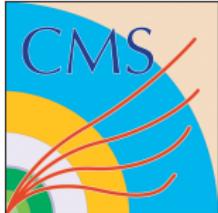


Measurement of $t\bar{t} \rightarrow b\bar{b}l\tau_h$ cross-section and Lepton Universality test on LHC

Oleksii Toldaiev

LIP

15 November 2017



Overview

Introduction with a short presentation of measurement of inclusive cross-section $t\bar{t} \rightarrow b\bar{b}\ell\tau_h$:

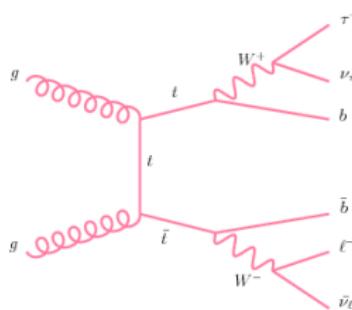
- 2016 data and object selection
- event categories and likelihood fit
- preliminary results from the fit in both $e\tau_h$ and $\mu\tau_h$ channels with main experimental uncertainties

Project of Lepton Universality test, measurement of $BR(W \rightarrow \tau)/BR(W \rightarrow \ell)$:

- current world-wide average 1.046 ± 0.023 shows excess of 2.5σ (from PDG)
- the ratio cancels many systematic uncertainties, but the main challenge is to reduce uncertainty of tau ID
- good reconstruction of Secondary Vertex of tau decay is the way to improve tau ID

Overview of cross-section measurement

Introduction



analysis strategy:

- we want to measure cross-section in $\tau_h + e$ and $\tau_h + \mu$ final states
- pre-select $t\bar{t}$ -rich sample of events with simple cuts
- main background is $\ell + \text{jets}$ where a jet fakes tau
- fit the distribution of transverse mass (M_T) between lepton and missing E_T
- also using kinematics of $\ell + \text{jets}$ channel split the events into $\ell\tau_h$ -rich and ℓj -rich categories

Datasets, event selection (Moriond17 recommendations)

Data: 03Feb2017ReReco, SingleMuon and SingleElectron, Summer16 MC.

Detailed list is in backup.

Event selection:

- lumisection certificates: Golden for SingleMuon and the prescaled certificate from Top physics group for SingleElectron
- pass E_T^{miss} filters for the data
- pass single-lep HLT triggers,
 - electrons — HLT_Ele27_WPTight_Gsf_v*
 - muons — HLT_IsoMu24_v, HLT_IsoTkMu24_v*

Object definitions:

- electrons: Tight ID, $p_T > 30\text{GeV}$, $\eta < 2.4$ and no “veto electrons”
- muons: Tight ID, $p_T > 27\text{GeV}$, $\eta < 2.4$, no “veto muons”
- taus: standard discriminators + Medim MVA anti-jet ID
 $p_T > 30\text{GeV}$, $\eta < 2.4$, cross-cleaned of leptons with $\delta R > 0.4$
- jets: Loose PF-based ID $p_T > 30\text{GeV}$, $\eta < 2.5$, cleaned of leptons
- b-tag: medium CSVv2

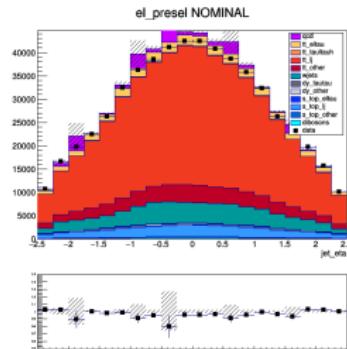
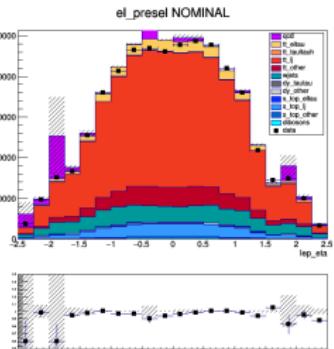
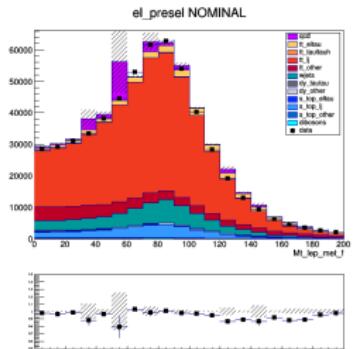
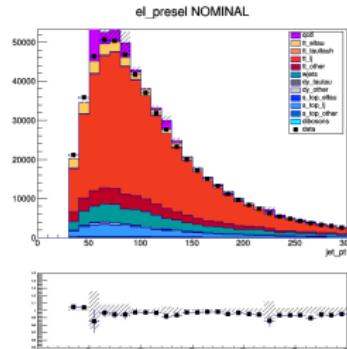
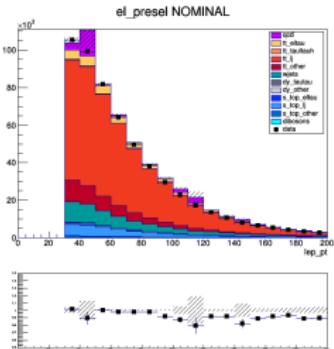
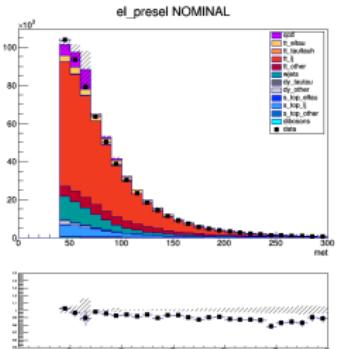
MC re-weighting

- MC weights for aMC@NLO datasets (-1 weights)
 - pile-up reweighting
 - top p_T reweighting (from 13TeV) (done as systematic variation)
 - recoil corrections and Z p_T and mass reweighting
- efficiency scale-factors and corresponding systematics:
 - trigger and lepton ID efficiencies are included
 - jet energy scale and resolution
 - b-tagging efficiency SF
 - tau ID efficiency SF and energy scale (from Summer16/ReReco Tau POG study)

Event selection for both $tt \rightarrow e\tau_h$ $tt \rightarrow \mu\tau_h$

- pre-selection: tight isolated lepton, at least 3 jets, at least 1 b-tagged jet, $E_T^{miss} > 40\text{GeV}$
- selection: at least 1 tau (Medium WP)
- 2 categories for fit (for e and μ , separately): depending on threshold of dijet-trijet mass parameter (discussed later)

Control plots, pre-selection for $t\bar{t} \rightarrow e\tau_h$



E_T^{miss} and transverse mass $M_T(\ell, E_T^{\text{miss}})$

Oleksii Toldaiev (LIP)

