIM

* = RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1

Datasets (UL18, Luminosity = 59.7 fb^{-1})

Process	Cross-section (fb)	Number of events	Dataset name
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
WW Deep Scattering	170.3	500,000	/WWTo2L2Nu_TuneCP5_DoubleScattering_13TeV-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

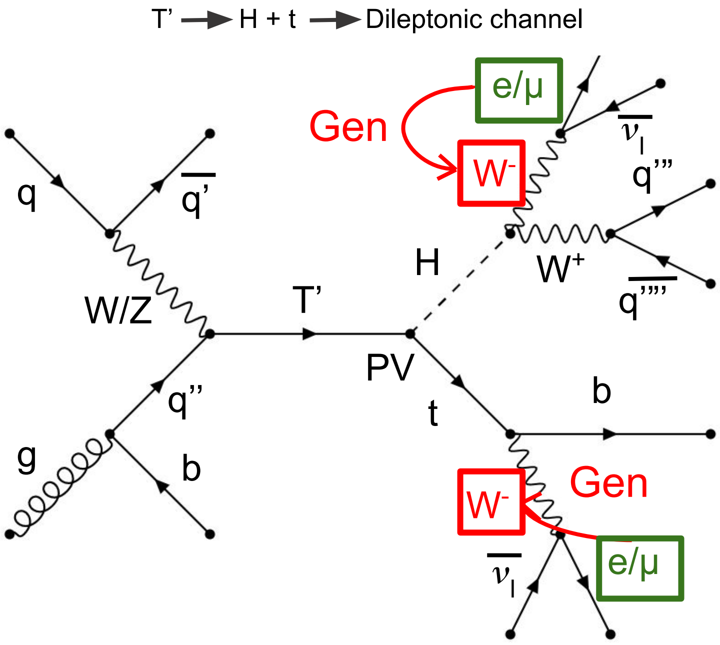
Number of scaled events = $\frac{\text{Number of events after selection multiplied by all the weights}}{\text{Number of events before selection multiplied by generator weights}}$ *Cross section*Luminosity

Cross section: Interaction probability for a given particle for a given reaction (fb)

Luminosity: Number of collisions detected by CMS (fb^{-1}, 59.7 fb^{-1} for 2018)

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



Trigger selection

- List of the trigger HLT paths for the different channels:
  - HLT_IsoMu24.
  - HLT_Ele32_WPTight_Gsf.
  - HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8.
  - HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ.
  - HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL.
  - HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL.

Muon identification

- List of additional studied variables:
  - Phi.
  - 3D impact parameter ip3d.
  - Mini PF relative charged isolation = Pt of muon/ $\sum_{R_{iso}}$(Pt of all charged particles): loose < 0.10, tight < 0.05[1].
  - PF relative 0.3 isolation = $\sum_{R\,=\,0.3}$ (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 = $\sum_{R\,=\,0.3}$ (Pt of charged hadrons) / Pt of muon: loose < 0.10, tight < 0.05[2].
  - PF relative 0.4 isolation = $\sum_{R\,=\,0.4}$ (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.
  - $\Delta\eta$ 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:
  - Pt > 25 GeV, |η| < 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 (|η| < 1.479) and < 0.03 in endcap (|η| > 1.479).
  - $\frac{\text{Electron energy}_{HCAL}}{\text{Electron energy}_{ECAL}} < 0.1.$
  - $\frac{1}{\text{Electron energy}_{ECAL}} - \frac{1}{Pt_{tracker}} < -0.04.$
  - 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%

Jet identification

- Cleaning of the jets in a cone of $\Delta R < 0.4$ with loose leptons:
  - Loose electron: Pt > 25 GeV, $|\eta| < 2.5$, loose ID, isolation loose, very tight sip3Dand tight charge.
  - Loose muon: Pt > 20 GeV, $|\eta| < 2.4$, tight ID, isolation loose, tight sip3D and tight charge.

