CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)

Run / Event: 139779 / 4994190

Four Tops in Hadronic Tau Channel and VLL Search

— A full status report

Huiling HUA

On behalf of 4tops hadronic tau team

Anshul Kapoor, Huiling Hua, Hongbo Liao, Ruobing Tu

TTX meeting

October 23rd, 2024

tttt

1 The beginning

2 Objects and triggers

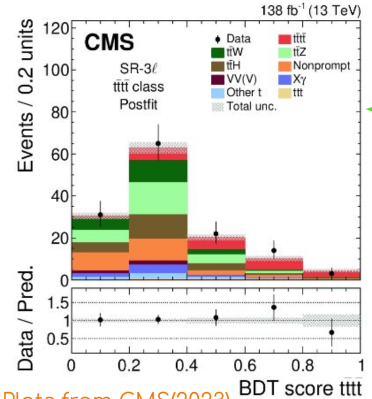
3 Background estimation

4 Signal extraction

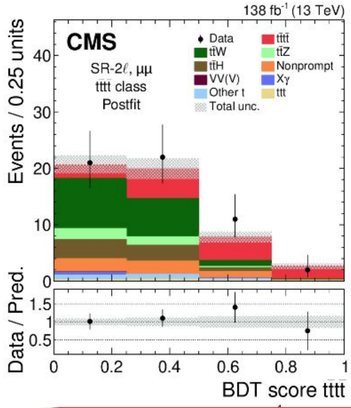
5 Search for VLL

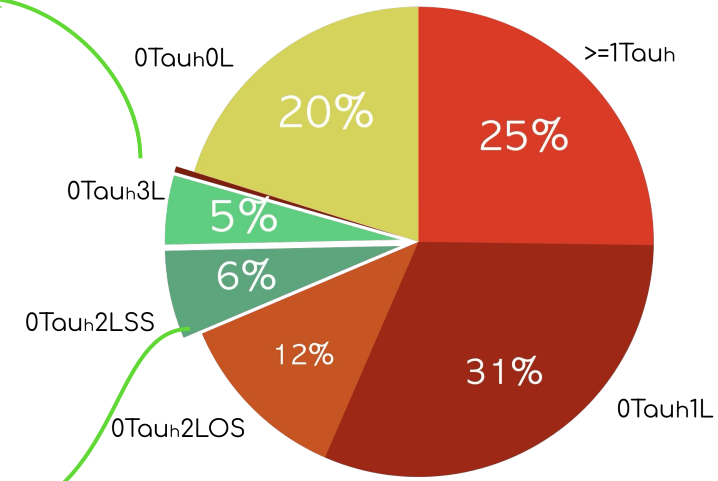
6 The end

Who is the next to 'see' four tops?



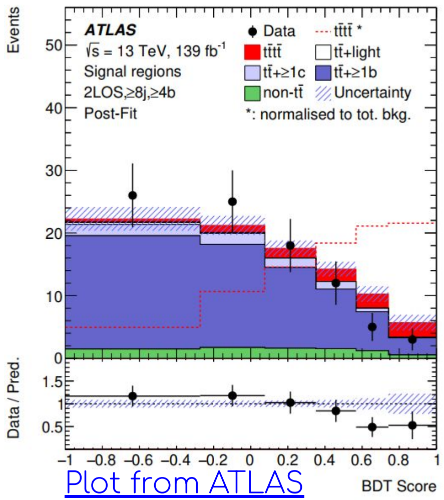
[Plots from CMS(2023)](#)



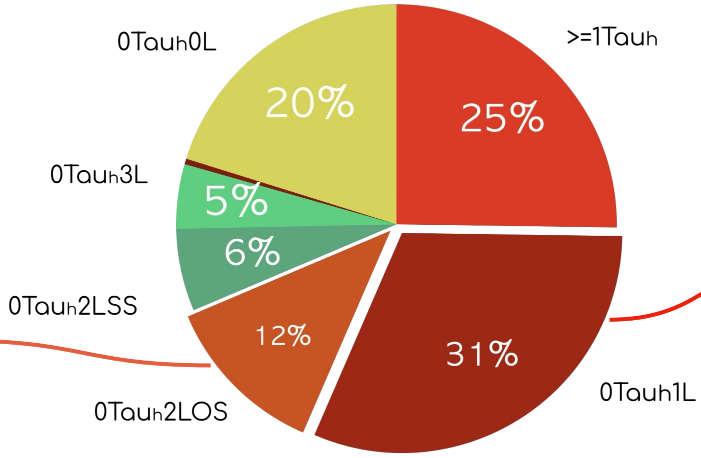


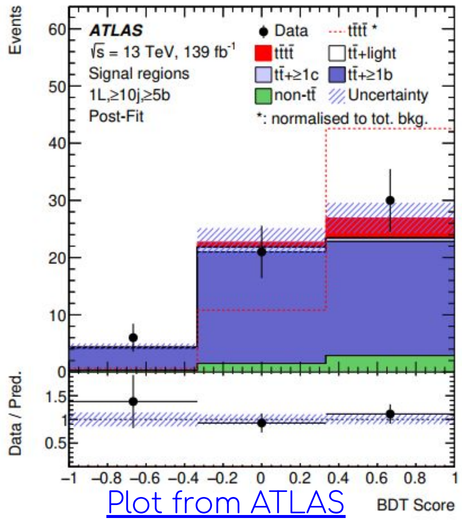
- SS and ML channel made the discovery last year
  - ATLAS and CMS both
  - Expected significance 4.9(5.6 observed)
  - No tau_h exclusion
- Only accounts for 11% of 4 tops branching ratio
- Better precision measurement calls for more 4 tops to be seen
- Which channel is going to be the next candidate?

Is it going to be single lepton channel?



[Plot from ATLAS]

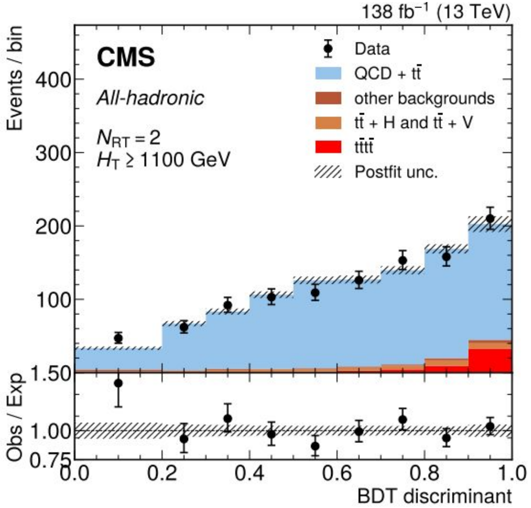


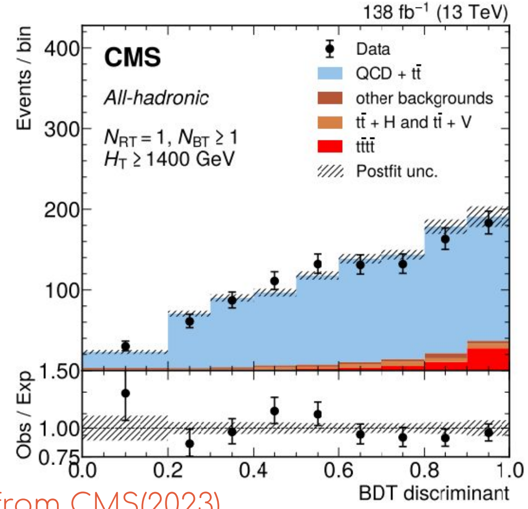


[Plot from ATLAS]

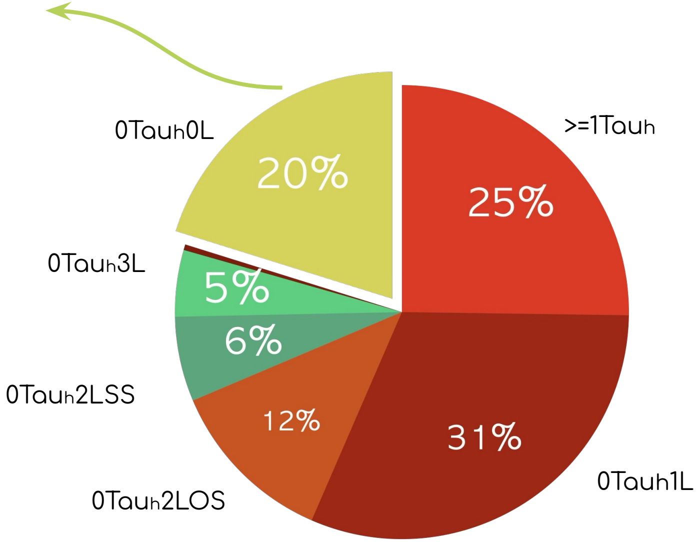
- Single lepton(SL) + 2 leptons opposite sign(2OS)
- CMS: [SL+2OS], only 2016 data
  - Expected significance 0.4 with 2016 data
- ATLAS: SL+2OS, full run 2
  - Expected significance 1.0(1.9 observed)
  - TT as major background

Is it going to be hadronic channel?



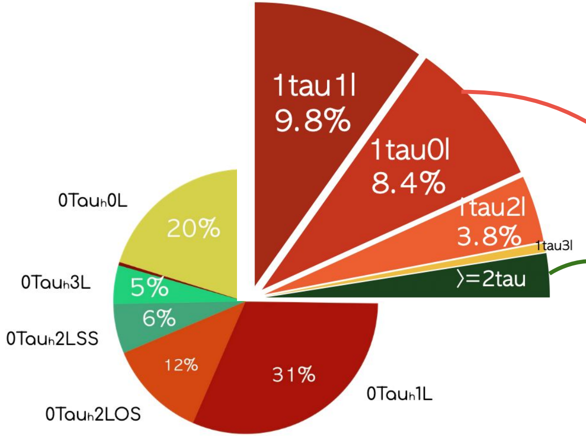


Plots from CMS(2023)



- Only results from CMS
- Expected significance: 0.4(observed 2.5)
- Ongoing effort in CMS with run 3

We bet on hadronic tau channel!



- Substantial branching ratio 25%
- Rich signatures of taus, leptons and jets
- Divide into subchannels: 1tau1l, 1tau0l, 1tau2l
- Tau efficiency not so great compared with leptons
- Analysis requires care to save signal acceptance
- Tau trigger efficiency not ideal, hardronic and leptonic triggers used instead
- Background most sensitive to tau fake rate

- No hope in 1tau3l and >=2tau
- 1tau3l: branch ratio too low
- >=2 tau: tau efficiency too low

Analysis strategy overview

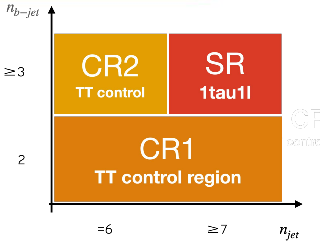
baseline

HT>500(480) GeV; n_{jet}>6
6th jet p_T>40(38) GeV
$n_{b\text{-}jet}$>=2

1tau1l SR

hadronic triggers*
n_{tau}=1; n_{lepFT}=1
n_{jet}>=7; $n_{b\text{-}jet}$>=3

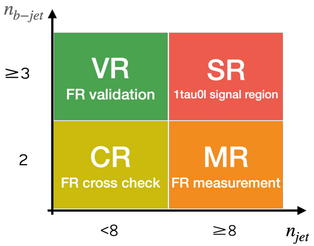
- sensitive channel
- tt as major background
- BDT with b-tag WP



1tau0l SR

hadronic triggers*
n_{tauFT}=1; n_{lep}=0
n_{jet}>=8; $n_{b\text{-}jet}$>=3

- least sensitive channel
- tt and QCD major background
- BDT with b-tag shape

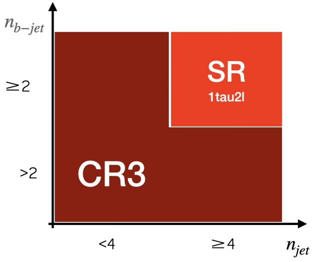


baseline → **1tau2l SR**

HT>200 GeV; n_{jet}>=4;
$n_{b\text{-}jet}$>=2; n_{Ftau}>=1

Leptonic triggers*
n_{tau}=1; n_{lepFT}=2
n_{jet}>=4; $n_{b\text{-}jet}$>=2

- sensitive channel
- tt and ttX major background
- BDT with b-tag WP



1 The beginning

2 Objects and triggers

3 Background estimation

tttt

4 Signal extraction

5 Search for VLL

6 The end

Object definition

Observable	tight muon	fakeable muon
pT	10 GeV	10 GeV
$\|\eta\|$	< 2.4	< 2.4
d_{xy}(cm)	< 0.05	< 0.05
d_z(cm)	< 0.1	< 0.1
SIP_{3D}	< 8	< 8
Muonn POG ID	Medium	Medium
Top-UL Lepton MVA(v1)	> 0.64	> 0.64 or
		($b - score_{matched\ jet} < 0.025$ and $p_T^{ratio} > 0.45$)

Observable	fakeable tau	tight tau
pT	20 GeV	20 GeV
$\|\eta\|$	$< 2.3(2.5)$	$< 2.3(2.5)$
$\|d_z\|$	< 0.2	< 0.2
Decay modes find	New	New
Decay modes	except 5 and 6	except 5 and 6
DeepTau vs jet	WP_VVLoose	WP_Medium
DeepTau vs electron	WP_VVVLoose	WP_VVLoose
DeepTau vs muon	WP_VLoose	WP_VLoose