leading lepton p_T and eta

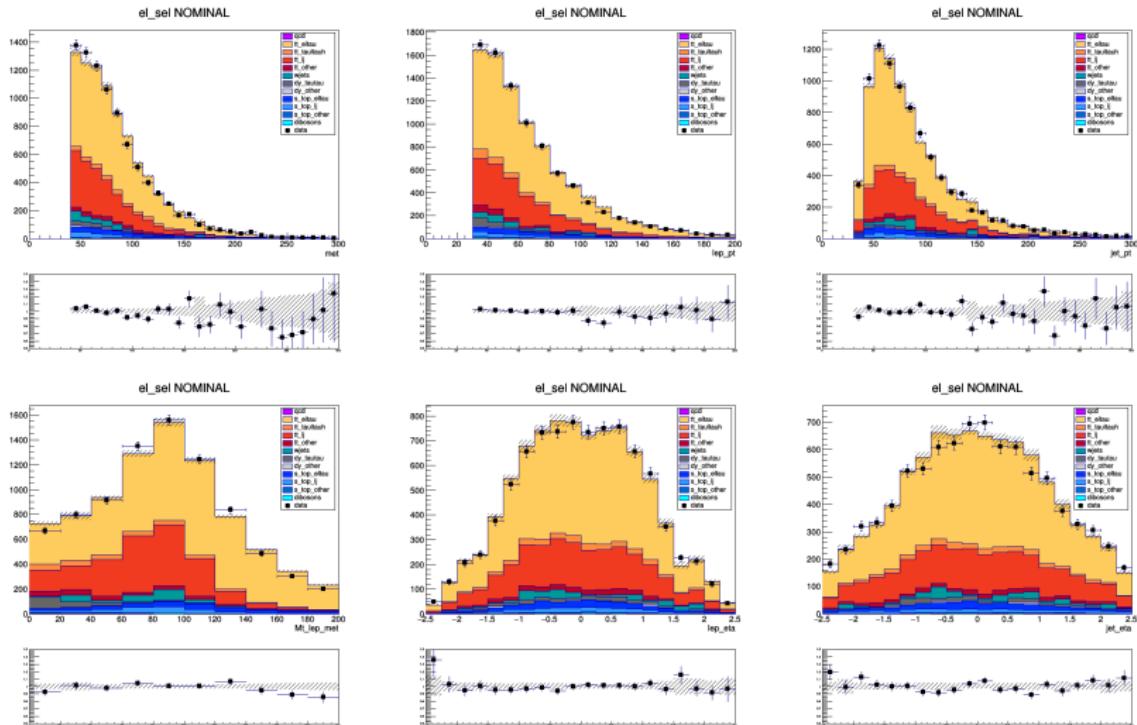
$t\bar{t} \rightarrow l\tau$ cross-section

leading jet p_T and eta

15 November 2017

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Control plots, selection for $t\bar{t} \rightarrow e\tau_h$



E_T^{miss} and transverse mass $M_T(\ell, E_T^{miss})$

Oleksii Toldaiev (LIP)

leading lepton p_T and
eta

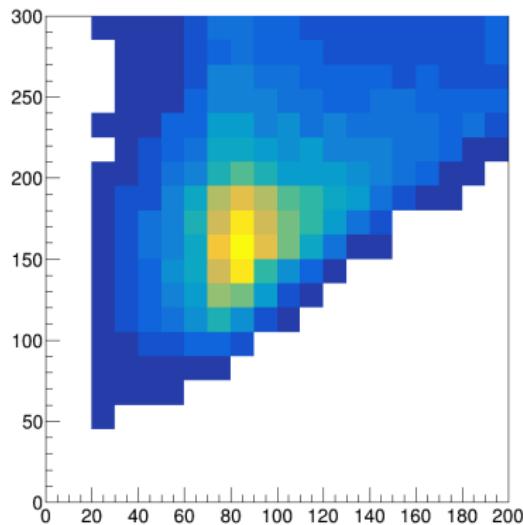
leading jet p_T and eta

Event categories for the fit, dijet-trijet parameters

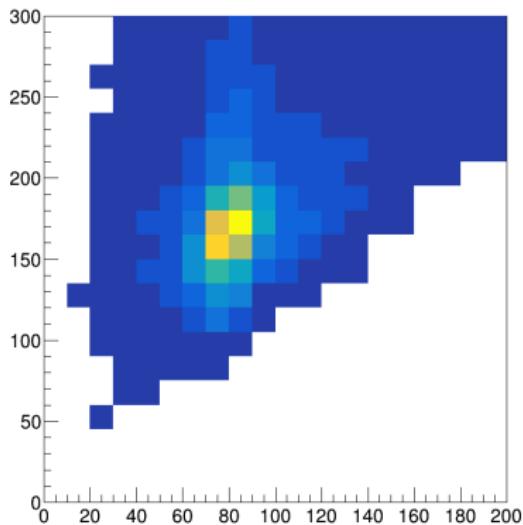
Using kinematics of main background $t\bar{t} \rightarrow \ell + jets$ construct a category to constrain it in the fit:

- split the jets into b-tagged and not b-tagged
- loop over all jet pairs of not b-tagged and find the one with mass closest to 80GeV
- loop over b-tagged jets and find the combination of 3 jets (1 b-tagged + jet pair) closest to 173GeV

Dijet-trijet parameters for event categories



2D histogram dijet-trijet mass in
signal

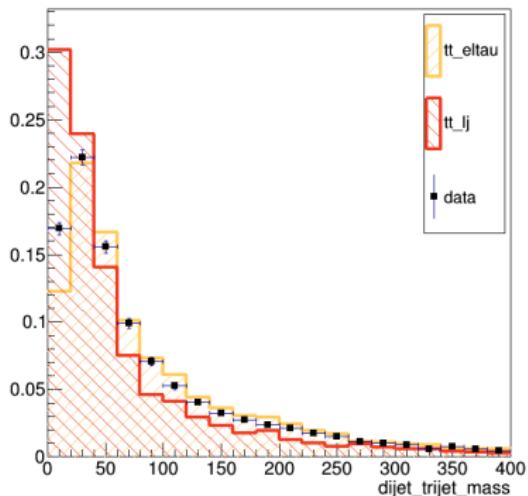


2D histogram dijet-trijet mass in
background

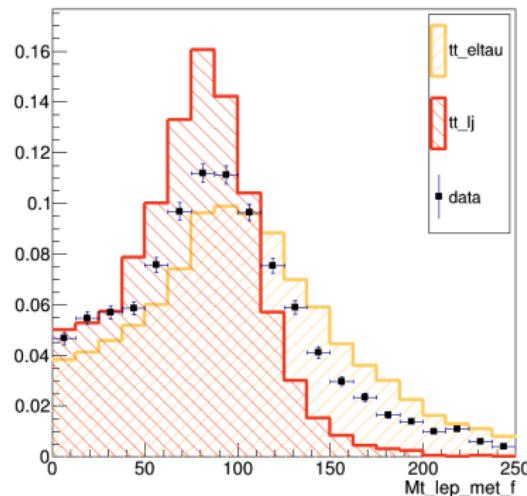
Shapes of dijet-trijet parameter and transverse mass

The separation between signal ($\ell\tau_h$) and background (ℓj) is provided by different shape of transverse mass distributions $M_T(\ell, E_T^{\text{miss}})$ and the dijet-trijet mass distance parameter.

The shape distributions (normalized to 1) are shown in electron-tau selection step:



dijet-trijet mass distance parameter



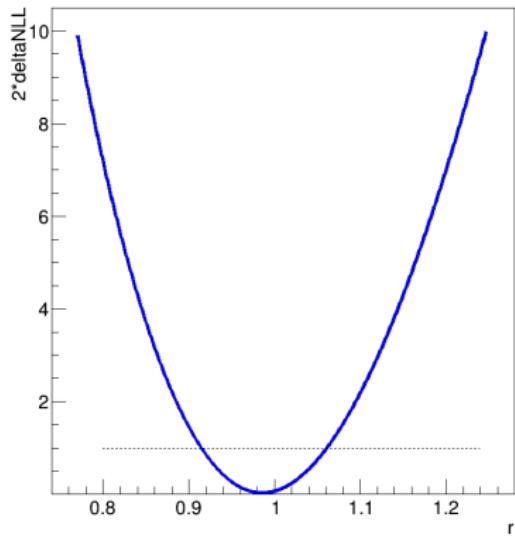
transverse mass $M_T(\ell, E_T^{\text{miss}})$

Fit results

NLL scan of the fit.

