Search for lepton flavor violation in pp collisions at $\sqrt{s}$ = 13 TeV with ATLAS detector

Xiangke Zhang

The 5th China LHC Physics Workshop

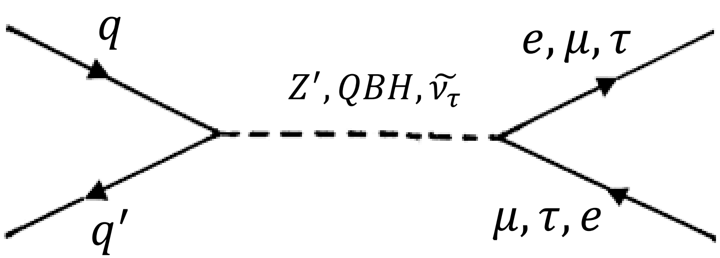
Shanghai JiaoTong University

Oct 26, 2019

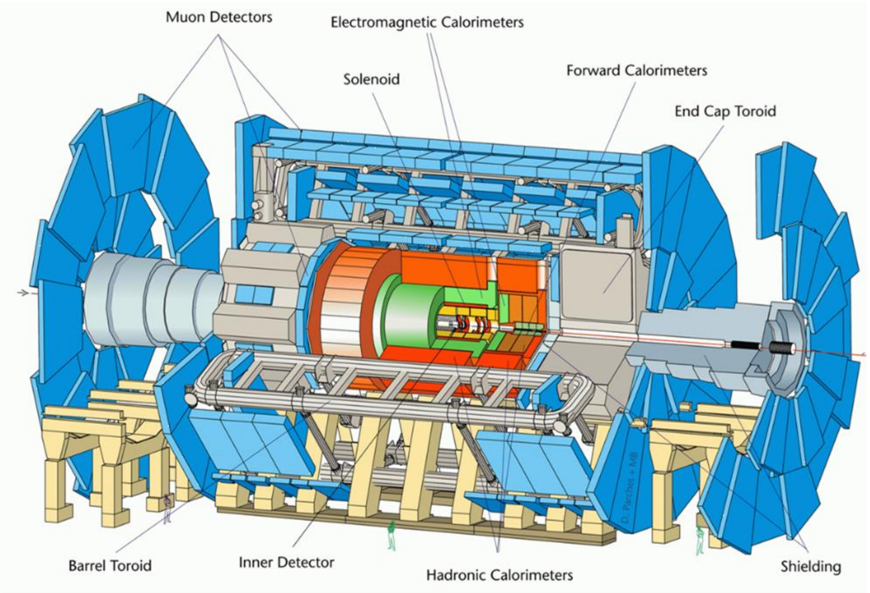
Contents

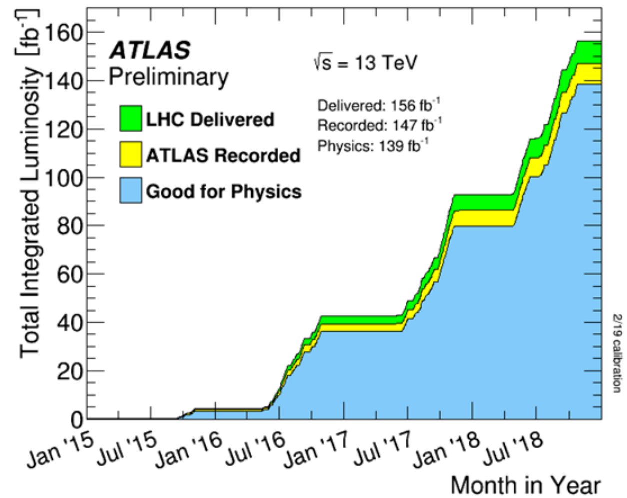
Physical models

models / Production & reason	SM	models with additional gauge symmetries	R-parity violating(RPV) SUSY	quantum black hole QBH
lepton pairs with different flavor (LFV)	Not allowed	allowed	allowed	allowed
Reason	LFC	Z'	sneutrino τ resonance	$pp \to QBH \to l^{\mp} l'^{\pm}$
Final state		$e\mu$, $e\tau$, $\mu\tau$		