Observable	tight electron	fakeable electron
pT	> 10 Gev	> 10 GeV
$\|\eta\|$	$< 2.5(1.442 < \|\eta\| < 1.566\ veto)$	$< 2.5(1.442 < \|\eta\| < 1.566\ veto)$
d_{xy}(cm)	0.05	0.05
d_z(cm)	0.1	0.1
SIP_{3D}	< 8	< 8
I_{rel}	0.4	0.4
conversion veto	yes	yes
missing inner hits	$<= 1$	$<= 1$
Top-UL Lepton MVA(v1)	> 0.81	> 0.81 or (EGammaMVAID=Loose and
		$b - score_{matched\ jet} < 0.1$ and $p_T^{ratio} > 0.5(0.4)$)

Observable	jet
pT	25
$\|\eta\|$	2.4
ID	tight ID
DeepJet	medium WP(medium b-jet)
DeepJet	tight WP(tight b-jet)

- Lepton definition same as that of SS&ML of tttt

Different channels, different triggers

Trigger	act. lumi(fb-1)	eff lumi	first run	last run	dataset
2018					
HLT_PFHT380_SixPFJet32_DoublePFBTagDeepCSV_2p2	17.7	17.7	315252	317488	jetHT
HLT_PFHT400_SixPFJet32_DoublePFBTagDeepCSV_2p94(MC)	42.1	42.1	317509	325175	jetHT
HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5	5.3	5.3	315252	315973	jetHT
HLT_PFHT430_SixPFJet40_PFBTagDeepCSV_1p5	12.4	12.4	315974	317488	jetHT
HLT_PFHT450_SixPFJet36_PFBTagDeepCSV_1p59(MC)	42.1	42.1	317509	325175	jetHT
HLT_PFHT330PT30_QuadPFJet_75_60_45_40_TriplePFBTagDeepCSV_4p5(MC)	59.8	59.8	315252	325175	jetHT

1tau1l SR

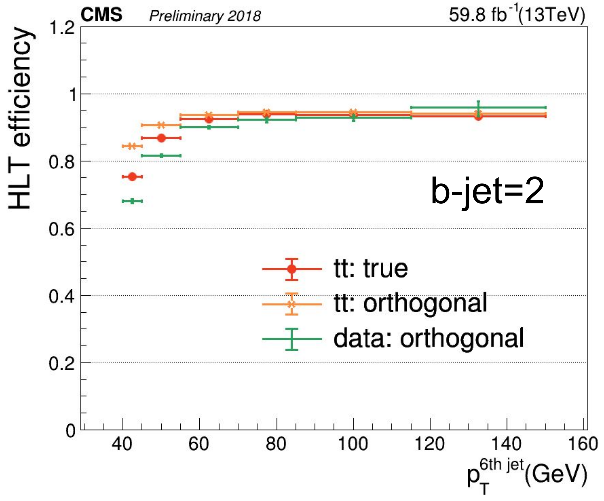
1tau0l SR

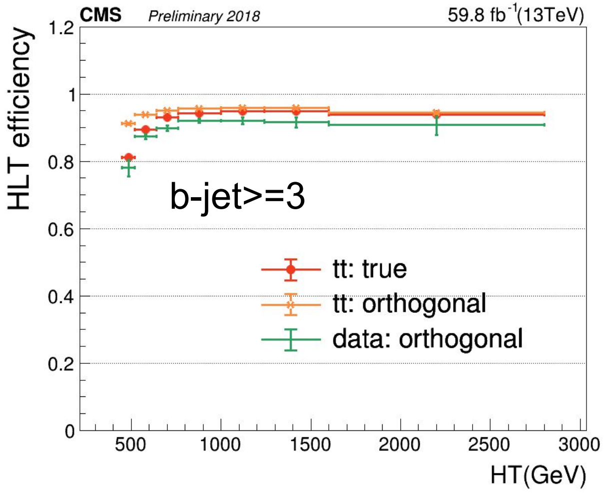
- Hadronic triggers used to capture signal events
- HT380+6jet+2btag || HT450+6jet+1btag|| HT330+4jet+3btag
- More efficient than single tau or lepton+tau triggers: 0.6
- Drives the cut of pT of 6th jet

1tau2l SR

- Single lepton || double lepton triggers used in 1tau2l
- The same as that of SS of four tops analysis
- Highly efficient for 4tops signal: 0.93 acceptance

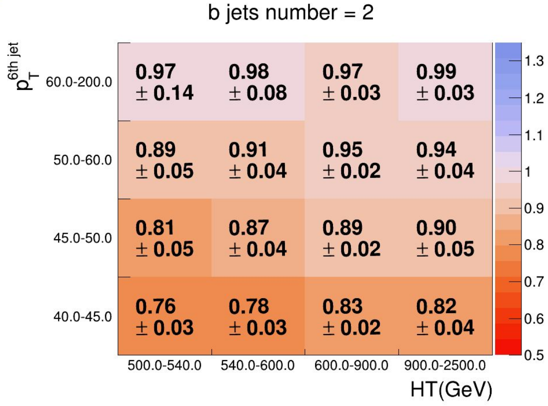
Efficiency measurement for hadronic triggers

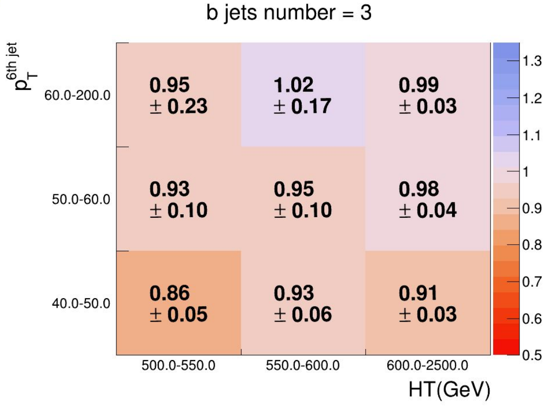


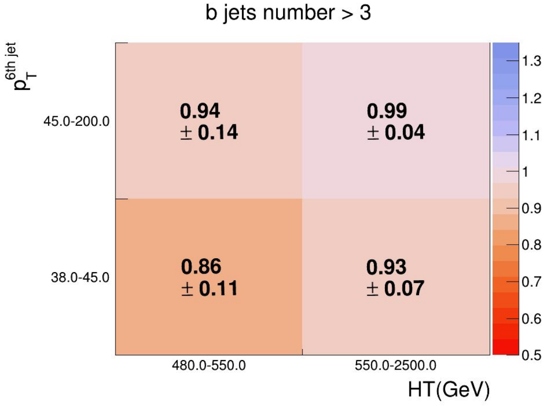


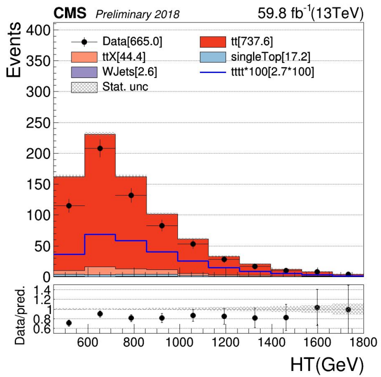
- Orthogonal method for measuring hadronic trigger efficiency
  - Orthogonal trigger HLT_IsoMu24(HLT_Iso27 in 2017)
- Denominator
  - n_{jet}>=6, $n_{b\text{-}jet}$>=2, HT>500 GeV(480 if $n_{b\text{-}jet}$>=3), 6th jet pt> 40 GeV(35 if $n_{b\text{-}jet}$>=3)
  - muon>=1, mu pT>=26 GeV(29 for 2017), HLT_IsoMu24(27 for 2017)
- Trigger drives baseline selection

Trigger scale factor and validation

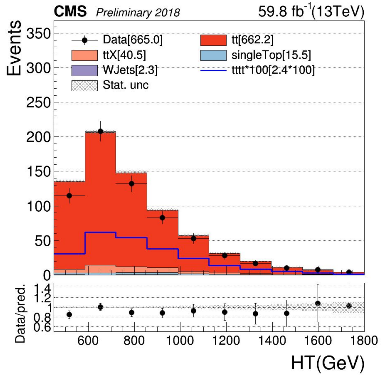








Applying trigger SF



1 The beginning

2 Objects and triggers

3 Background estimation

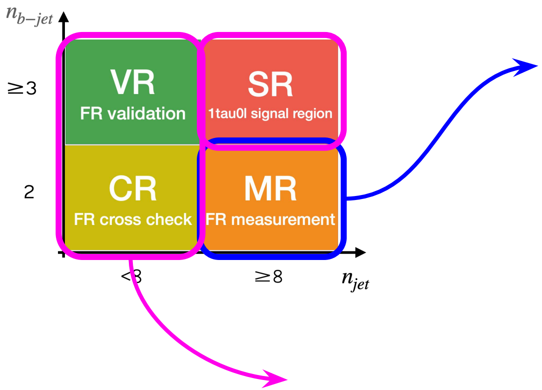
tttt

4 Signal extraction

5 Search for VLL

6 The end

Fake tau estimation: one fake object

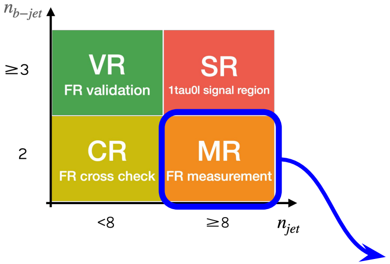


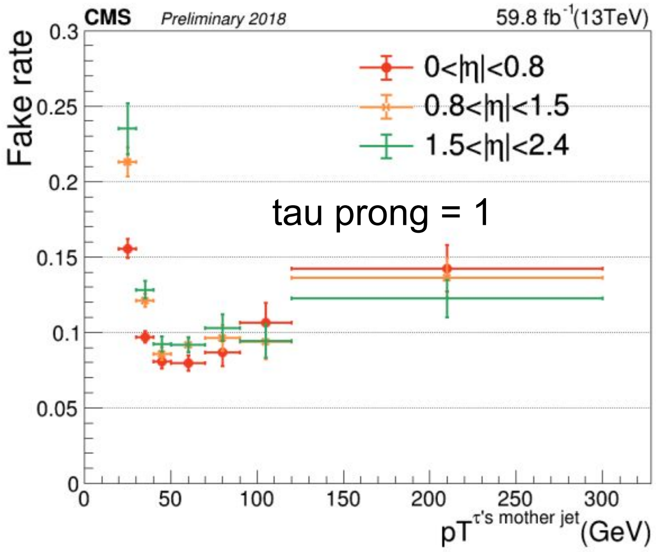
- Define fake rate $FR = \frac{N^{notGen\tau}_{T\tau}}{N^{notGen\tau}_{F\tau}} = \frac{N^{data}_{T\tau} - N^{gen\tau}_{T\tau}(MC)}{N^{data}_{F\tau} - N^{gen\tau}_{F\tau}(MC)}$
  - The probability of fake tau passing tight tau selection of not-prompt tau
- Find good region to measure FR
  - Close to signal region to reduce source systematic uncertainty
  - Populate with fake tau events to increase statistic for the measurement

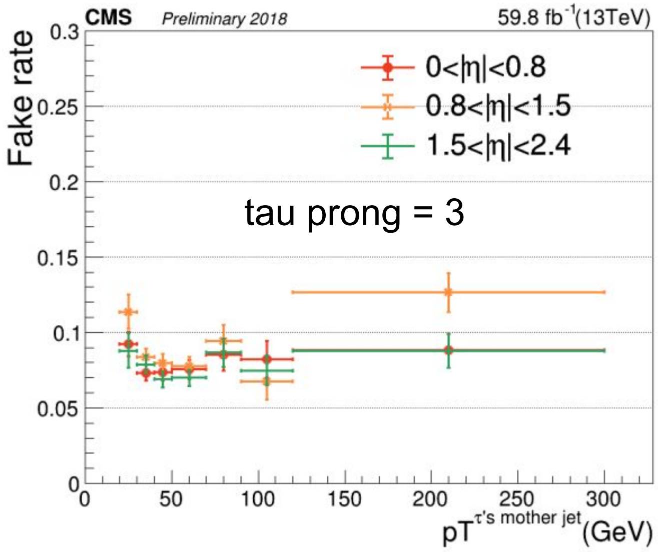
- Apply FR in fake not tight region
- As long as the FR the same in MR and any application region

$$
\begin{aligned}
N_{fake\tau} &= N^{notGen\tau}_{F\tau} \times FR \\
&= N^{notGen\tau}_{F\overline{T}} \times \frac{FR}{1-FR} \\
&= (N^{data}_{F\overline{T}} - N^{gen\tau(MC)}_{F\overline{T}}) \times \frac{FR}{1-FR}
\end{aligned}
$$