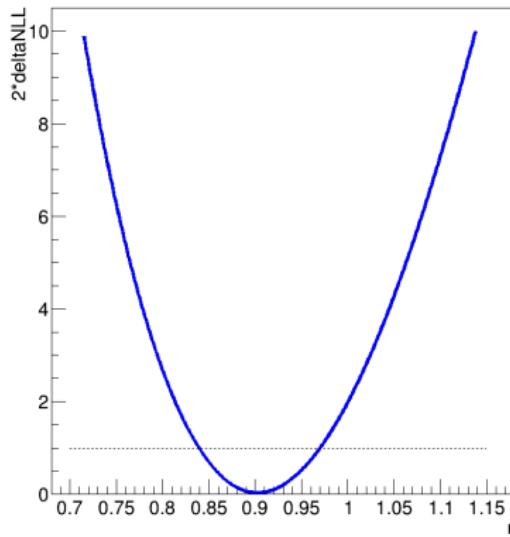
0.987 ± 0.075 in electron+tau

$2*\delta\text{NLL}:r \{\delta\text{NLL}>0 \&& 2*\delta\text{NLL}<10\}$

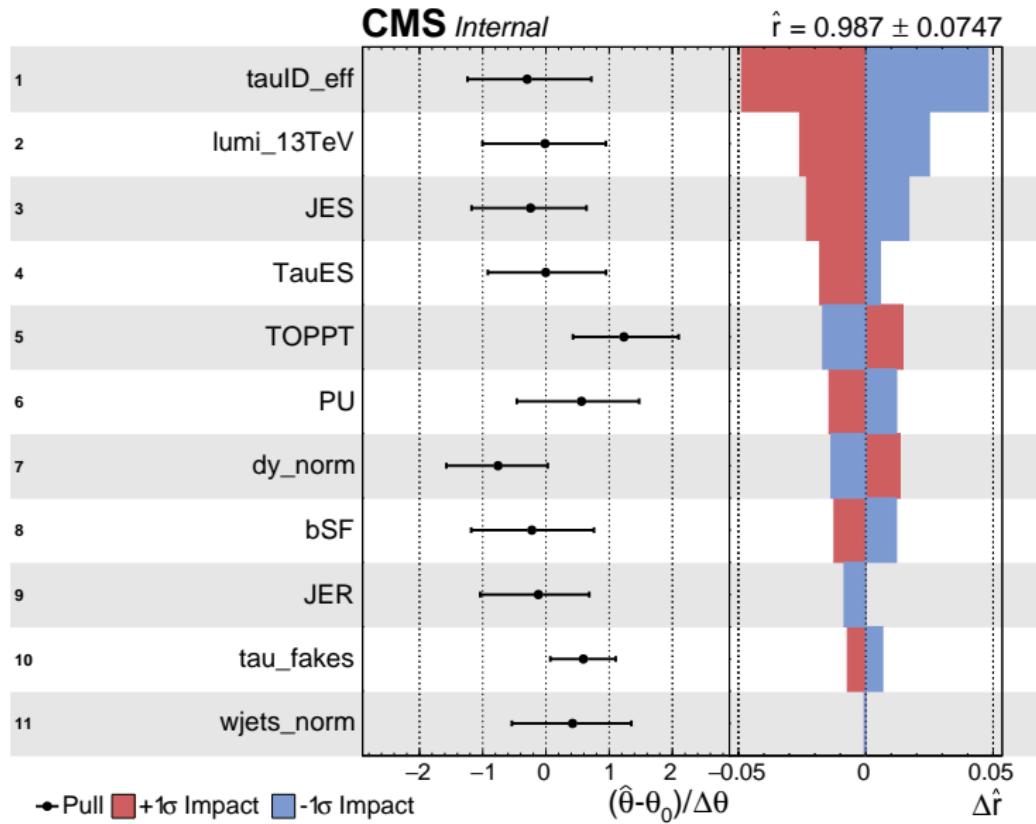


0.903 ± 0.067 in muon+tau

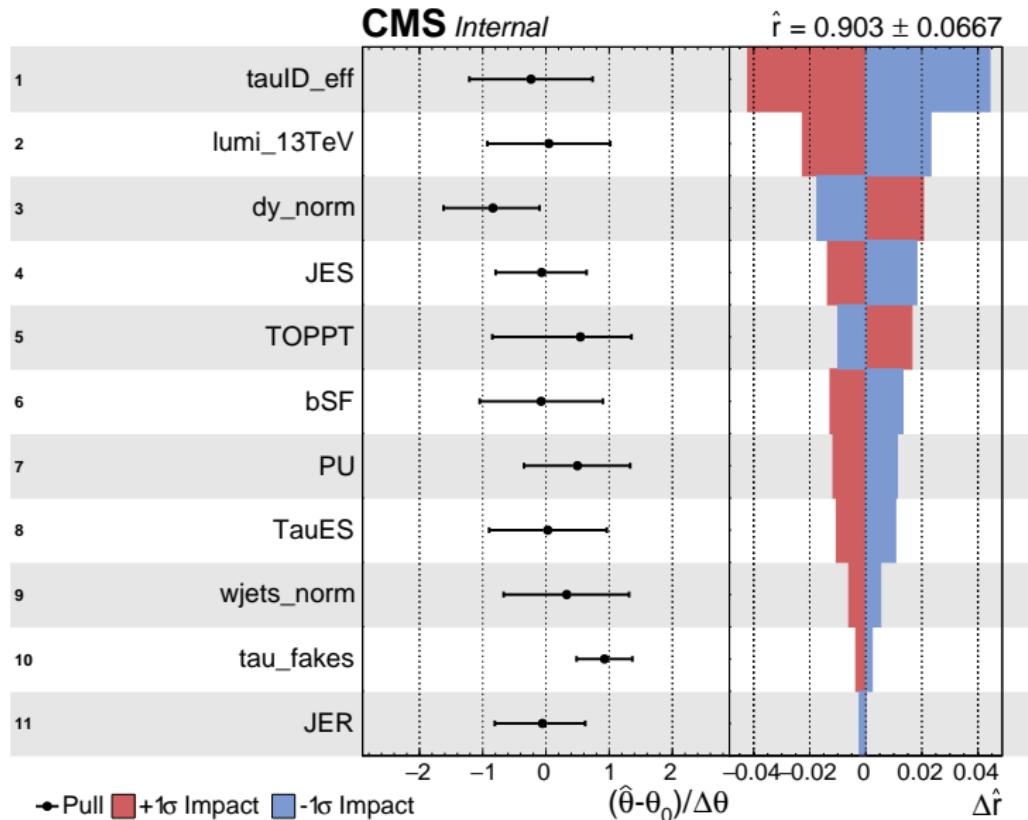
$2*\delta\text{NLL}:r \{\delta\text{NLL} > 0 \&& 2*\delta\text{NLL} < 10\}$



Fit results, impacts, electron+tau



Fit results, impacts, muon+tau

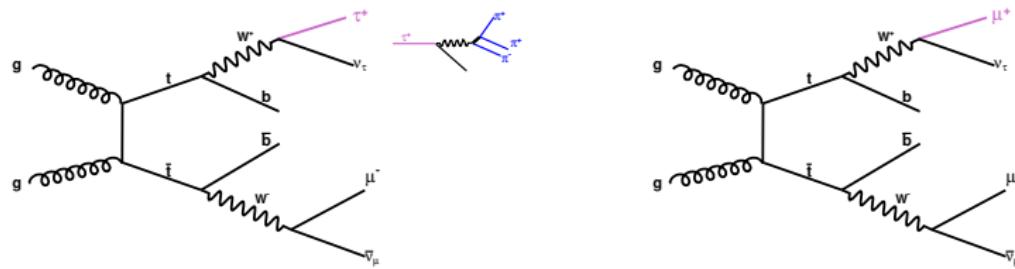


Summary and following steps

- the fit provides constrain for systematic uncertainty on fake taus in the channel
- overall systematic uncertainty is on the order of 7%
- main uncertainty is tau ID, about 5%
- the control distributions look fine
- to add other systematics
- prepare documentation (AN 2017/289) and start pre-approval process