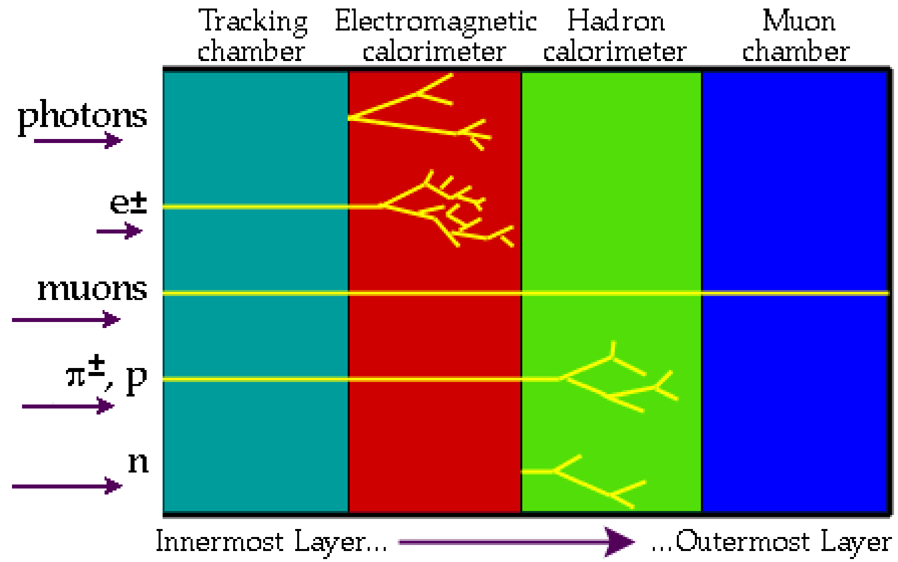
ATLAS detector





ATLAS

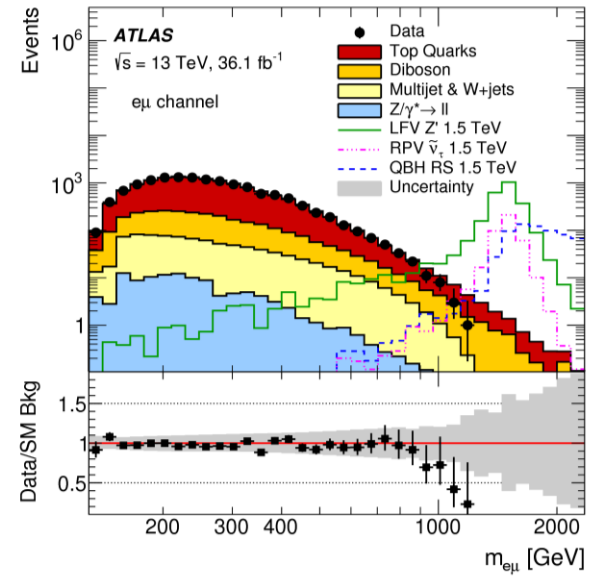
Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables



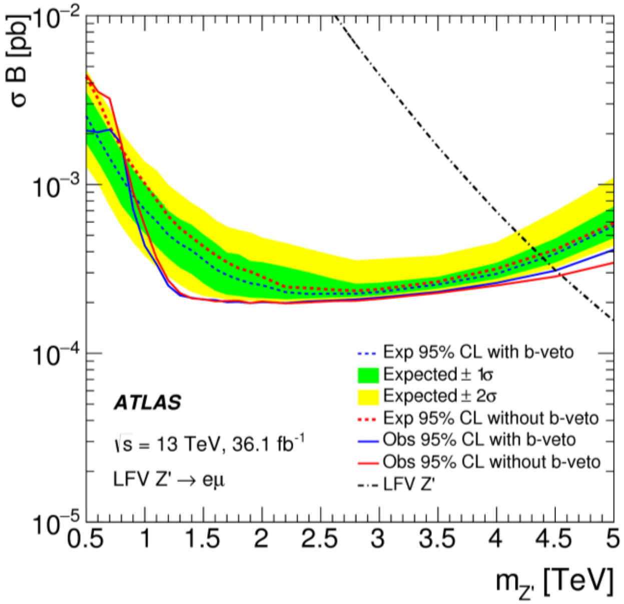
Analysis strategy

The aim of this search is to find an excess in the dilepton invariant mass spectrum that could point to lepton-flavour violating decays.