Fake tau estimation: tau fake rate

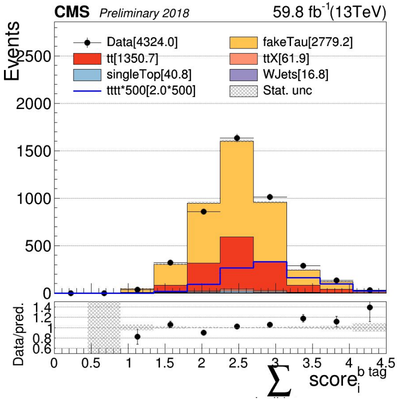


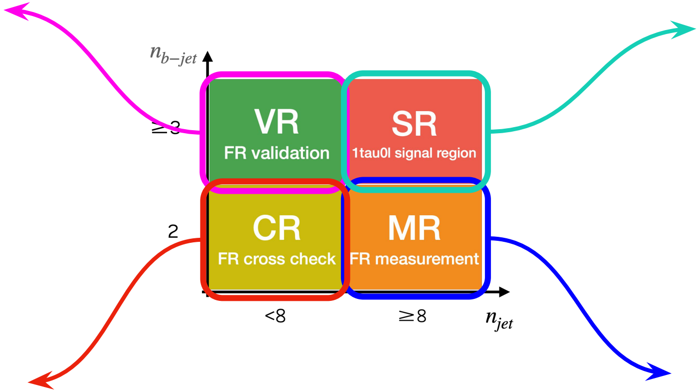


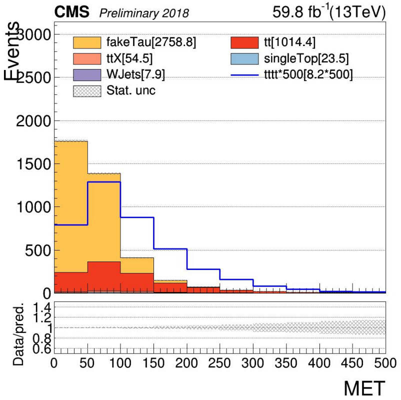


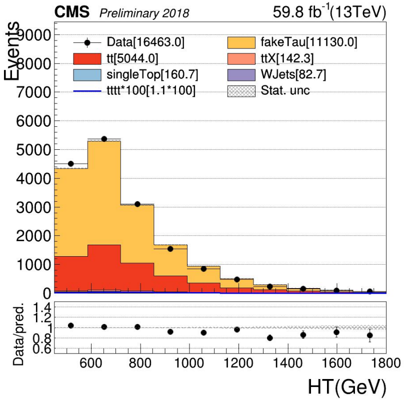
- Measurement region defined as n_{jet}>=8, $n_{b\text{-}jet}$=2
- Tau FR as a function of pt of tau's matched jet, eta and tau prong

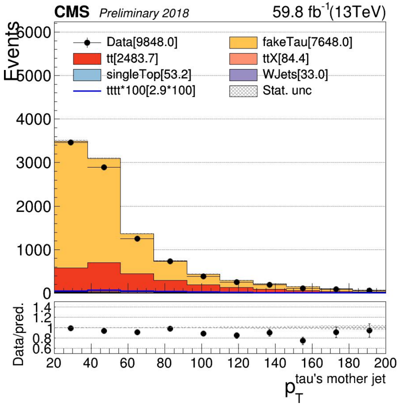
Fake tau estimation: closure test



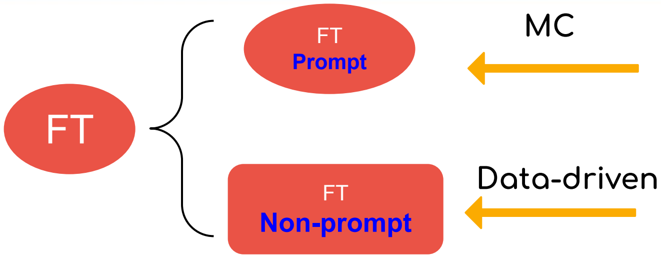






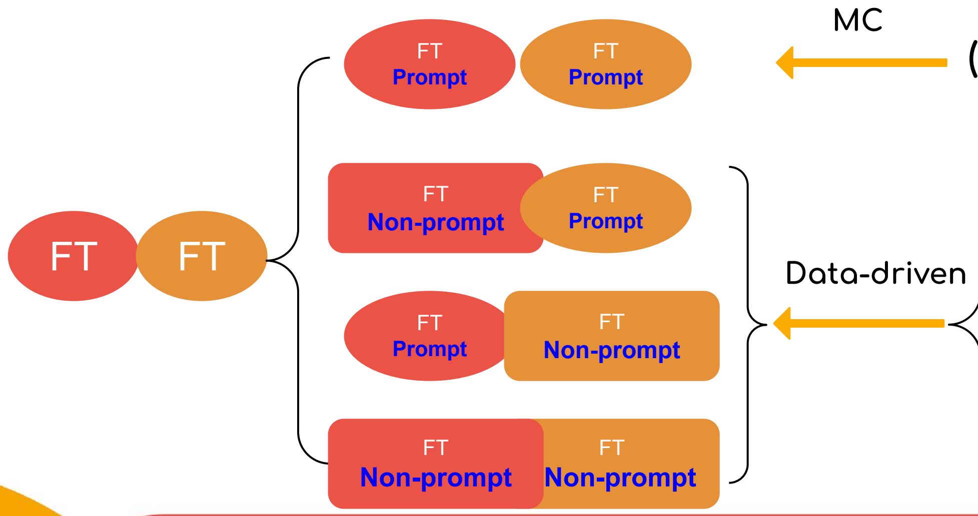


Fake lepton estimation: one and two fake objects



FT region: prompt lepton, weight = SF

F not T region: $\left(N^{data}_{F\overline{T}} - N^{gen\tau(MC)}_{F\overline{T}}\right) \times \frac{FR}{1-FR}$

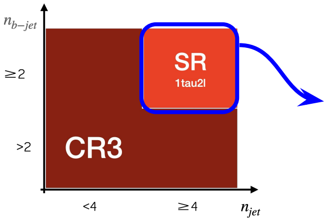


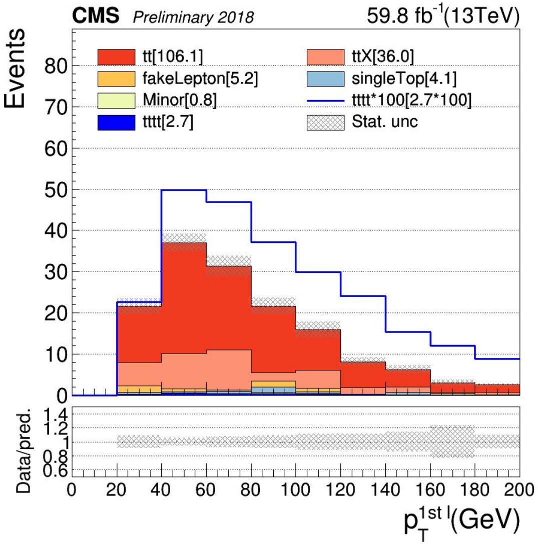
(FT,FT) region : prompt lepton, weight = SF1*SF2

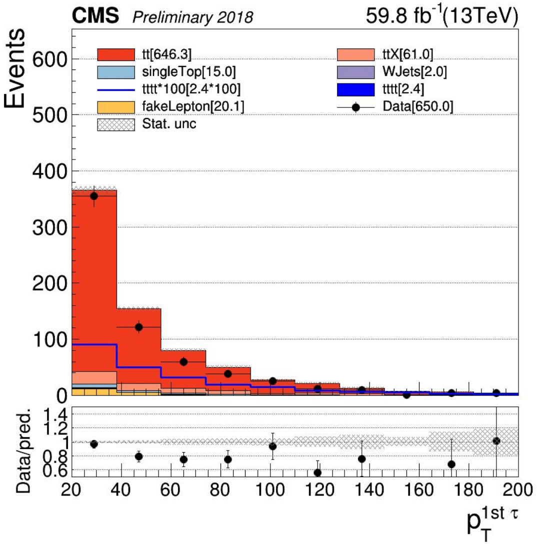
$(FT, F\overline{T}), (F\overline{T}, FT)$: weight = $FR/(1-FR)$

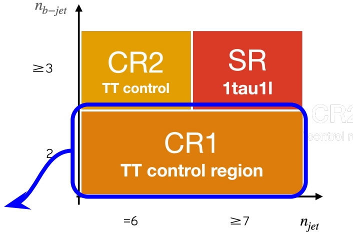
$(F\overline{T}, F\overline{T})$: weight = $-(FR1 * FR2)/(1-FR1)*(1-FR2)$

Fake lepton in 1tau1l and 1tau2l









- Lepton FR borrowed from SS & ML channel of four tops
  - Exactly the same lepton definition and very similar phase space with SS&ML channel
  - Many thanks to Neils for providing SF and instructions!
- Fake lepton minor background compared with tt and ttX

1 The beginning

2 Objects and triggers

3 Background estimation

tttt

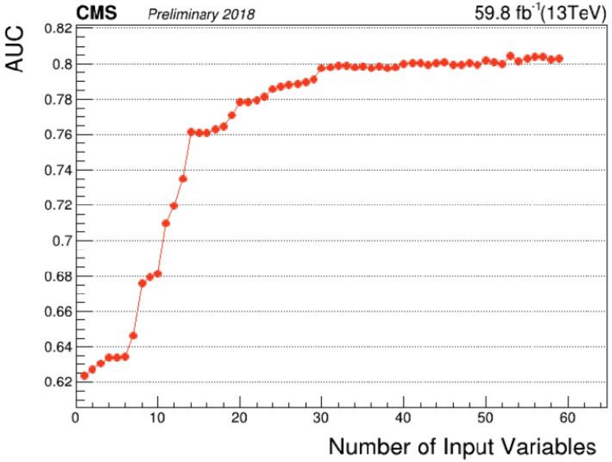
4 Signal extraction

5 Search for VLL

6 The end

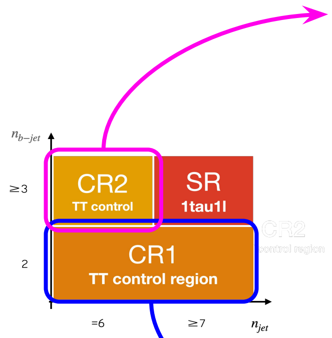
Signal extraction: 1tau1l, BDT training

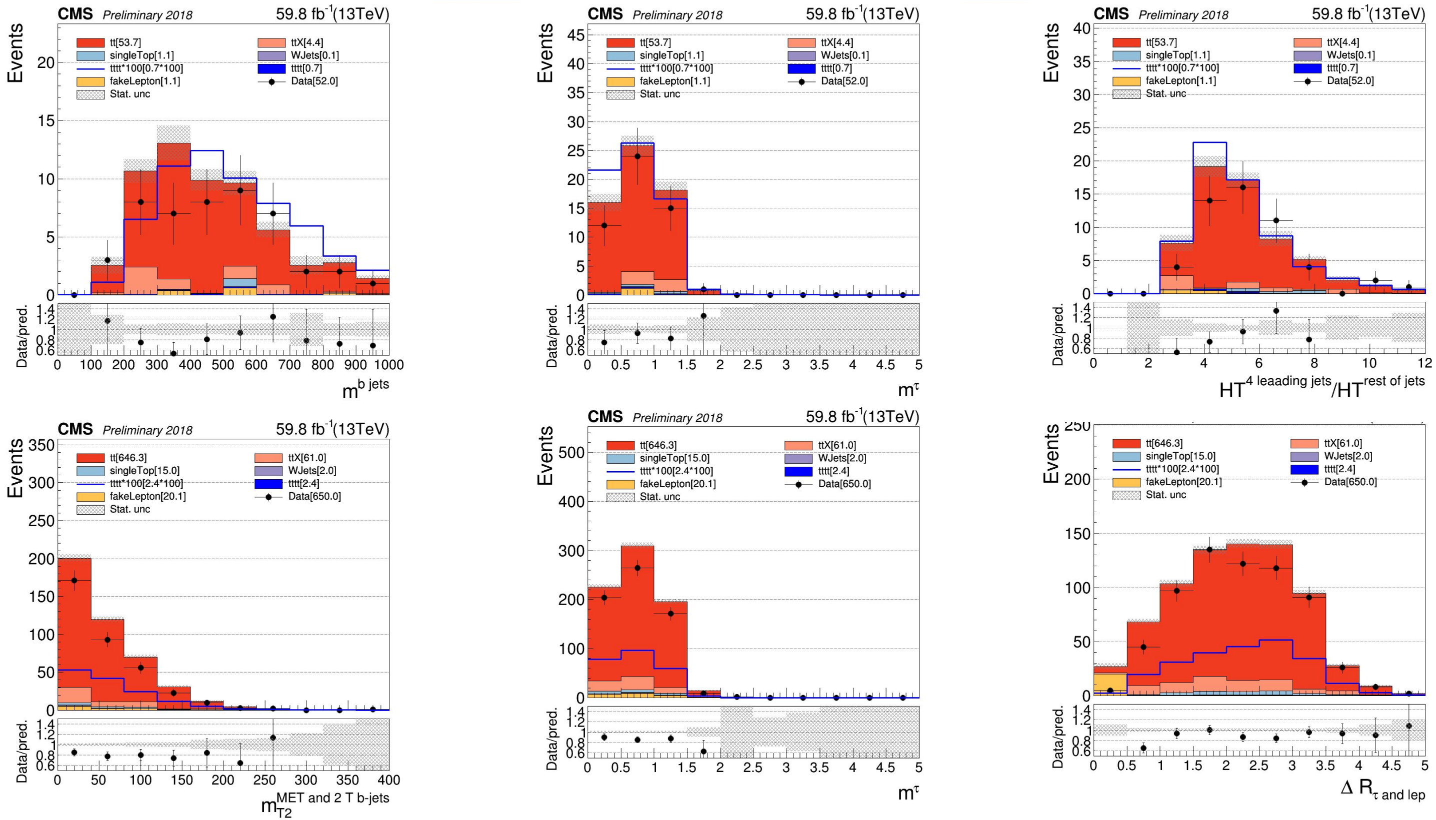
Object	Variable
Tau and lepton variables	p_T^{τ}
	$charge_{\tau} * charge_l$
	$m(\tau, l)$
	m_{τ}
	$mT(\tau, MET)$
	p_T^{μ}
	$mT2(\tau, l, MET)$
B-jet variables	$\boxed{n_{b-jetM}}$
	$\boxed{m_{b-jetT}}$
	$m_{b-jetsM}$
	$min\Delta R(b-jetsT)$
	$min\Delta R(b-jetsM)$
	$min\Delta R(b-jetsM, \tau)$
	$m_{T2}(2\ leading\ b-jetsT, MET)$
	$min\Delta R(b-jetsT, l)$
	$HT_{b-jetsM}$
Jet variables	n_{jet}
	$HT_{leading\ 4\ jets}/HT_{all\ jets}$
	centrality
	$p_T^{1st\ jet}$
	$p_T^{4th\ jet}$
	$p_T^{7th\ jet}$
	MHT_{jets}
	$min\Delta R(jets)$
	$m(jets, \tau)$
	MET/HT