Lepton Universality test

Measurement



$$\begin{aligned}\sigma(\mu\tau) &= \sigma_{pp}(t\bar{t})B(W \rightarrow \mu)B(W \rightarrow \tau) \\ \sigma(\mu\mu) &= \sigma_{pp}(t\bar{t})B(W \rightarrow \mu)(B(W \rightarrow \mu) + B(W \rightarrow \tau \rightarrow \mu))\end{aligned}\quad (1)$$

$$\begin{aligned}\frac{\sigma(\mu\tau)}{\sigma(\mu\mu)} &= \frac{B(W \rightarrow \tau)}{B(W \rightarrow \mu) + B(W \rightarrow \tau \rightarrow \mu)} \\ &= \frac{\frac{B(W \rightarrow \tau)}{B(W \rightarrow \mu)}}{1 + B(W \rightarrow \tau) \frac{B(\tau \rightarrow \tau)}{B(W \rightarrow \mu)}}\end{aligned}\quad (2)$$

Current measurement

$W \rightarrow e\nu$	$(10.75 \pm 0.13) \%$
$W \rightarrow \mu\nu$	$(10.57 \pm 0.15) \%$
$W \rightarrow \tau\nu$	$(11.25 \pm 0.20) \%$

from Particle Data Group (2012)

- measurements from LEP (WW channel) and Tevatron (W+jets)
- excess of about 2.5σ
- relative uncertainty $\approx 3.5\%$
- about 2% is needed
- roughly 20k of $W \rightarrow \ell\tau_h$ events can be expected in $100fb^{-1}$, thus systematic uncertainty is main concern

Current systematic uncertainties

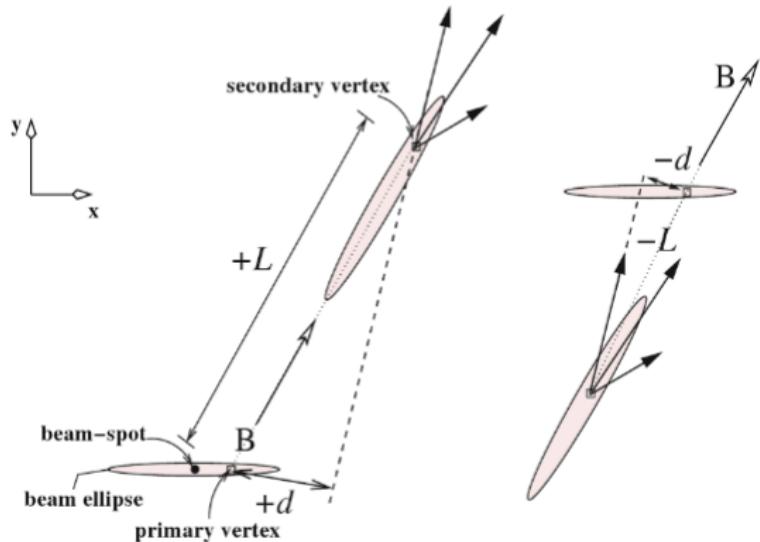
TOP-12-026

Source	Uncertainty [%]		
	$e\tau_h$	$\mu\tau_h$	Combined
Experimental uncertainties:			
τ_h jet identification	6.0	6.0	6.0
τ_h misidentification background	4.3	4.3	4.3
τ_h energy scale	2.4	2.5	2.5
b-jet tagging, jet misidentification	1.6	1.6	1.6
jet energy scale, jet energy resolution, E_T^{miss}	1.9	1.9	1.9
lepton reconstruction	0.8	0.6	0.5
other backgrounds	0.6	0.7	0.7
luminosity	2.6	2.6	2.6
Theoretical uncertainties:			
matrix element-parton shower matching	1.7	1.3	1.5
factorisation/renormalisation scale	2.9	2.9	2.9
generator	1.5	1.5	1.5
hadronisation	1.7	1.7	1.7
top-quark p_T modelling	0.7	0.5	0.6
parton distribution functions	0.8	0.7	0.7
total systematic uncertainty	9.6	9.5	9.5

- many uncertainties cancel out
- but the related to tau ID are largest
- thus one needs to improve tau ID
- it can be done in tau decay into 3 charged hadrons with the secondary vertex of the decay

from TOP-12-026, similar to what I usually have

Secondary Vertex in $\tau \rightarrow 3\pi + \nu_\tau$



main parameters are:

- flight length is distance between PV and SV
- flight length significance is flight length divided by uncertainty

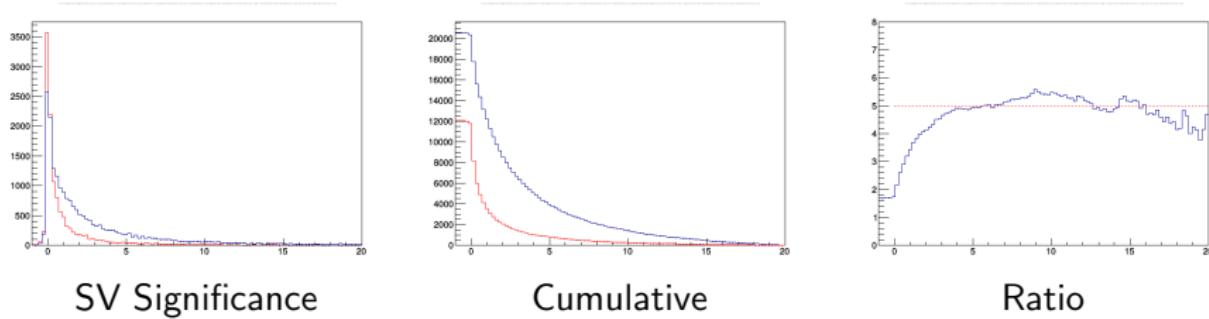
Primary Vertex (SV) and Secondary Vertex (SV)

Tau Secondary Vertex in MINIAOD and ID from Tau POG

- some significance of Secondary Vertex is already stored in MINIAOD taus
- and it is used in MVA ID from Tau POG
- but a study shows the Secondary Vertex can be reconstructed better
- in fact, a geometrical solution for 3 tracks and their impact parameters yields better result (on the following slides)