For that purpose, lepton pairs of $e\mu$, $e\tau_{had-vis}$ and $\mu\tau_{had-vis}$ are selected and their invariant mass is calculated.



Phys Rev D 98, 092008



The background-only hypothesis to look for possible deviations from SM. If no globally significant deviations are found, exclusion limits of the various models searched are extracted.

Background processes

Irreducible backgrounds	**Reducible backgrounds**
SM Drell-Yan($q\bar{q} \to Z/\gamma^* \to ll$) $t\bar{t}$ Single top Diboson(WW,WZ and ZZ)	QCD（Light jets $b\bar{b}$ $c\bar{c}$) W+jets
With two prompt leptons in the final state	Jets or non-prompt leptons are reconstructed as prompt leptons
MC simulation	Data-driven

Physics objects and events selection

Electron selection	Muon selection
P_T > 65 GeV & |eta| < 2.47 Crack region LH-Medium Electrons FixedCutTight Isolation Inner tracking requirement	P_T > 65 GeV & |eta| < 2.5 Use only combined muon FixedCutLoose Isolation Muon Quality Hight P_T Inner tracking requirement
Tau selection	**Event selection**
P_T > 65 GeV & |eta| < 2.47 Crack region Medium ID |charge|=1 Number prongs = 1 or 3	Combination of single electron and muon trigger Exactly two different-flavor leptons Opposite sign requirement $m_{ll'}$> 130 GeV and $\Delta\phi_{ll'}$>2.7

Fake background(Multijet) in the eμ channel: Matrix Method

$$\begin{bmatrix} N_{TT} \\ N_{LT} \end{bmatrix} = \begin{bmatrix} r_e & f_e \\ 1 & 1 \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{FR} \end{bmatrix}$$

N_{TT}: a sample where both electron and muon pass tight cut.

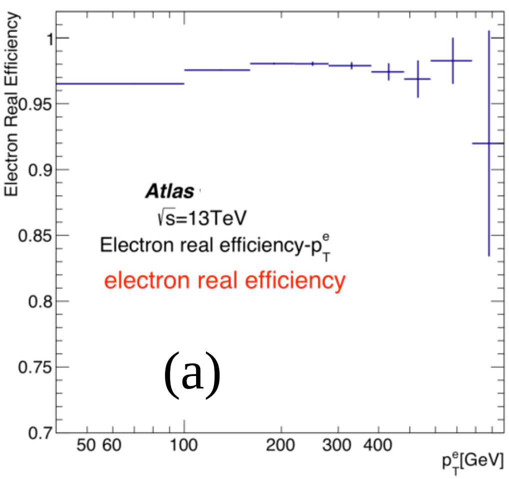
N_{LT}: a sample where electron passed loose cut and muon passed tight cut.

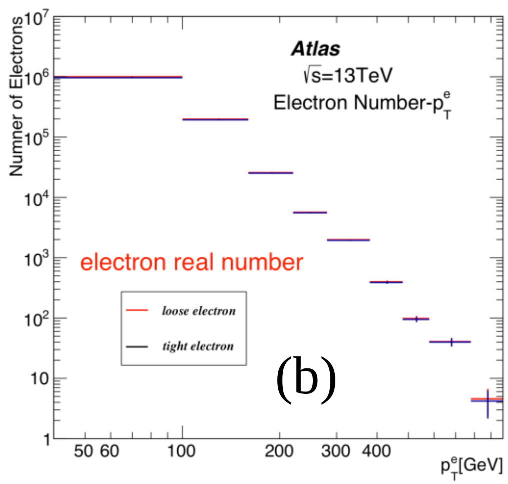
r_e : The real efficiency is $N_e^{Passtight}/N_e^{Loose}$ measured by MC samples.

f_e: The fake rate measured by multijet enriched sample in data.