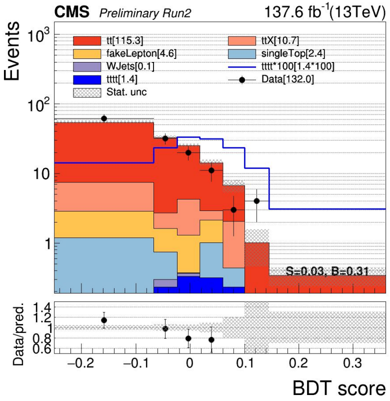
- Input variables selected with correlation removal method
- Various leptonic top decay information and hadronic information used to fully capture signal
  - Transverse mass(m2), stransverse mass(mT2)...
  - HT, centrality, sphericity
  - With b-tag WP information rather than shape

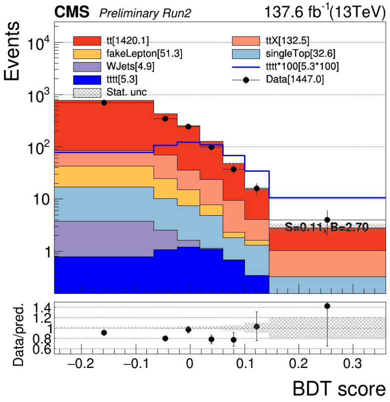
1tau1l: validation of BDT inputs

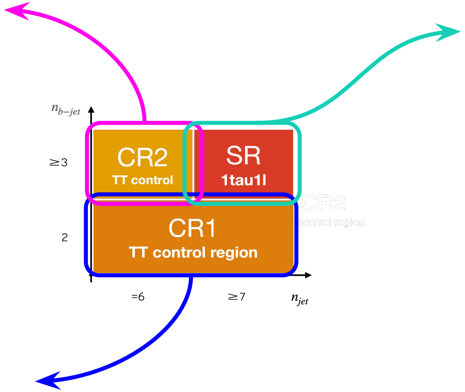


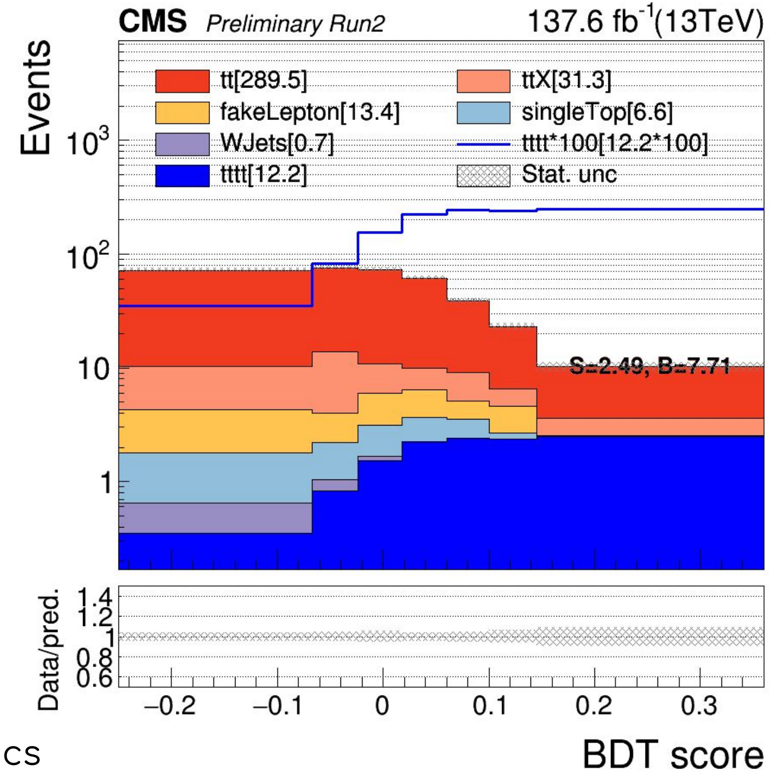


BDT distribution in 1tau1l



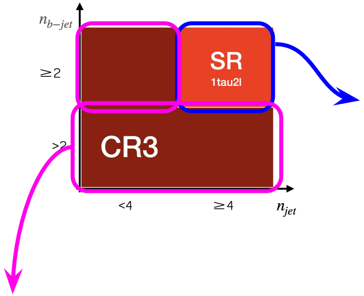


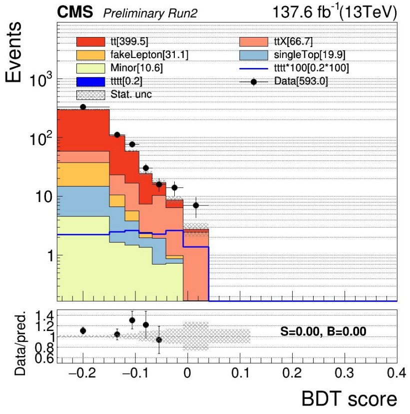


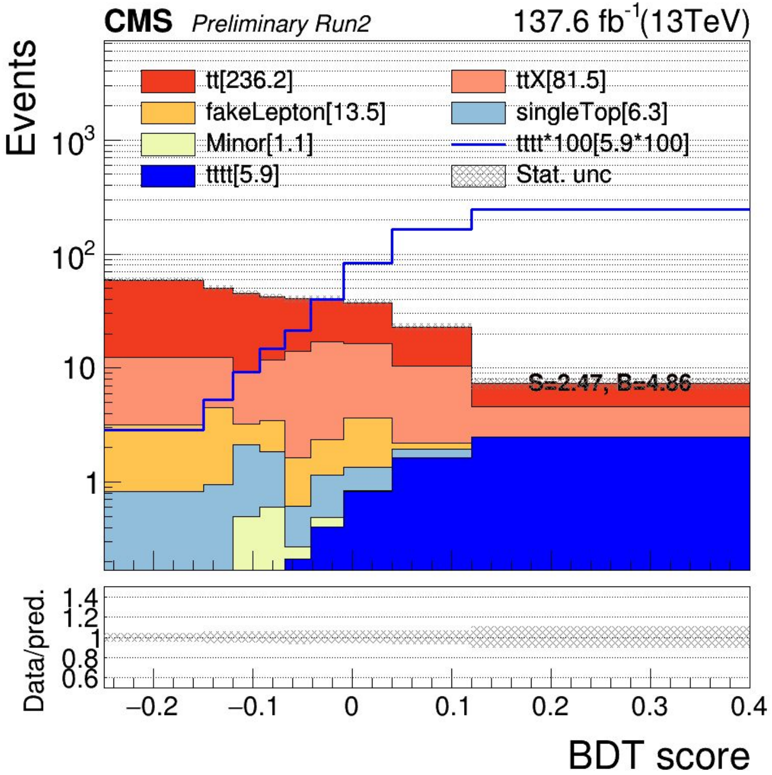


- Expected significance 0.93
- Considered all major systematics

1tau2l: BDT distribution

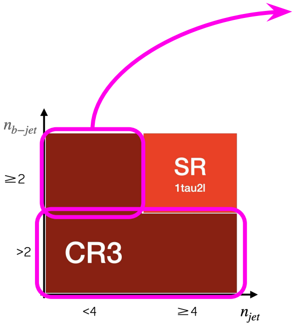


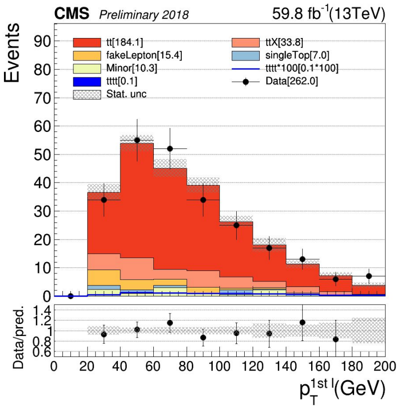


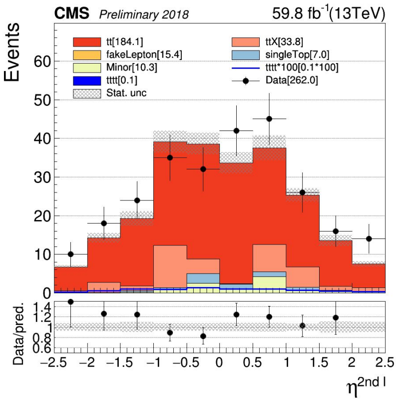


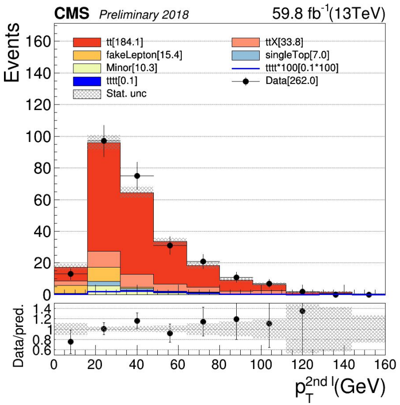
- BDT input variables selected with same method in 1tau1l
- B-tag WP information used
- Second lepton information harnessed
- Expected significance: 1.03
- All major systematics considered