Significance of geometrical SV

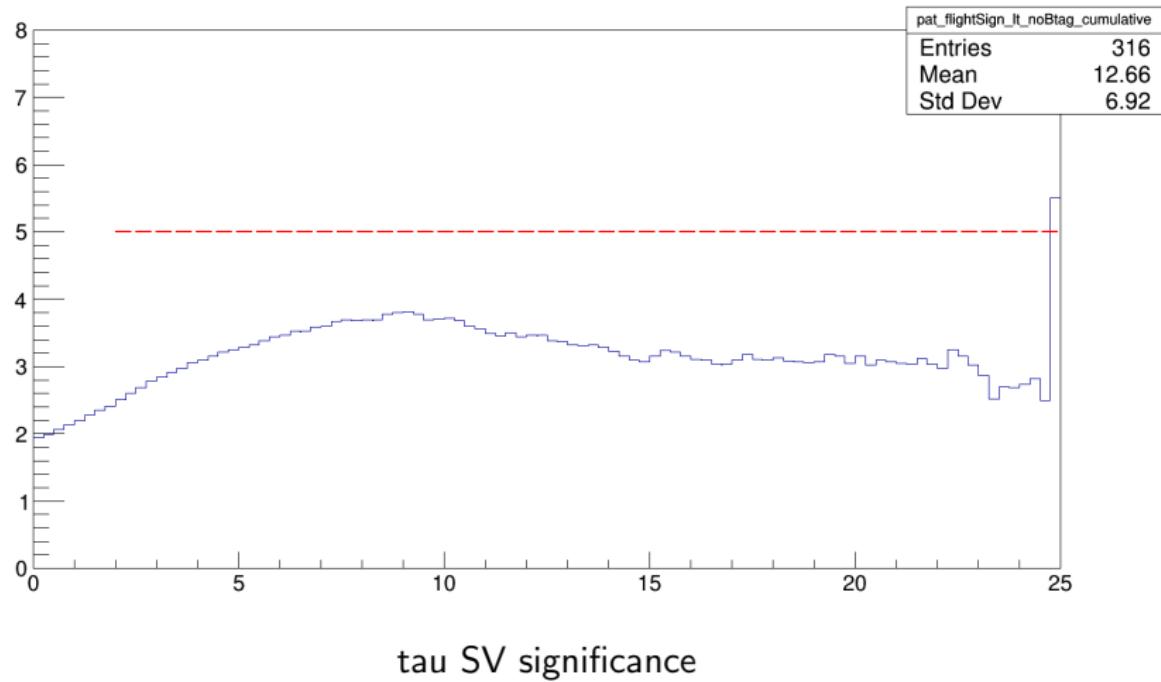
Plot of SV significance in signal $t\bar{t} \rightarrow \ell\tau_h$ (blue) and main background $t\bar{t} \rightarrow \ell\text{jets}$ (red). Cumulative distribution shows amount of events at given cut on Significance. And ratio of signal/background numbers of events is given on right.



At cut of Significance = 4 the ratio signal/background is about 5.
The cumulative ratio is about 2, which is exactly what I have now in cross-section measurement.

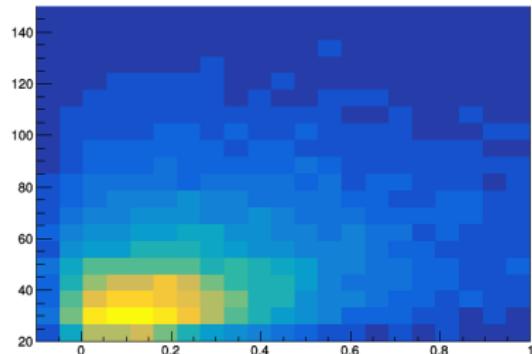
PAT tau SV, ratio of cumulative distribution

The same ratio distribution for the same events with tau SV Significance from MINIAOD. Maximum ratio is about 3.5 times.

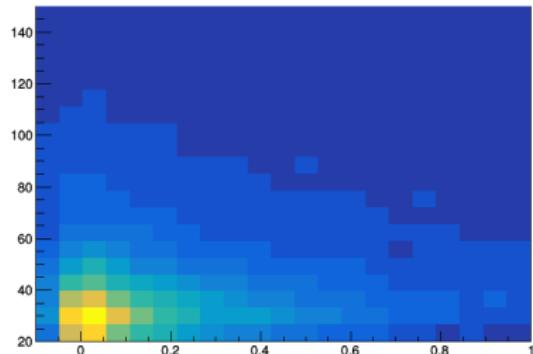


Correlation between flight length and tau energy

Small correlation is seen in flight length (X axis) VS energy (Y axis) distribution.



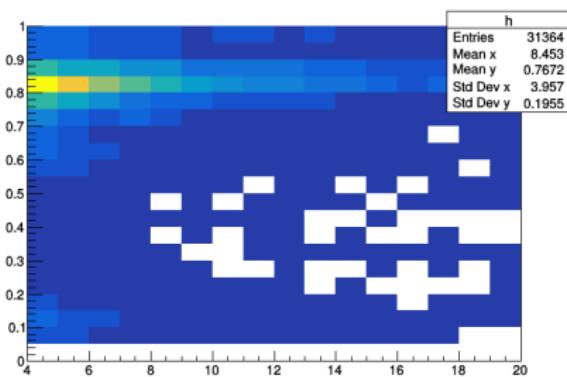
true taus



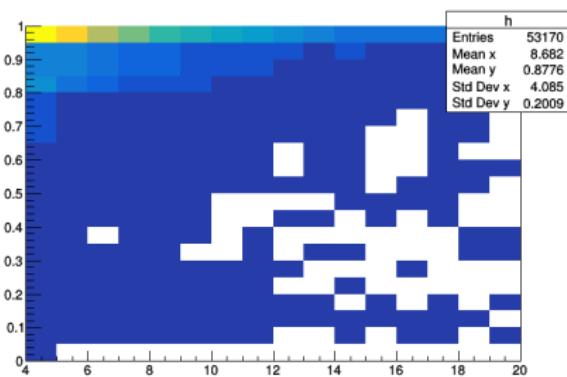
fake taus from jets

B-discriminant of tau jet at high SV Significance

B-jets also fake taus and have large SV Significance, but the b-tagging algorithm catches them: SV flight length significance on X axis, b-discriminator of tau jet on Y axis.