Corrections/Filters

- List of corrections already applied:
  - Generator weights.
  - Pileup weights.
  - B-tag weights (performed with the Method 1d of the documentation).
  - Jet energy corrections.
- List of corrections to apply in the future:
  - Jet energy resolution.
  - Missing Transverse Energy (MET) corrections.
  - Lepton ID/Isolation/Trigger weights.
- Filters for 2018 applied:
  - Flag_goodVertices
  - Flag_globalSuperTightHalo2016Filter
  - Flag_HBHENoiseFilter
  - Flag_HBHENoiseIsoFilter
  - Flag_EcalDeadCellTriggerPrimitiveFilter
  - Flag_BadPFMuonFilter
  - Flag_eeBadScFilter
  - Flag_ecalBadCalibFilter

Object identification - Summary

Muon	Pt > 20 GeV, |η| < 2.4, tight ID, tight isolation, tight sip3D, tight charge.
Electron	Pt > 25 GeV, |η| < 2.5, tight ID, tight isolation, very tight sip3D, tight charge.
Jet	Pt > 30 GeV, |η| < 4.5, tight ID. The overlap with the leptons is removed in a cone of ΔR < 0.4 (see backup).
B-jet	Pt > 30 GeV, |η| < 2.5, tight ID, medium DeepJet b-tag. Identical overlap condition as the jets.

← B-jet identification discriminant. Three values: loose, medium or tight. ✓

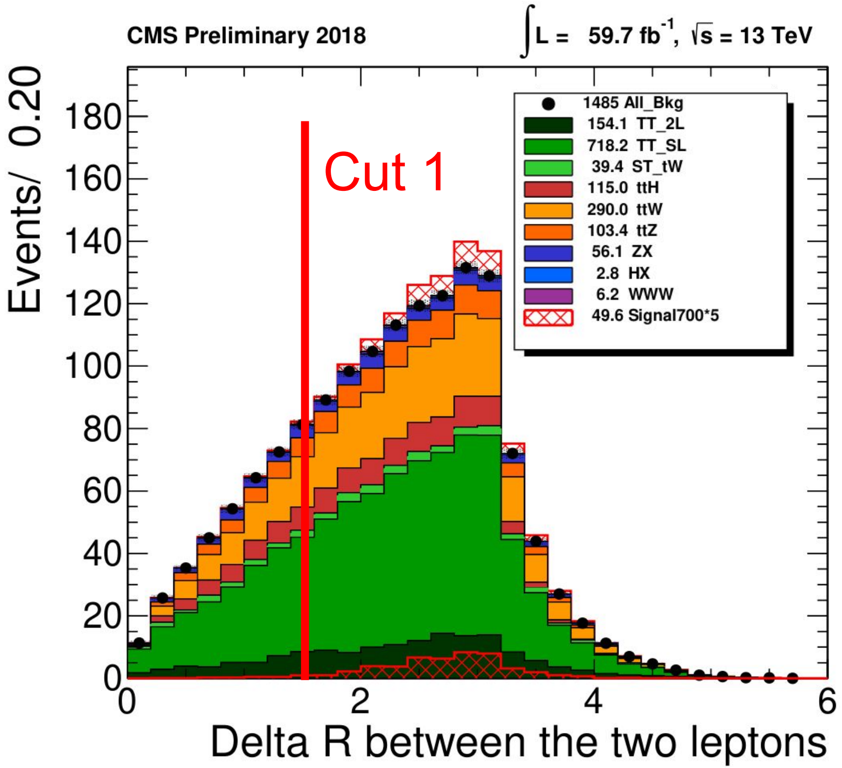
$$\frac{\sum_{R_{iso}} (\text{Particles}) - Pt(\text{lepton})}{Pt\ (\text{lepton})} < 0.05 \text{ (tight)}$$

where (R_{iso} = 10 GeV /Pt (lepton)) is the cone size.