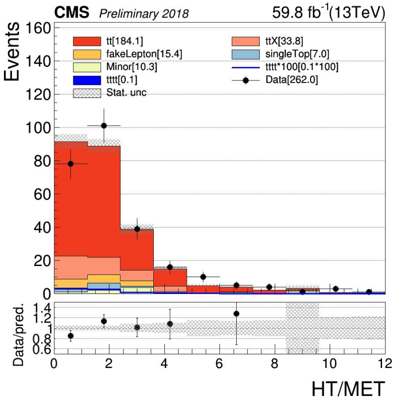
1tau2l: validation of BDT inputs

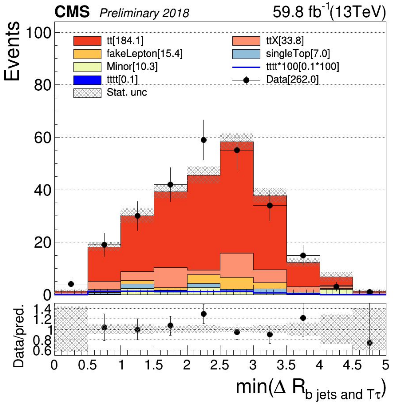


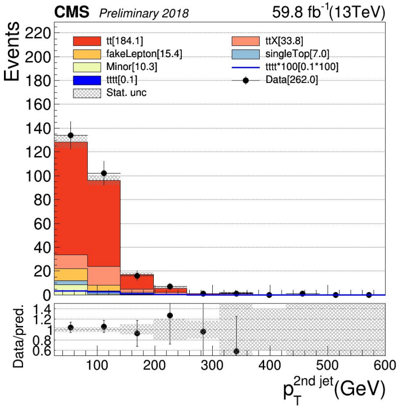




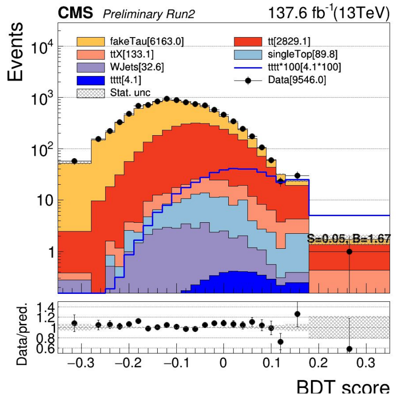


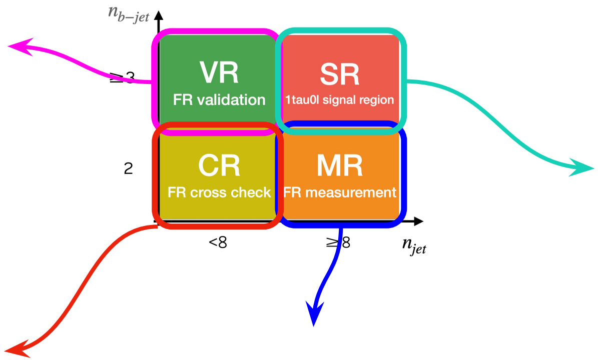


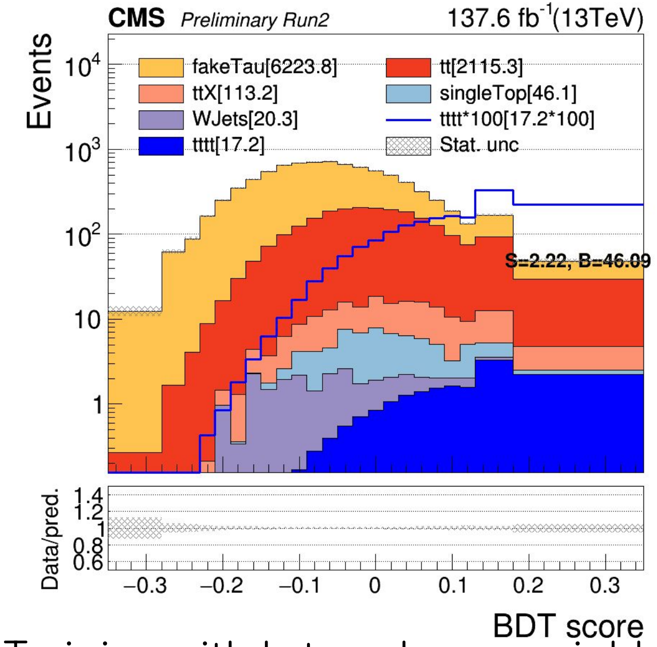


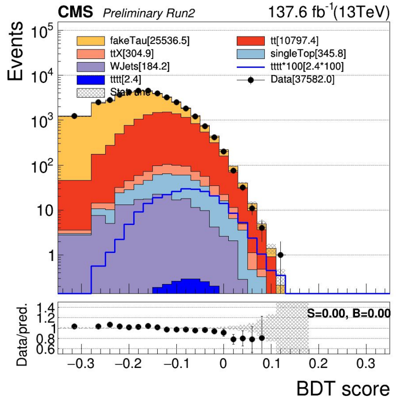


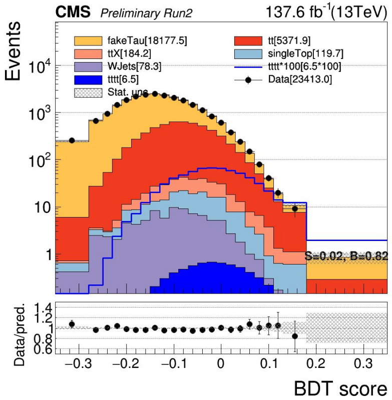
1tau0l: BDT distribution





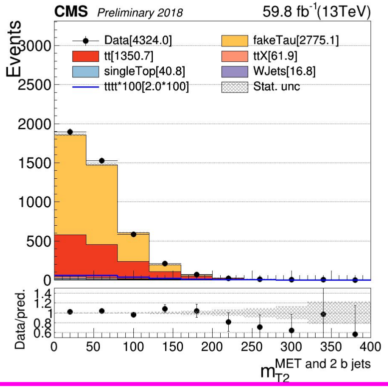


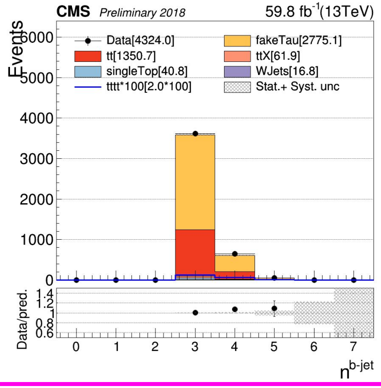


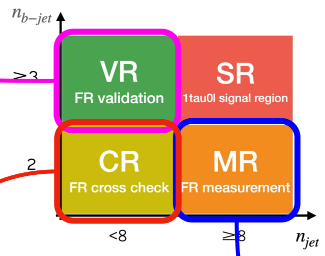


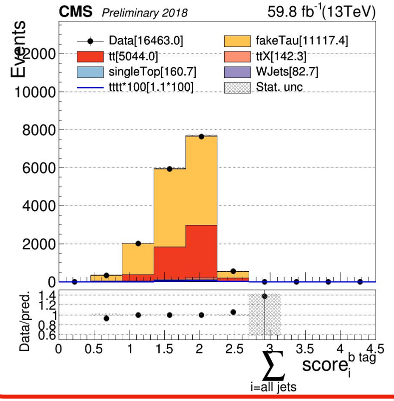
- Training with b-tag shape variables
- Most challenging channel with expected significance of 0.33 sigma

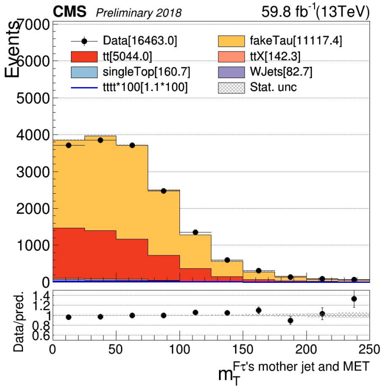
1tau0l: BDT input validation

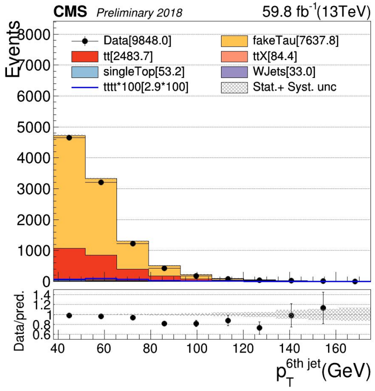


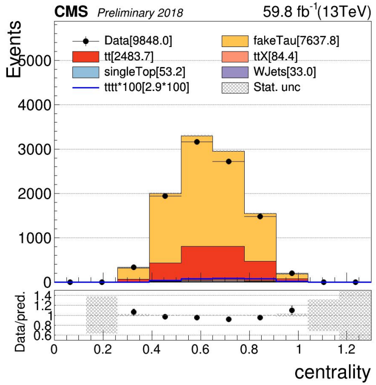












Theoretical and experimental systematics

Experimental uncertainties

- B-tag WP(1tau1l and 1tau2l) efficiency and shape scale factor(1tau0l)
- Tau efficiency SF and energy scale correction(TES)
- Lepton efficiency SF and energy scale correction
- Jet energy scale correction(JES and JER)
- Trigger scale factor
- Pileup reweighting, prefiring reweighting
- MET
- Tau FR, lepton FR

Theoretical uncertainties

- QCD renormalization and factorization
- Pdf
- ISR and FSR

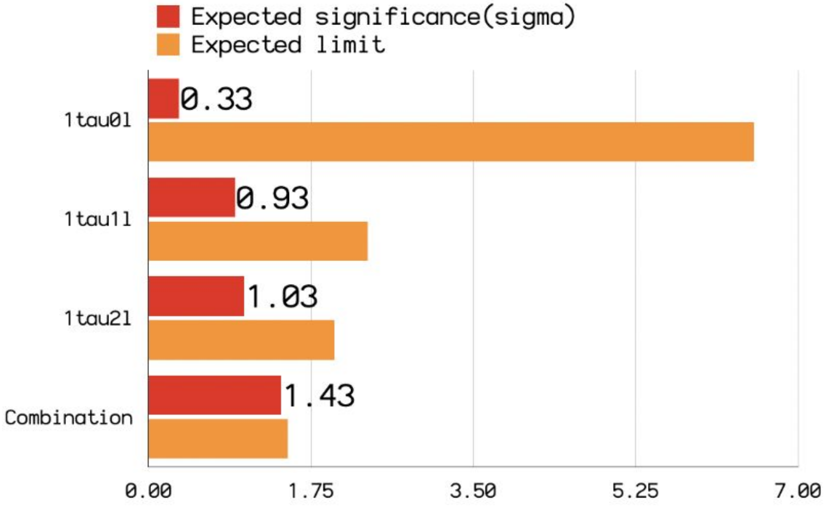
All systematics in place except leptonic trigger SF in 1tau2l

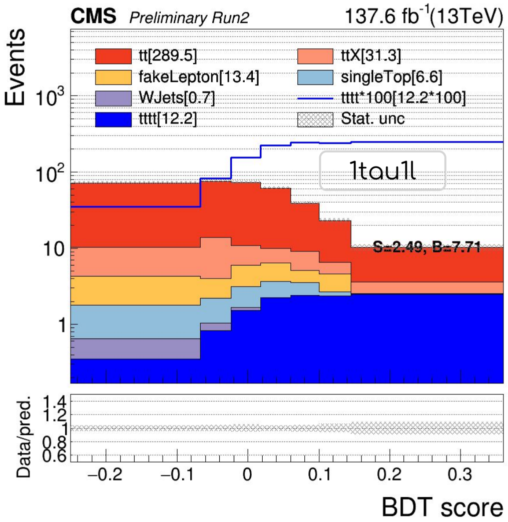
- Going to borrow leptonic trigger SF from SS of 4tops
- Leptonic trigger SF close to unity

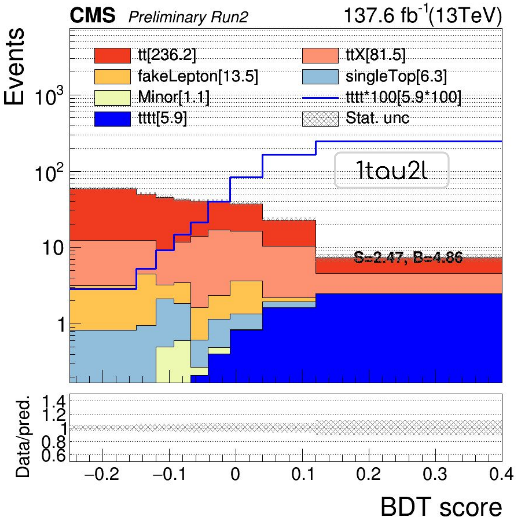
The results shown in this presentation included all systematic variation except

- All the energy scale correction
- MET, and leptonic trigger SF in 1tau2l
- ISR and FSR

Results with 3 channels combined



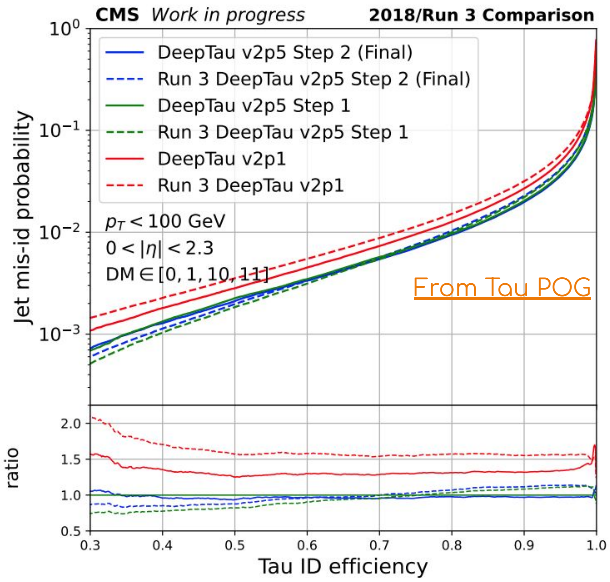




- Achieved 1.43 sigma of expected significance considering major systematics
- Sensitivity better than that of single lepton channel(1.0) and full hadronic channel!
- Tau channel very promising see 4tops in run 3!

What have we learned with run 2 and where to improve in run 3?

- The main bottleneck is tau efficiency
  - Only 30% generator level hadronic tau get selected
  - 30% of generated tau pt<25 GeV
  - High tau fake bg due to lots of jets and b-jets in the event
  - Good tau identification will be the key!
- Improved tau tagging and b-tagging in run 3
  - New DeepTau and PNTau
- Better HLT in run 3 to increase signal acceptance
  - ParkingHH trigger for 1tau0l
  - Single-lepton cross trigger for 1tau1l



From Tau POG

1 The beginning

2 Objects and triggers

3 Background estimation

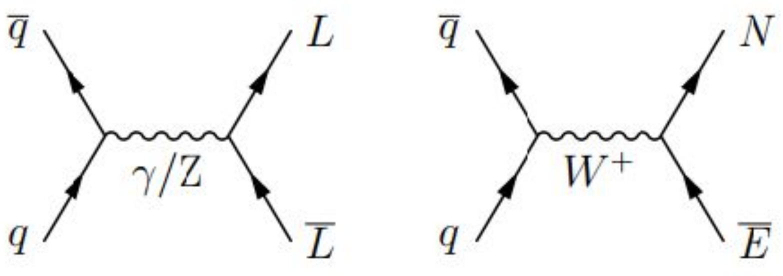
tttt

4 Signal extraction

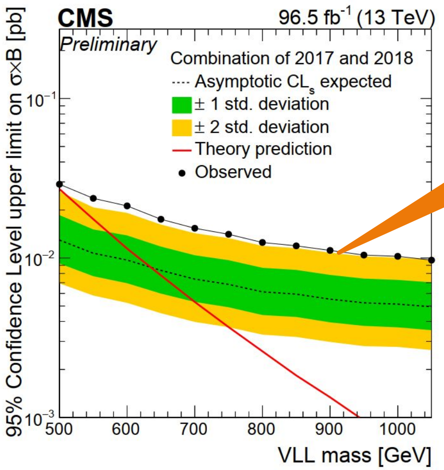
5 Search for VLL

6 The end

Intriguing excess in the search of VLL in 4321 model



From B2G-21-004



Is there really new physics?