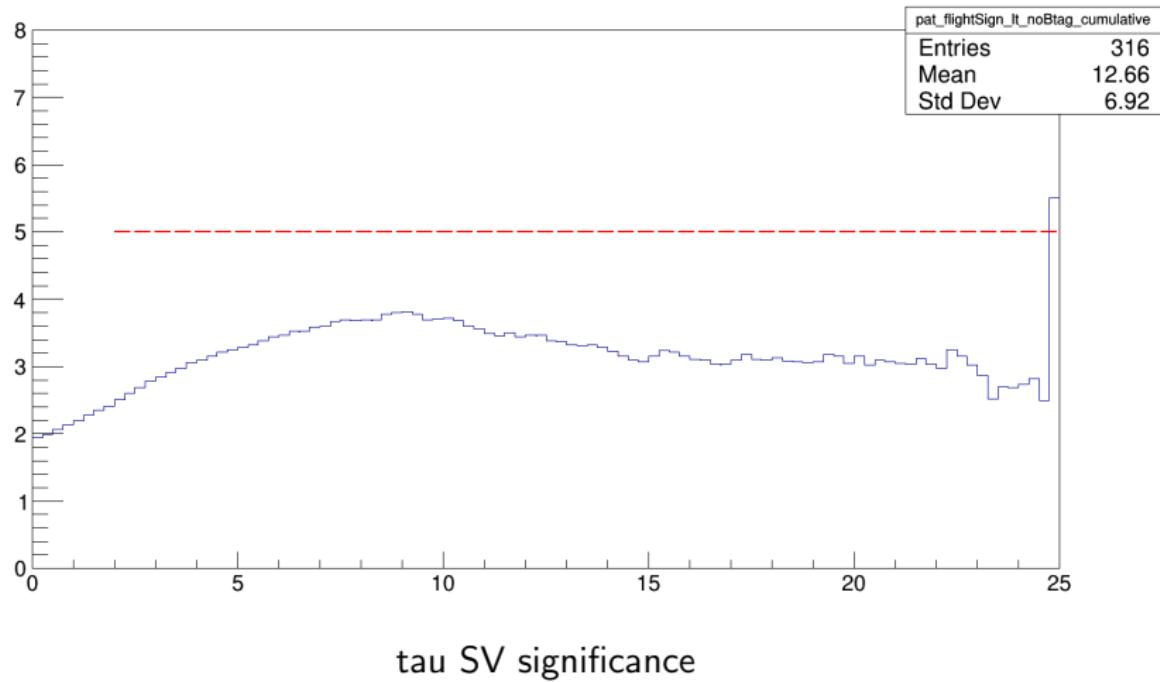
true taus



fake taus from jets

MINIAOD SV Significance in current $t\bar{t}$ selection

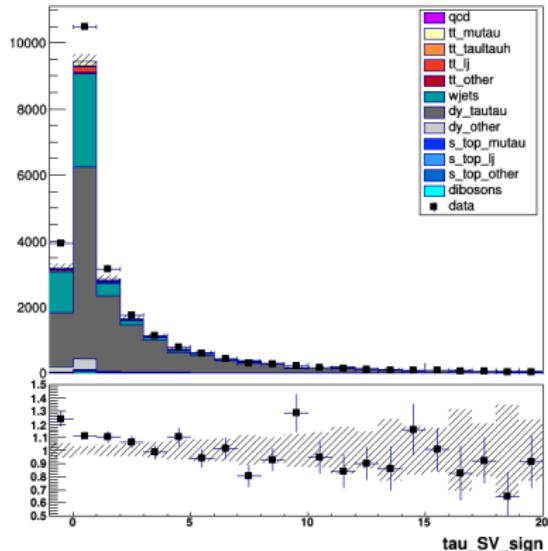
The same ratio distribution for the same events with tau SV Significance from MINIAOD. Maximum ratio is about 3.5 times.



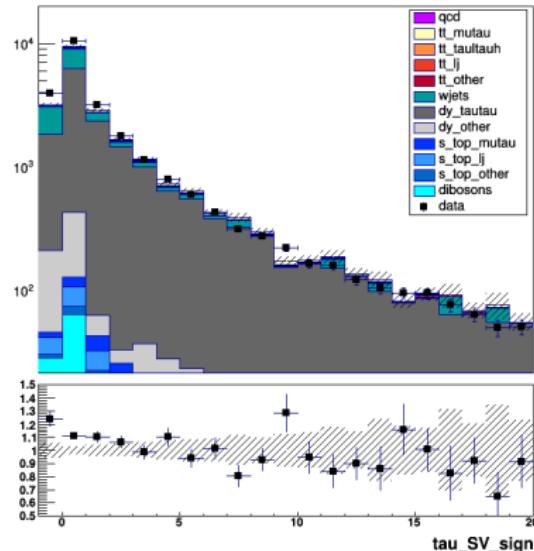
Geometrical SV Significance in $Z \rightarrow \tau_\ell \tau_h$ control region

Usual selection for $Z \rightarrow \tau_\ell \tau_h$ from Tau POG studies is saved as a control region.
One can see effect of SV Significance in the region.

ctr_mu_dy_tt NOMINAL



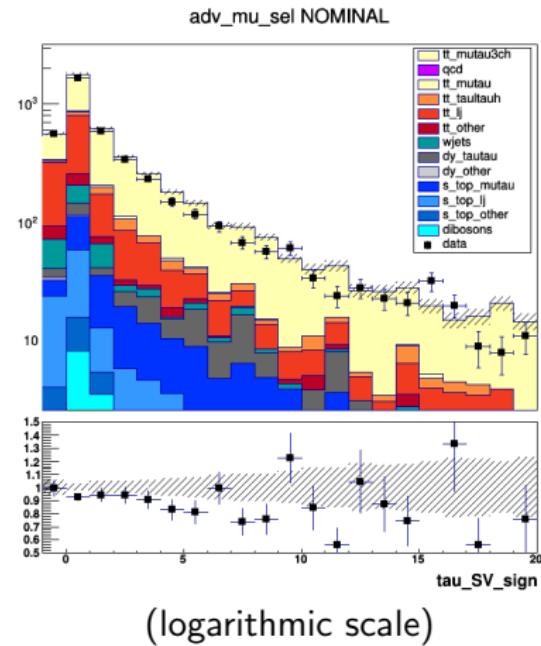
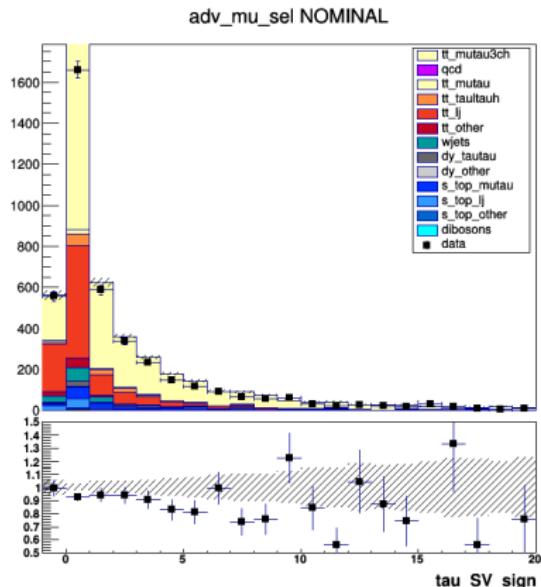
ctr_mu_dy_tt NOMINAL



(logarithmic scale)

Geometrical SV Significance in $t\bar{t} \rightarrow \mu\tau_h$ selection

SV significance in the usual selection for $t\bar{t} \rightarrow \mu\tau_h$.



Prospects

- indeed track information in MiniAOD is sufficient to significantly improve SV
- work on fitting algorithm for SV reconstruction
- the study of effect on tau ID uncertainty is on-going
- other studies for the analysis:
 - use kinematic parameters of tau decay could be used (Dalitz parameters of cascade two-body decay $\tau \rightarrow a1 \rightarrow \pi\rho \rightarrow 3\pi$)
 - effect of tracking efficiency on tau ID
 - couple theoretical questions
- the plan is to launch this analysis next year with target for preliminary results for Tau Conference in September

backup

Current measurements

$\Gamma(\mu^+\nu)/\Gamma_{\text{total}}$

<i>VALUE (units 10^{-2})</i>	<i>EVTS</i>
10.57 ± 0.15 OUR FIT	
$10.78 \pm 0.24 \pm 0.10$	2397
$10.65 \pm 0.26 \pm 0.08$	1998
$10.03 \pm 0.29 \pm 0.12$	1423
$10.87 \pm 0.25 \pm 0.08$	2216

Γ_3/Γ

$\Gamma(\tau^+\nu)/\Gamma_{\text{total}}$

<i>VALUE (units 10^{-2})</i>	<i>EVTS</i>
11.25 ± 0.20 OUR FIT	
$11.14 \pm 0.31 \pm 0.17$	2177
$11.46 \pm 0.39 \pm 0.19$	2034
$11.89 \pm 0.40 \pm 0.20$	1375
$11.25 \pm 0.32 \pm 0.20$	2070

Γ_4/Γ

from Particle Data Group (2012)

Current measurements

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$

Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
1.046 ± 0.023 OUR FIT				
0.961 \pm 0.061	980	⁴² ABBOTT	00D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
0.94 \pm 0.14	179	⁴³ ABE	92E CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
1.04 \pm 0.08 \pm 0.08	754	⁴⁴ ALITTI	92F UA2	$E_{cm}^{p\bar{p}} = 630$ GeV
1.02 \pm 0.20 \pm 0.12	32	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.995 \pm 0.112 \pm 0.083	198	ALITTI	91C UA2	Repl. by ALITTI 92F
1.02 \pm 0.20 \pm 0.10	32	ALBAJAR	87 UA1	Repl. by ALBAJAR 89

⁴² ABBOTT 00D measure $\sigma_W \times B(W \rightarrow \tau\nu_\tau) = 2.22 \pm 0.09 \pm 0.10 \pm 0.10$ nb. Using the ABBOTT 00B result $\sigma_W \times B(W \rightarrow e\nu_e) = 2.31 \pm 0.01 \pm 0.05 \pm 0.10$ nb, they quote the ratio of the couplings from which we derive this measurement.