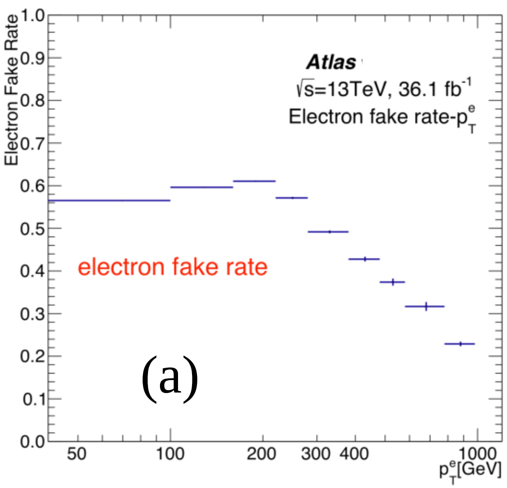
N_{RR} is data sample made up of a “real” electron and a “real” muon and N_{FR} is data sample made up of a “fake” electron and a “real” muon.

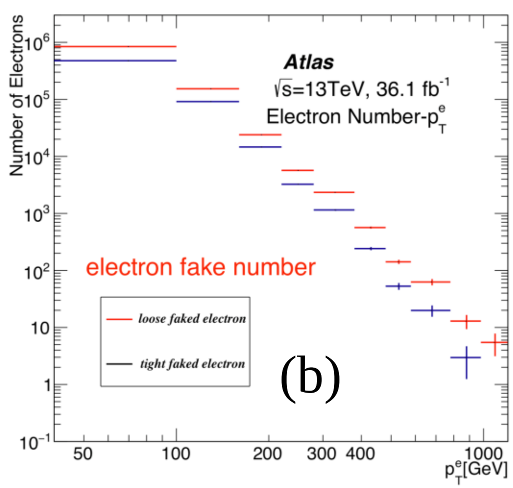
Fake background(Multijet) in eμ channel: Matrix Method





The electron real efficiency (a) and number of tight and loose electrons (b) as a function of the electron P_T.





The electron fake rate(a) and the number of tight and loose electrons in the multijet enriched sample(b) as a function of electron P_T.

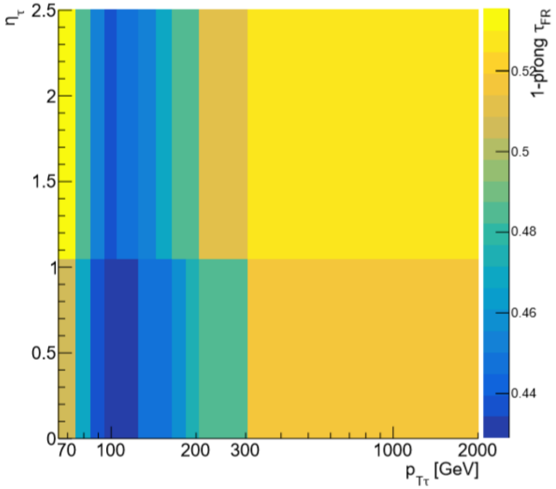
Fake background(W+jets) in eτ and μτ channel: Data-driven

W+jets background enriched sample in data:

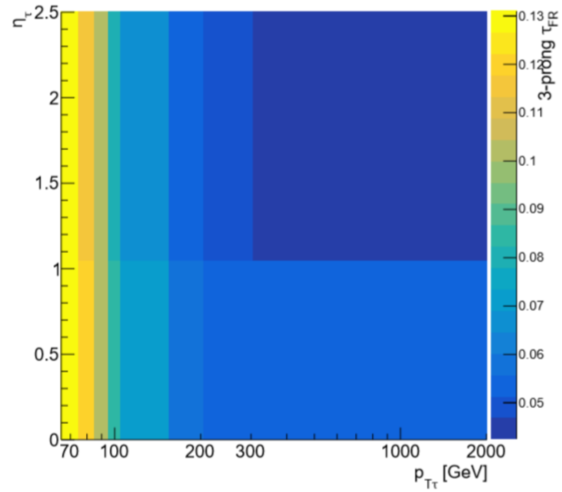
- Only one electron or muon passing the same criteria as for the signal selection;
- veto eτ/μτ pairs with invariant mass $80 < m_{l\tau} < 110$ GeV to remove events coming real Z decays, where $l = e, \mu$;
- Taus required to satisfy TauJetBDT score > 0.40;
- $\Delta\phi(l, \tau) < 2.7$ to ensure orthogonality with the signal region, where $l = e, \mu$;
- $m_T\left(l, E_{Miss}^T\right) > 80$ GeV,where $l = e, \mu$.

The tau fake rate is defined as: $\tau_{FR} = \frac{N_\tau^{PassID}}{N_t^{Tot}}$

Fake background(W+jets) in eτ and μτ channel: Data-driven

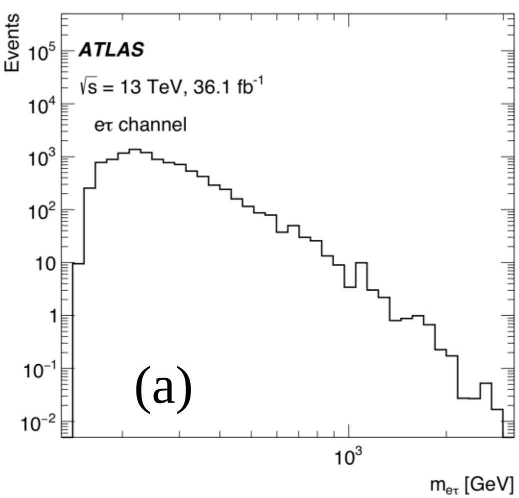


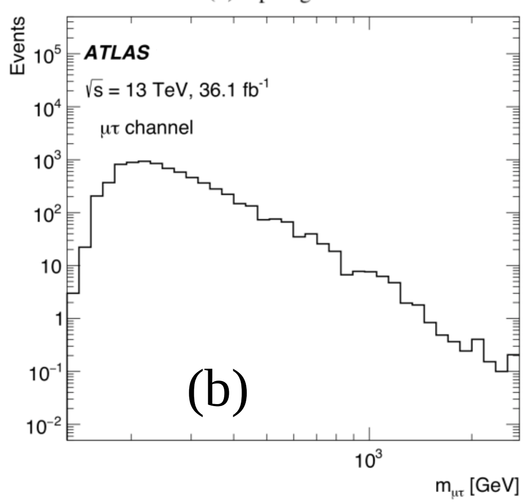
(a) 1-prong taus



(b) 3-prongs taus

Tau fake rate in the P_T-η plane for 1-prong(a) and 3-prongs(b) tau decays using data measured in the W+jets control region.





W+jets distributions in electron-tau (a) and muon-tau (b) invariant mass spectrum obtained applying the nominal fake rate to the MC simulation.

Fake background(Multijet) in eτ and μτ channel: Data-driven

Three regions about multijet sample in data:

	Object selection	Lepton-pair charges
R_1	Non-isolated e/μ & $\tau_{\text{had-vis}}$ failing τ ID requirements (p_{T_ℓ} & p_{T_τ} < 200 GeV)	Same-charge
R_2	Isolated e/μ & pass ID $\tau_{\text{had-vis}}$ (p_{T_ℓ} & p_{T_τ} < 200 GeV)	Same-charge
R_3	Non-isolated e/μ & $\tau_{\text{had-vis}}$ failing τ ID requirements	Same-charge + Opposite-charge