Or it is the random nature of the universe that's playing with us?(p value<1%)

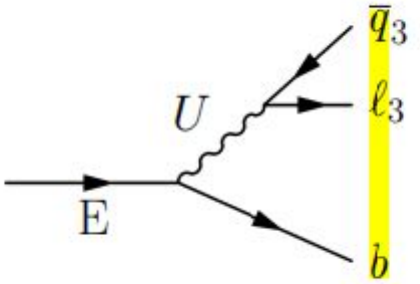
- VLL in 4321 model
  - Motivated by anomalies from Rk and RD measurement
  - Extend SM to U(4)×SU(3) ×SU(2) ×U(1) symmetry
- Close to 3 sigma testing against SM in VLL all hadronic channel!
- Vector-like leptons: the lightest particle predicted by the model, mass <1 TeV
- VLL production: coupling with Z/gamma or W boson through electro-weak interaction to produce pairs: EE, NN, EN

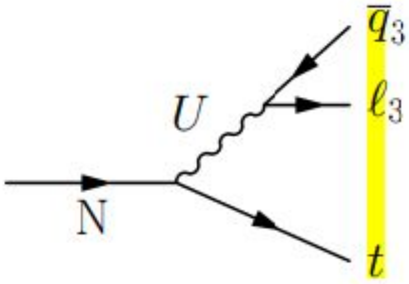
	2017	2018	Combination
0-τ	0	0	0
1-τ	1.44	1.65	1.93
2-τ	0.83	2.04	2.26
1+2-τ	1.63	2.55	2.88
0+1+2-τ	1.38	2.57	2.83

huiling.hua@cern.ch

Huiling Hua

VLL_4321: decay mode and final states



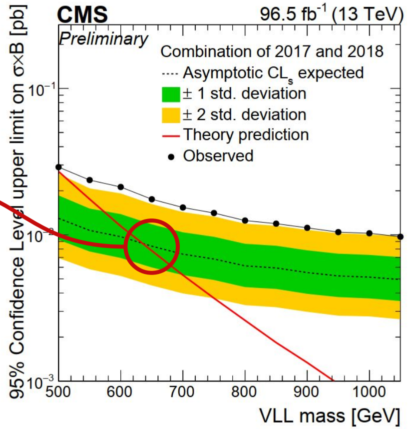


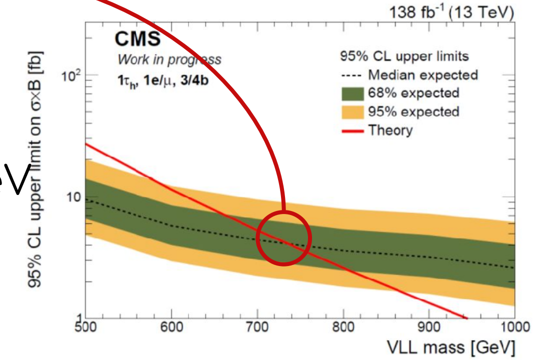
- Depending on how top quark and tau lepton decay
  - E->b(tv), E->b(btau)
  - N->t(tv), N->t(btau)
- Final state can have up to 4 tau, 4l
- Four top tau phase space perfect for VLL search

Channel	VLL decay mode	Final state
1tau0l	$EE \to b(tv_\tau)b(tv_\tau)$	$\tau + 0l + 4b + 2j + 3v_\tau + 0v_l$
	$EE \to b(tv_\tau)b(b\tau)$	$\tau + 0l + 3b + 2j + 1v_\tau + 0v_l$
	$EN \to b(tv_\tau)t(tv_\tau)$	$\tau + 0l + 4b + 6j + 2v_\tau + 0v_l$
	$EN \to b(tv_\tau)t(b\tau)$	$\tau + 0l + 3b + 4j + 1v_\tau + 0v_l$
	$EN \to b(b\tau)t(tv_\tau)$	$\tau + 0l + 4b + 4j + 1v_\tau + 0v_l$
	$EN \to b(b\tau)t(b\tau)$	$\tau + 0l + 4b + 0j + 1v_\tau + 0v_l$
	$NN \to t(tv_\tau)t(tv_\tau)$	$\tau + 0l + 4b + 6j + 3v_\tau + 0v_l$
	$NN \to t(tv_\tau)t(b\tau)$	$\tau + 0l + 4b + 6j + 1v_\tau + 0v_l$
1tau1l	$EE \to b(tv_\tau)b(tv_\tau)$	$\tau + 1l + 4b + 0j + 3v_\tau + 1v_l$
	$EE \to b(b\tau)b(tv_\tau)$	$\tau + 1l + 4b + 0j + 2v_\tau + 1v_l$
	$EN \to b(tv_\tau)t(tv_\tau)$	$\tau + 1l + 3b + 0j + 2v_\tau + 1v_l$
	$EN \to b(tv_\tau)t(b\tau)$	$\tau + 1l + 4b + 2j + 1v_\tau + 1v_l$
	$EN \to b(b\tau)t(tv_\tau)$	$\tau + 1l + 4b + 2j + 1v_\tau + 1v_l$
	$NN \to t(tv_\tau)t(tv_\tau)$	$\tau + 1l + 4b + 4j + 1v_\tau + 1v_l$
	$NN \to t(b\tau)t(tv_\tau)$	$\tau + 1l + 4b + 4j + 1v_\tau + 1v_l$
1tau2l	$EN \to b(tv_\tau)t(tv_\tau)$	$\tau + 2l + 4b + 0j + 3v_\tau + 2v_l$
	$EN \to b(tv_\tau)t(b\tau)$	$\tau + 2l + 4b + 0j + 2v_\tau + 2v_l$
	$EN \to b(b\tau)t(tv_\tau)$	$\tau + 2l + 4b + 0j + 1v_\tau + 2v_l$
	$NN \to t(tv_\tau)t(tv_\tau)$	$\tau + 2l + 4b + 4j + 3v_\tau + 2v_l$
	$NN \to t(b\tau)t(tv_\tau)$	$\tau + 2l + 4b + 2j + 1v_\tau + 2v_l$

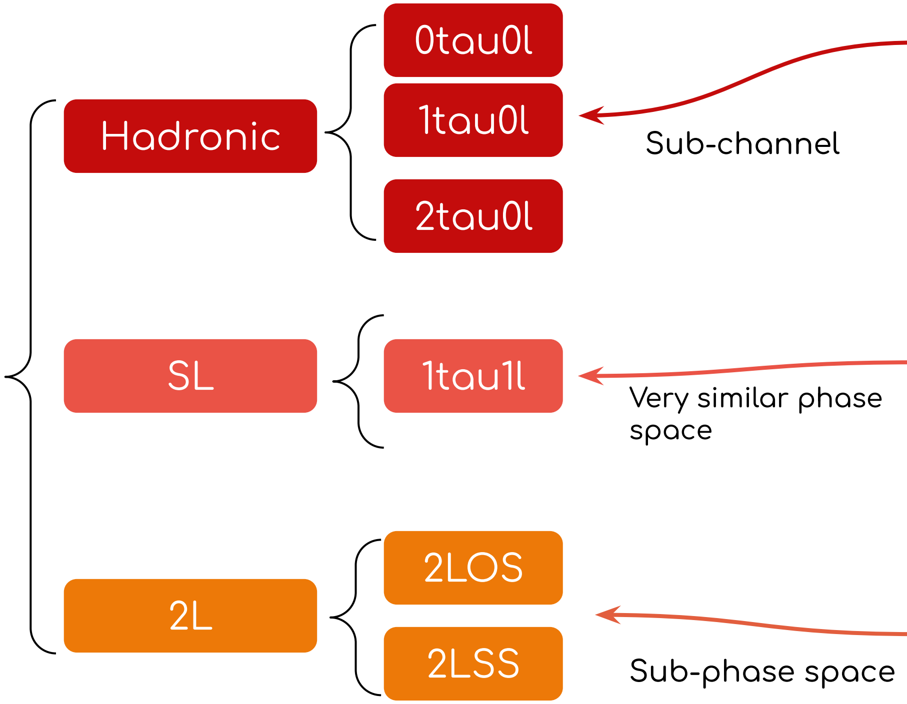
The state of art of VLL_4321 search

- Hadronic
  - 0tau0l
  - 1tau0l
  - 2tau0l
    - ★ Published result from CMS
    - ★ Intriguing excess
    - ★ Limit of VLL mass: 650 GeV
- SL
  - 1tau1l
    - ★ Ongoing effort on SUSY
    - ★ CADI talk last Friday!
    - ★ Preliminary limit: 750 GeV
- 2L
  - 2LOS
  - 2LSS
    - ★ Ongoing effort on SUSY
    - ★ Very preliminary limit: 500 GeV





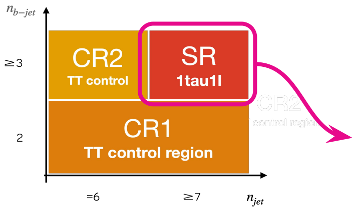
Four top phase space: perfect for VLL 4321 search

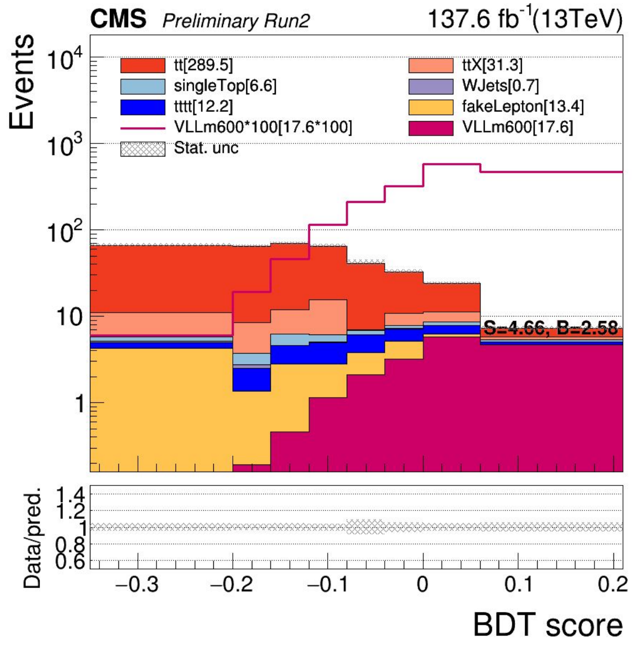


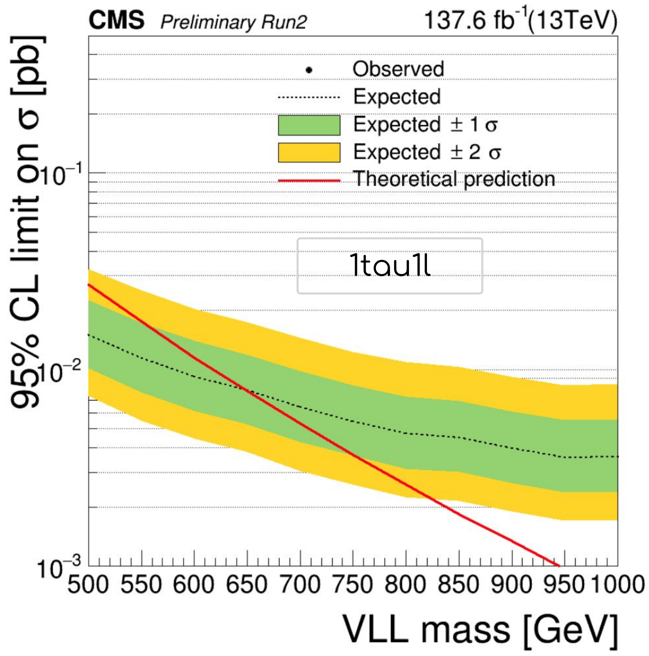
Channel	VLL decay mode	Final state
1tau0l	$EE \to b(t\nu_\tau)b(t\nu_\tau)$	$\tau + 0l + 4b + 2j + 3\nu_\tau + 0\nu_l$
	$EE \to b(t\nu_\tau)b(b\tau)$	$\tau + 0l + 3b + 2j + 1\nu_\tau + 0\nu_l$
	$EN \to b(t\nu_\tau)t(t\nu_\tau)$	$\tau + 0l + 4b + 6j + 2\nu_\tau + 0\nu_l$
	$EN \to b(t\nu_\tau)t(b\tau)$	$\tau + 0l + 3b + 4j + 1\nu_\tau + 0\nu_l$
	$EN \to b(b\tau)t(t\nu_\tau)$	$\tau + 0l + 4b + 4j + 1\nu_\tau + 0\nu_l$
	$EN \to b(b\tau)t(b\tau)$	$\tau + 0l + 4b + 0j + 1\nu_\tau + 0\nu_l$
	$NN \to t(t\nu_\tau)t(t\nu_\tau)$	$\tau + 0l + 4b + 6j + 3\nu_\tau + 0\nu_l$
	$NN \to t(t\nu_\tau)t(b\tau)$	$\tau + 0l + 4b + 6j + 1\nu_\tau + 0\nu_l$
1tau1l	$EE \to b(t\nu_\tau)b(t\nu_\tau)$	$\tau + 1l + 4b + 0j + 3\nu_\tau + 1\nu_l$
	$EE \to b(b\tau)b(t\nu_\tau)$	$\tau + 1l + 4b + 0j + 2\nu_\tau + 1\nu_l$
	$EN \to b(t\nu_\tau)t(t\nu_\tau)$	$\tau + 1l + 3b + 0j + 2\nu_\tau + 1\nu_l$
	$EN \to b(t\nu_\tau)t(b\tau)$	$\tau + 1l + 4b + 2j + 1\nu_\tau + 1\nu_l$
	$EN \to b(b\tau)t(t\nu_\tau)$	$\tau + 1l + 4b + 2j + 1\nu_\tau + 1\nu_l$
	$NN \to t(t\nu_\tau)t(t\nu_\tau)$	$\tau + 1l + 4b + 4j + 1\nu_\tau + 1\nu_l$
	$NN \to t(b\tau)t(t\nu_\tau)$	$\tau + 1l + 4b + 4j + 1\nu_\tau + 1\nu_l$
1tau2l	$EN \to b(t\nu_\tau)t(t\nu_\tau)$	$\tau + 2l + 4b + 0j + 3\nu_\tau + 2\nu_l$
	$EN \to b(t\nu_\tau)t(b\tau)$	$\tau + 2l + 4b + 0j + 2\nu_\tau + 2\nu_l$
	$EN \to b(b\tau)t(t\nu_\tau)$	$\tau + 2l + 4b + 0j + 1\nu_\tau + 2\nu_l$
	$NN \to t(t\nu_\tau)t(t\nu_\tau)$	$\tau + 2l + 4b + 4j + 3\nu_\tau + 2\nu_l$
	$NN \to t(b\tau)t(t\nu_\tau)$	$\tau + 2l + 4b + 2j + 1\nu_\tau + 2\nu_l$