⁴³ ABE 92E use two procedures for selecting $W \rightarrow \tau\nu_\tau$ events. The missing E_T trigger leads to $132 \pm 14 \pm 8$ events and the τ trigger to $47 \pm 9 \pm 4$ events. Proper statistical and systematic correlations are taken into account to arrive at $\sigma B(W \rightarrow \tau\nu) = 2.05 \pm 0.27$ nb. Combined with ABE 91C result on $\sigma B(W \rightarrow e\nu)$, ABE 92E quote a ratio of the couplings from which we derive this measurement.

⁴⁴ This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

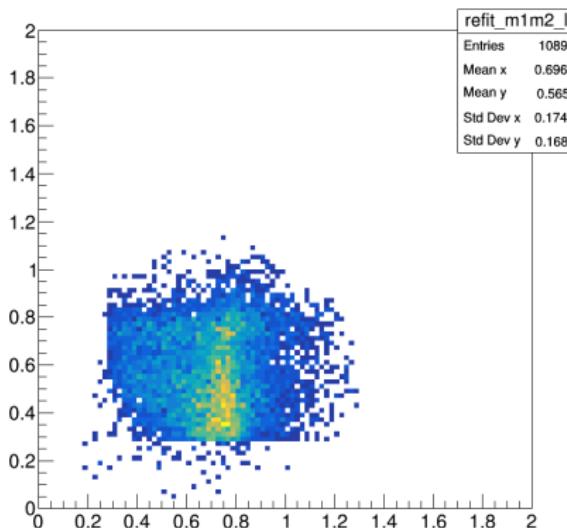
from Particle Data Group (2012)

Dalitz parameters in true and fake taus

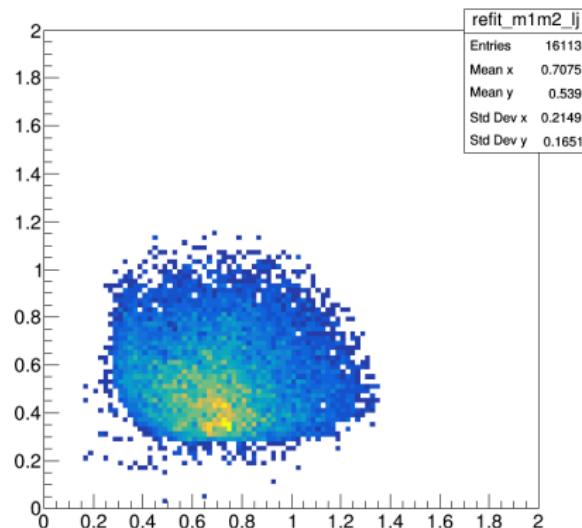
built on invariant masses of pairs of tracks

X axis = $m(OS, SS1)$

Y axis = $m(OS, SS2)$



signal

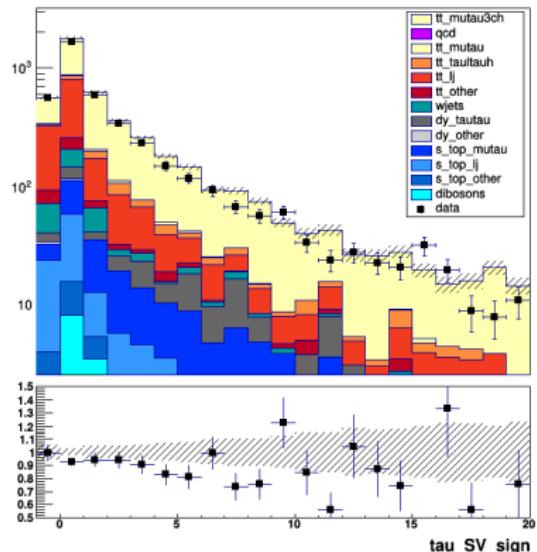


background

Comparison of b-discriminator-cut in $t\bar{t} \rightarrow \mu\tau_h$ selection

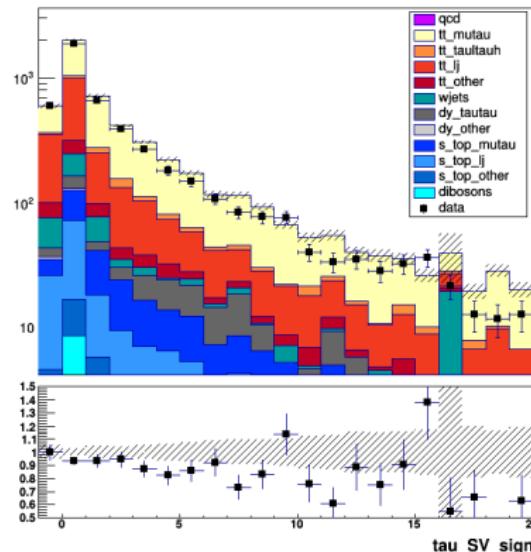
SV significance in the usual selection for $t\bar{t} \rightarrow \mu\tau_h$ with and without cut of 0.9 on b-discriminator.

adv_mu_sel NOMINAL



with b-discriminator < 0.9

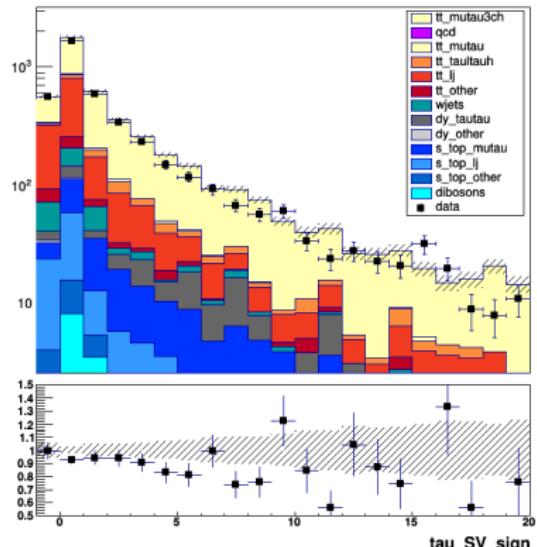
mu_sel NOMINAL



without b-discriminator < 0.9

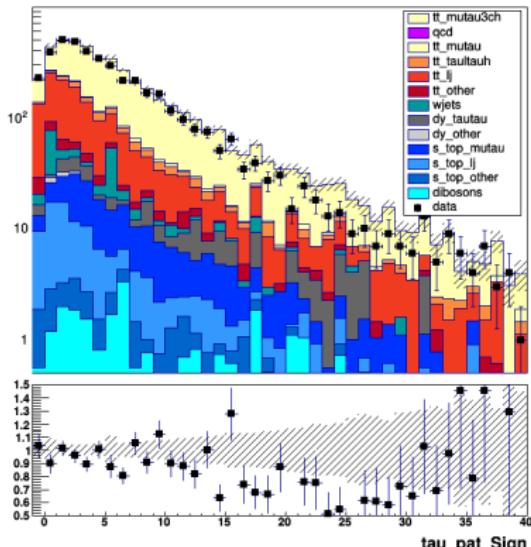
Comparison of geometrical and MINIAOD SV significance in $t\bar{t} \rightarrow \mu\tau_h$ selection