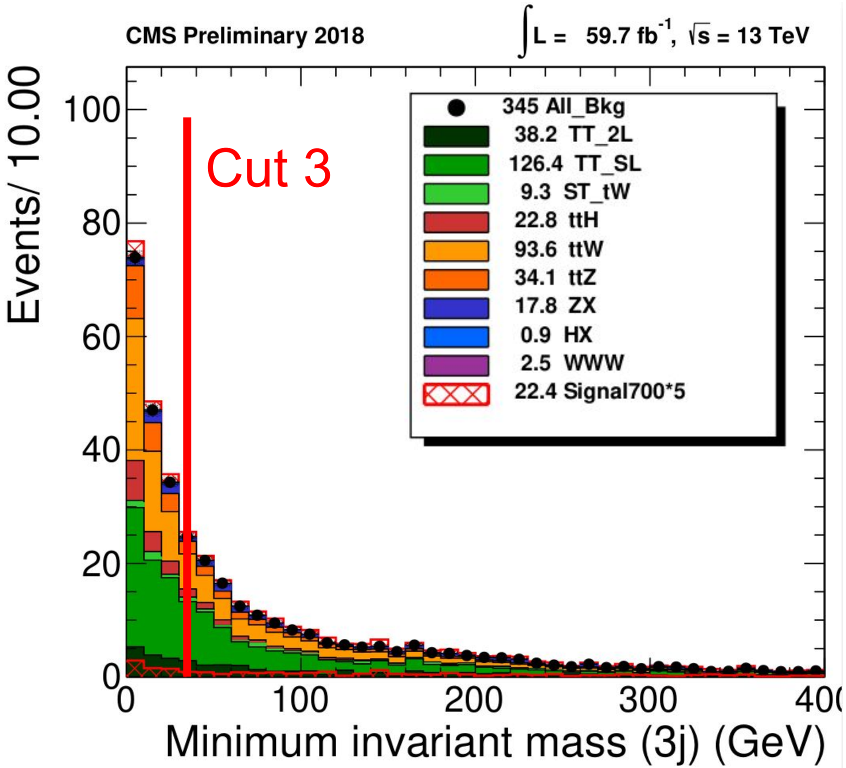
Selection criteria

- List of additional studied variables:
  - Pt of 1^{st} and 2^{nd} lepton.
  - Pt of sum of the two leptons.
  - Δφ between the two leptons.
  - Mass of sum of the two leptons.
  - Pt of 1^{st}, 2^{nd} and 3^{rd} jet.
  - Ht = Sum of Pt of the jets.

Selection criteria



Cut 1: ΔR (leptons) > 1.8



Cut 3: Min($m_{bqq'}$ - m_{top}) > 34 GeV

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Selection criteria - Results

	Signal (600 GeV)	Signal (625 GeV)	Signal (650 GeV)	Signal (675 GeV)	Signal (700 GeV)	Signal (800 GeV)	Signal (900 GeV)	Signal (1 TeV)	Signal (1.1 TeV)	Sum of backgrounds
Cut 0	20.3	15.7	12.6	12.7	9.9	5.4	3.1	1.8	1.0	1.5E3
Cut 1	17.9	14.1	11.4	11.6	9.2	5.1	3.0	1.7	1.0	1.0E3
Cut 2	10.0	7.6	5.7	6.4	5.3	3.1	2.0	1.1	0.7	377.3
Cut 3	7.5	6.1	4.6	5.0	4.1	2.6	1.7	0.9	0.6	207.5
Cut 4	6.6	5.6	4.0	4.6	3.6	2.3	1.5	0.9	0.5	182.5

Signal (1.3 TeV)	Signal (1.4 TeV)	Signal (1.5 TeV)	Signal (1.6 TeV)	Signal (1.7 TeV)	Signal (1.8 TeV)	Sum of backgrounds
0.4	0.2	0.14	0.09	0.06	0.04	1.5E3
0.4	0.2	0.14	0.09	0.06	0.04	1.0E3
0.3	0.16	0.10	0.07	0.04	0.03	377.3
0.2	0.14	0.09	0.06	0.04	0.03	207.5
0.2	0.13	0.08	0.05	0.03	0.02	182.5