- Only 2017 and 2018 data in hadronic channel
- 3 channels combined together can provide a more comprehensive insight into VLL

VLL in 1tau1l

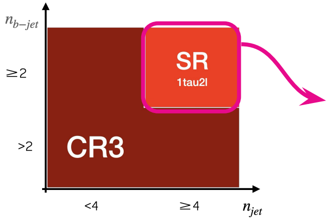


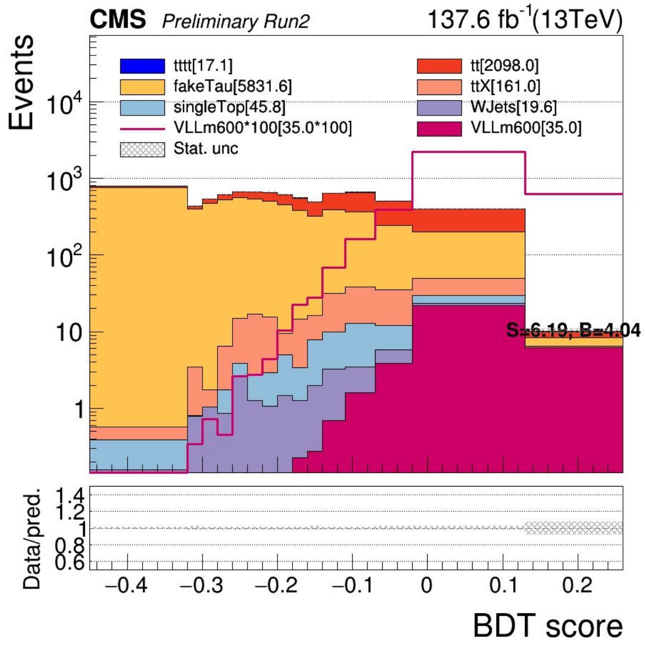


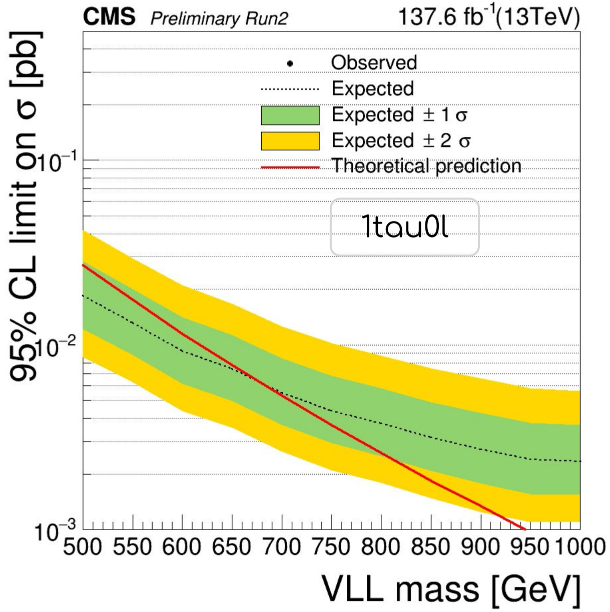


- BDT training against all backgrounds including tttt
- Separate BDT training for each mass point to optimize performance
- Limit on mass at 660 GeV at 1tau1l

VLL@m600 in 1tau0l

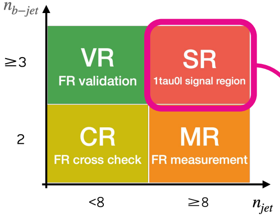


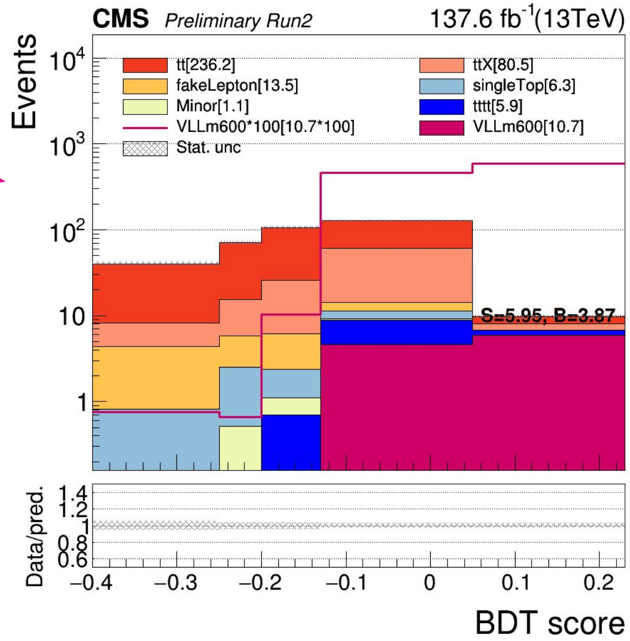


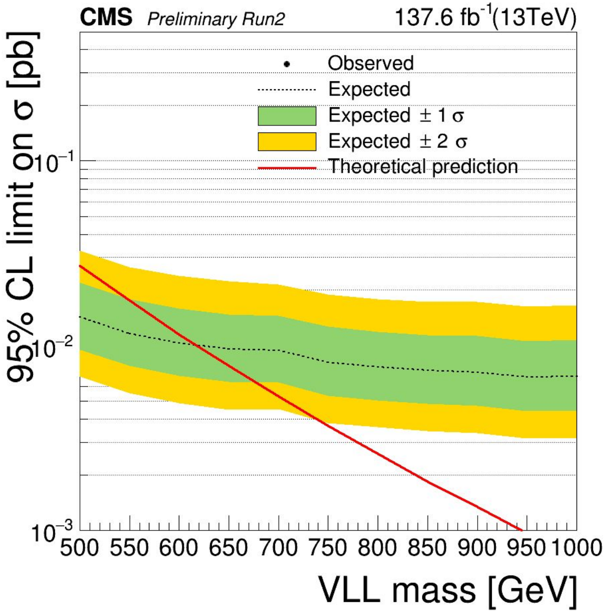


- BDT training against all backgrounds including tttt
- Separate BDT training for each mass point to optimize performance
- Limit on mass at 700 GeV at 1tau0l

VLL@m600 in 1tau2l



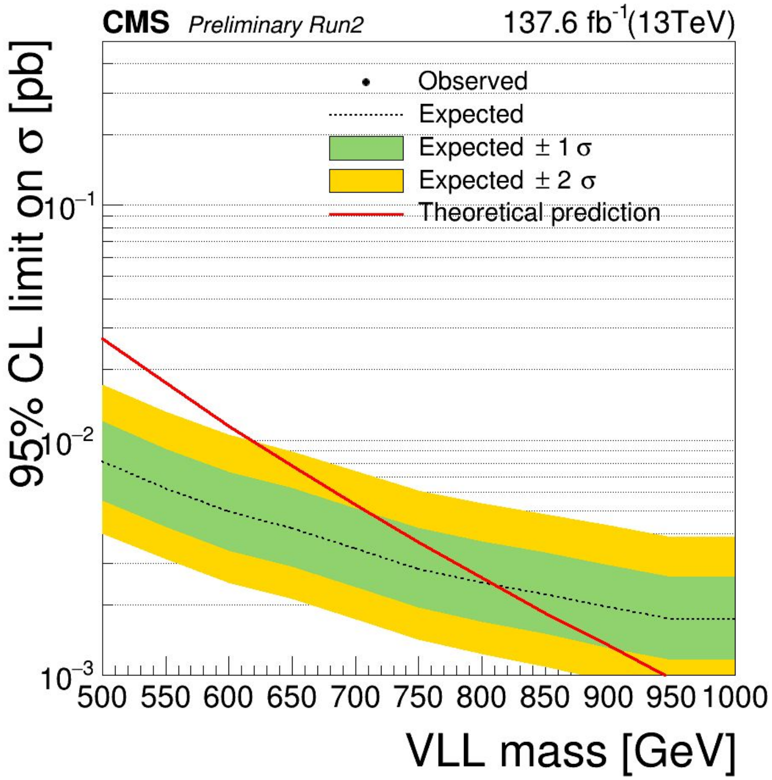




- BDT training against all backgrounds including tttt
- Separate BDT training for each mass point to optimize performance
- Limit on mass at 630 GeV at 1tau2l

huiling.hua@cern.ch
Huiling Hua

Limit on VLL mass with run 2



- Most stringent limit on VLL mass at 820 GeV!
- Major systematics considered
- Results with 1tau1l, 1tau0l and 1tau2l combined
- What would be the observed significance when we unblind?

1 The beginning

2 Objects and triggers

3 Background estimation

tttt

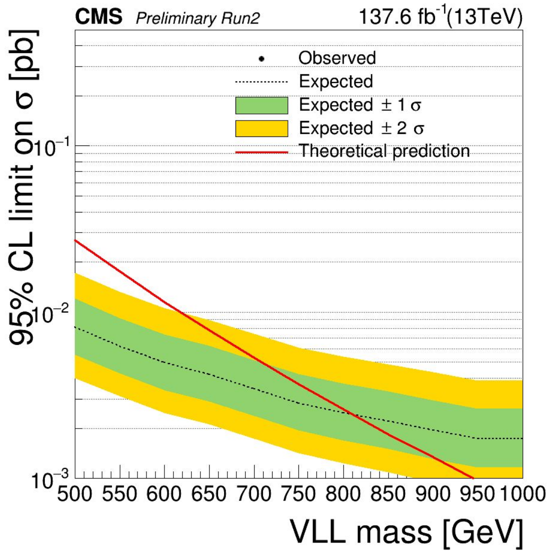
4 Signal extraction

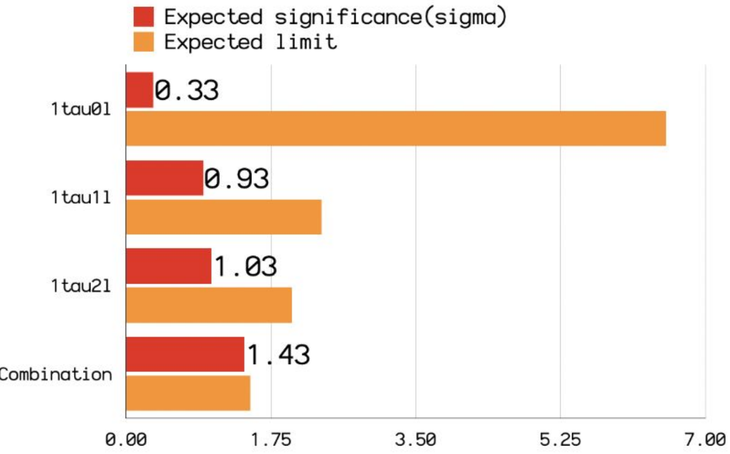
5 Search for VLL

6 The end

The end(of this presentation)

- Hadronic tau channel a very promising candidate to see four tops after SS&ML channel
  - Expected significance of 1.4 sigma
- VLL search in tau final states yielding the most stringent constraint on the mass
  - Expected limit on mass parameter: 820GeV
  - Can we confirm the anomaly or celebrate SM when we unblind?