adv_mu_sel NOMINAL



geometrical significance

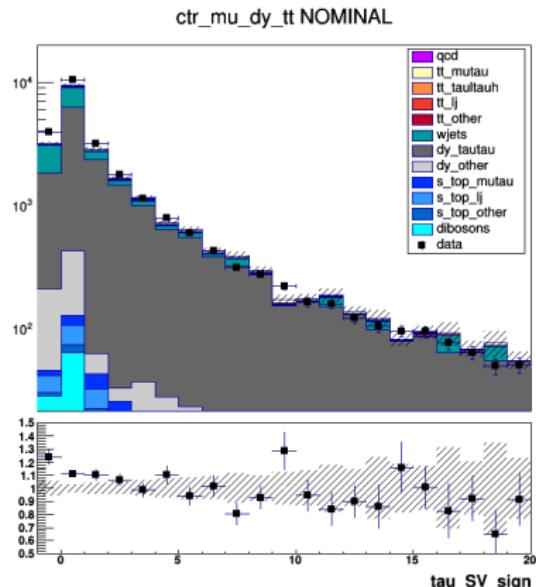
adv_mu_sel NOMINAL



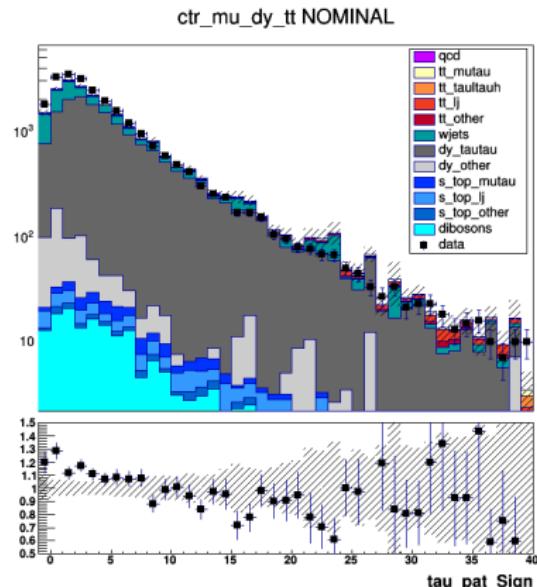
significance from MINIAOD

Both have cut of 0.9 on b-discriminator.

Comparison of geometrical and MINIAOD SV significance in $Z \rightarrow \tau_\ell \tau_h$



geometrical significance



significance from MINIAOD

Both have cut of 0.9 on b-discriminator.

Datasets, full listing

03Feb2017 ReReco

name	dataset
SingleElectron	/ SingleElectron /Run2016B–03Feb2017.ver2–v2/MINIAOD
	/ SingleElectron /Run2016C–03Feb2017–v1/MINIAOD
	/ SingleElectron /Run2016D–03Feb2017–v1/MINIAOD
	/ SingleElectron /Run2016E–03Feb2017–v1/MINIAOD
	/ SingleElectron /Run2016F–03Feb2017–v1/MINIAOD
	/ SingleElectron /Run2016G–03Feb2017–v1/MINIAOD
	/ SingleElectron /Run2016H–03Feb2017.ver2–v1/MINIAOD
	/ SingleElectron /Run2016H–03Feb2017.ver3–v1/MINIAOD
SingleMuon	/SingleMuon/Run2016B–03Feb2017_ver2–v2/MINIAOD
	/SingleMuon/Run2016C–03Feb2017–v1/MINIAOD
	/SingleMuon/Run2016D–03Feb2017–v1/MINIAOD
	/SingleMuon/Run2016E–03Feb2017–v1/MINIAOD
	/SingleMuon/Run2016F–03Feb2017–v1/MINIAOD
	/SingleMuon/Run2016G–03Feb2017–v1/MINIAOD
	/SingleMuon/Run2016H–03Feb2017_ver2–v1/MINIAOD
	/SingleMuon/Run2016H–03Feb2017_ver3–v1/MINIAOD

MC datasets

RunIISummer16MiniAODv2—PUMoriond17_80X_mcRun2_asymptotic_2016_TranchelV_v6/MINIAODSIM

dataset	cross-section
ttbar	
/TT_TuneCUETP8M2T4_13TeV_powheg_pythia8/...	831.76
s-top	
/ST_tW_top_5f_inclusiveDecays_13TeV_powheg_pythia8_TuneCUETP8M1/...	35.85
/ST_tW_antitop_5f_inclusiveDecays_13TeV_powheg_pythia8_TuneCUETP8M1/...	35.85
/ST_t-channel_top_4f_inclusiveDecays_13TeV_powhegV2_madspin_pythia8_TuneCUETP8M1/...	80.95
/ST_t-channel_antitop_4f_inclusiveDecays_13TeV_powhegV2_madspin_pythia8_TuneCUETP8M1/...	136.02
/ST_s-channel_4f_leptonDecays_13TeV_amcatnlo_pythia8_TuneCUETP8M1/...	3.36
wjets	
/WJetsToLNu_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	47447.2
/W1JetsToLNu_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	9493
/W2JetsToLNu_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	3120
/W3JetsToLNu_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	942.3
/W4JetsToLNu_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	524.2
dyjets	
/DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV_amcatnloFXFX_pythia8/...	18830
/DYJetsToLL_M-50_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	5765.4
qcd	
/QCD_HT100to200_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	27540000
/QCD_HT200to300_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	1717000
/QCD_HT300to500_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	351300
/QCD_HT500to700_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	31630
/QCD_HT700to1000_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	6802
/QCD_HT1000to1500_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	1206
/QCD_HT1500to2000_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	120.4
/QCD_HT2000toInf_TuneCUETP8M1_13TeV_madgraphMLM_pythia8/...	25.25

General event selection and triggers

- good luminosity, golden json certificate for SingleMuon and the certificate json from Top Trigger group for SingleElectron (without L1 prescaled lumisections)
Cert_271036–284044_13TeV_23Sep2016ReReco_Collis (36fb^{-1})
LSforPath_HLT_Ele27_WPTight_Gsf_withLowestSeed_L1_SingleIsoEG26_OR_L1_SingleEle27 (32fb^{-1})
- pass E_T^{miss} filters for the data, with new Flag_noBadMuons for the muon fix
- pass **single-lep HLT triggers**,
electrons — HLT_Ele27_WPTight_Gsf_v* data and v8 MC
muons — HLT_IsoMu24_v, HLT_IsoTkMu24_v* data and v4 MC

Object definition (Moriond17 recommendations)

- electrons:

Tight cut-based ID, $p_T > 30\text{ GeV}$, $\eta < 2.4$

no "veto electrons" – Loose ID, $p_T > 15\text{ GeV}$, $\eta < 2.5$

- muons:

Tight cut-based ID (std in PAT muons), $p_T > 27\text{ GeV}$, $\eta < 2.4$,

no "veto muons" – Loose ID, $p_T > 10\text{ GeV}$, $\eta < 2.5$

- taus:

$\text{decayModeFinding} > 0.5$

$\text{againstMuonTight3} > 0.5$

$\text{againstElectronTightMVA6} > 0.5$;

$\text{byMediumIsolationMVArun2v1DBoldDMwLT} > 0.5$

$p_T > 30\text{ GeV}$, $\eta < 2.4$

cross-cleaned of leptons with $\delta R > 0.4$

- jets:

corrected with Summer16_23Sep2016HV4, resolution smeared, propagated to E_T^{miss}

Loose PF-based ID $p_T > 30\text{ GeV}$, $\eta < 2.5$

cross-cleaned of leptons with $\delta R > 0.4$

- b-tag: medium CSVv2 with CSVv2_Moriond17_B_H.csv SFs

MC re-weighting

- MC weights for aMC@NLO datasets (-1 weights)
 - pile-up reweighting
 - top p_T reweighting (from 13TeV) (done as systematic variation)
 - recoil corrections and Z p_T and mass reweighting
- efficiency scale-factors and corresponding systematics:
 - trigger and lepton ID efficiencies are included
 - jet energy scale and resolution
 - b-tagging efficiency SF
 - tau ID efficiency SF and energy scale (from Summer16/ReReco)

Fit results, fitted nuisances