- Analysis note v4 ready with all details described
- Many thanks to Top, TTX conveners and Jan, Neils, Charis, Kyle……
- Analysis complete with a few missing piece

Back up

Theoretical and experimental systematics

Experimental uncertainties

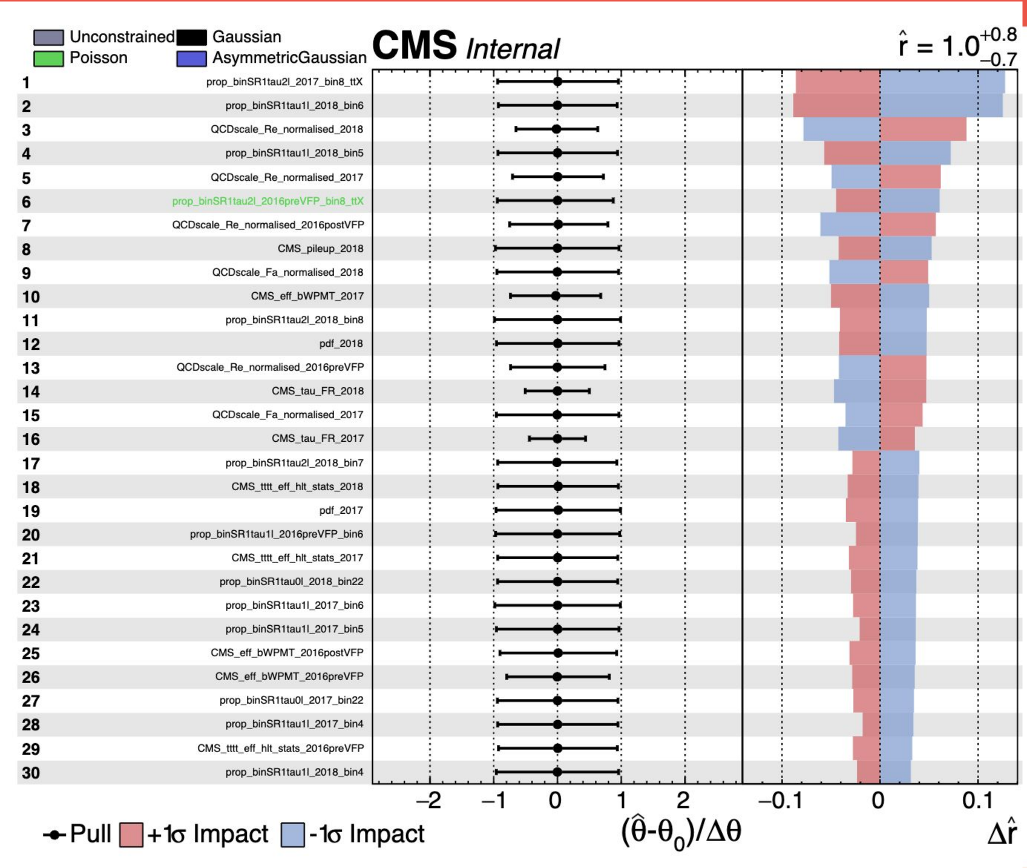
- B-tag WP(1tau1l and 1tau2l) efficiency and shape scale factor(1tau0l)
- Tau efficiency SF and energy scale correction(TES)
- Lepton efficiency SF and energy scale correction
- Jet energy scale correction(JES and JER)
- Trigger scale factor
- Pile up reweighting
- Prefiring reweighting
- MET

Theoretical uncertainties

- QCD renormalization and factorization
- Pdf
- ISR and FSR

- All systematics inplace except leptonic trigger SF in 1tau2l
  - Going to borrow trigger SF from SS of 4tops
  - Leptonic trigger SF should have very small impact
- The results shown in this presentation included all systematic variation except
  - All the energy scale correction
  - MET, and leptonic trigger SF in 1tau2l
  - ISR and FSR

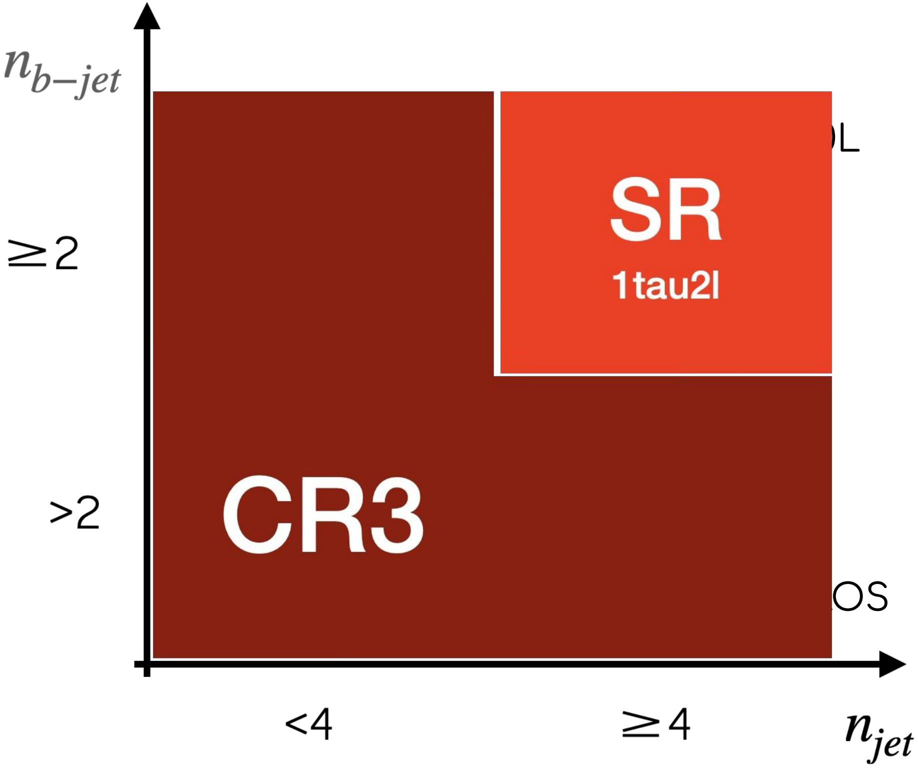
Impact on four top significance



Impact of VLL

Questions to answer

- Why FR constrained?
- Why theoretical uncertainty big?
- Tau fake rate difference between data and MC
- Overlap with SS, combination
- Post fit Vs pre fit



>=1Tau$_h$

0Tau$_h$1L

Back up

hadronic triggers in 1tau0l and 1tau1l

Trigger	act. lumi(fb-1)	eff lumi	first run	last run	dataset
2016					
HLT_PFHT380_SixJet32_DoubleBTagCSV_p075(MC)	4.8	4.8	297046	299329	JetHT
HLT_PFHT450_SixJet40_BTagCSV_p056(MC)	35.9	35.9	272760	284044	JetHT
HLT_PFJet450(MC)	35.9	35.9	272760	284044	JetHT
2017					
HLT_PFHT400_SixJet30_DoubleBTagCSV_p056	35.9	35.9	272760	284044	JetHT
HLT_PFHT430_SixJet40_BTagCSV_p080	4.8	4.8	297046	299329	JetHT
HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5(MC)	36.7	32.1	299368	306460	JetHT
HLT_HT300PT30_QuadJet_75_60_45_40_TripeCSV_p07_v	4.8	4.8	297046	299329	BTagCSV
HLT_PFHT300PT30_QuadPFJet_75_60_45_40_TriplePFBTagCSV_3p0(MC)	36.7	36.7	299368	306460	BTagCSV
HLT_PFHT1050(MC)	41.5	41.5	296070	306460	JetHT
2018					
HLT_PFHT380_SixPFJet32_DoublePFBTagDeepCSV_2p2	17.7	17.7	315252	317488	jetHT
HLT_PFHT400_SixPFJet32_DoublePFBTagDeepCSV_2p94(MC)	42.1	42.1	317509	325175	jetHT
HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5	5.3	5.3	315252	315973	jetHT
HLT_PFHT430_SixPFJet40_PFBTagDeepCSV_1p5	12.4	12.4	315974	317488	jetHT
HLT_PFHT450_SixPFJet36_PFBTagDeepCSV_1p59(MC)	42.1	42.1	317509	325175	jetHT
HLT_PFHT330PT30_QuadPFJet_75_60_45_40_TriplePFBTagDeepCSV_4p5(MC)	59.8	59.8	315252	325175	jetHT

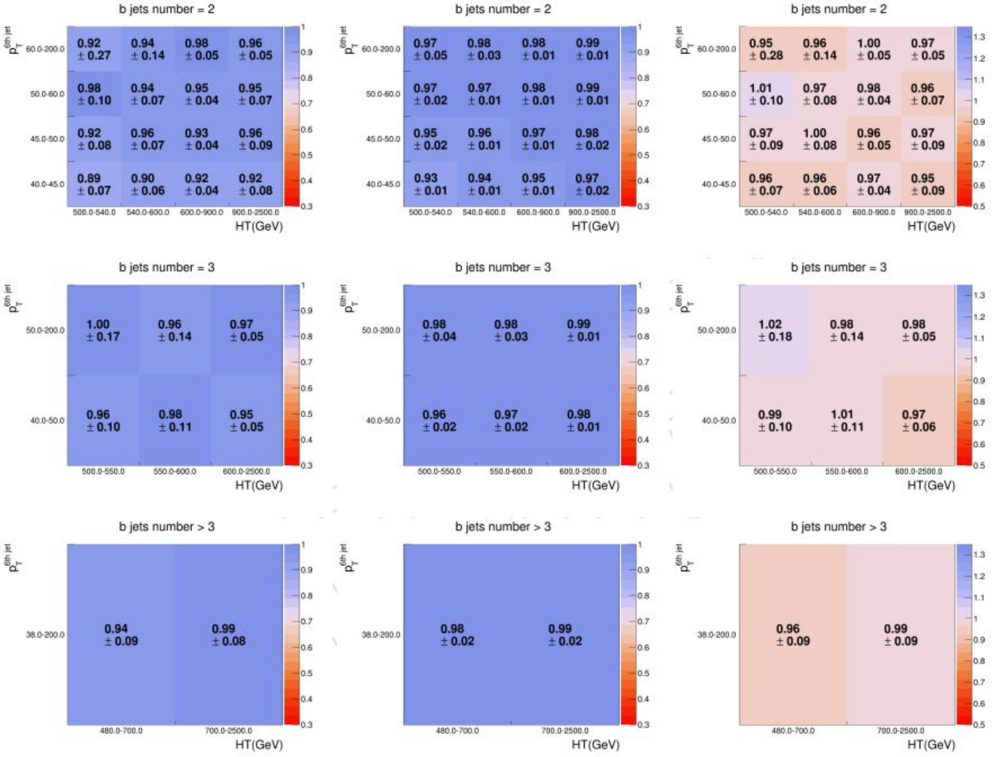
Table 5: Hardronic triggers for 1tau0l and 1tau1l. The trigger path MC in the bracket is the trigger path used in MC.

Leptonic triggers in 1tau2l

trigger	dataset
2018	
HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8	DoubleMuon
HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	EGamma
HLT_IsoMu24	SingleMuon
HLT_Ele32_WPTight_Gsf	EGamma
2017	
HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL	DoubleEG
HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
HLT_IsoMu27	SingleMuon
HLT_Ele35_WPTight_Gsf	SingleElectron
2016	
HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ OR HLT_Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL_DZ	DoubleMuon
HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	DoubleEG
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL(run<=2816)	MuonEG
HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ(run>=278273)	MuonEG
HLT_IsoMu24 OR HLT_IsoTkMu24	SingleMuon
HLT_Ele27_WPTight_Gsf	SingleElectron

Table 6: Leptoinic trigger path for 1tau2l

Hadronic trigger SF: 2016preVFP



Hadronic trigger SF: 2016postVFP

hadronic trigger SF: 2017

Hadronic trigger SF: 2018

1tau2l: BDT

Object	Variable
Lepton variables	$p_{\mathrm{T}}^{1st\ l}$
	$\phi_{1st\ l}$
	$\eta_{1st\ l}$
	$p_{\mathrm{T}}^{2nd\ l}$
	$\eta_{2nd\ l}$
	$m_{(l,l)}$
	$charge_{1st\ l} * charge_{2nd\ l}$
Tau variables	p_{T}^{τ}
	$\eta_{\tau's\ matched\ jet}$
	m_{τ}
	$m_{T2}(\tau, 1st\ l, MET)$
	$\Delta R(\tau, l)$
	$charge_{\tau} * charge_{1st\ l} * charge_{2nd}$
B-jet variables	n_{b-jetM}
	n_{Tb-jet}
	$min\Delta R(b-jetsM, \tau)$
	$m_{T2}(leading\ 2\ b-jetsM, MET)$
Jet variables	$p_{\mathrm{T}}^{5st\ jet}$
	$min\Delta R(jets)$
	HT/MET
	MET/HT
	$m_{jets,\tau}$

Table 15: BDT inputs for 1tau2l

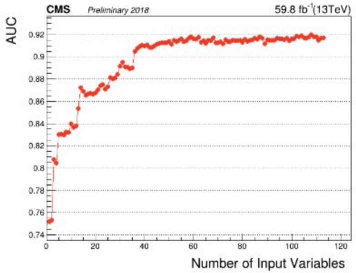


Figure 45: AUC vs number of variables in 1tau2l

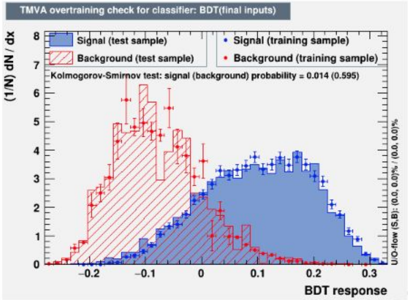


Figure 46: Overtraining check for 1tau2l

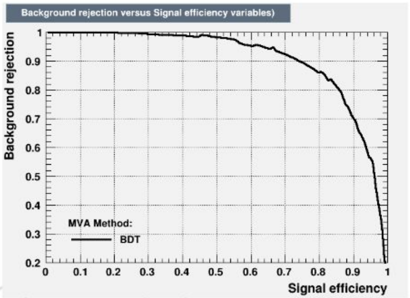


Figure 47: Rejection B vs S in 1tau2l

VLL cross section: pb