In each region it is assumed that the multijet contribution is equal to:

$$N_{Multijet}^{Reg} = N_{Data}^{Reg} - N_{MC}^{Reg}$$

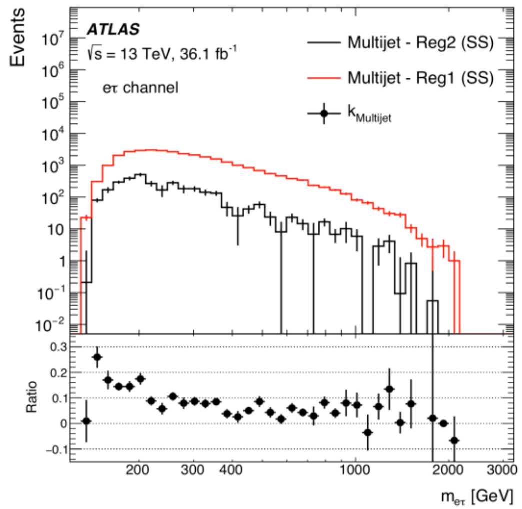
The ratio of isolated to non-isolated events found in regions 2 and 1:

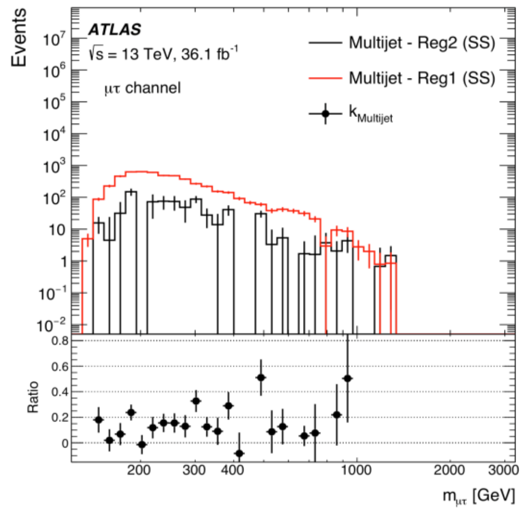
$$K_{Multijet} = \frac{N_{Multijet}^{Reg.2}}{N_{Multijet}^{Reg.1}}$$

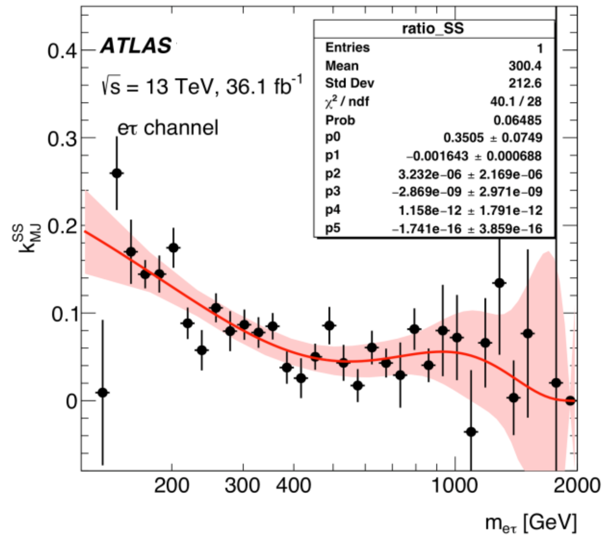
The number of multijet events in the signal region:

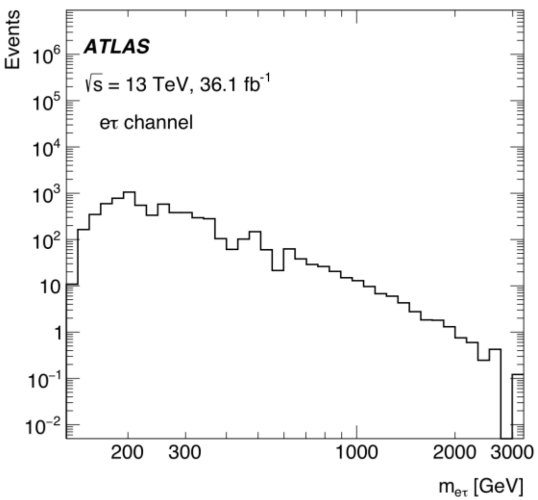
$$N_{Multijet}^{SR} = N_{Multijet}^{Reg.3} \cdot K_{Multijet}$$

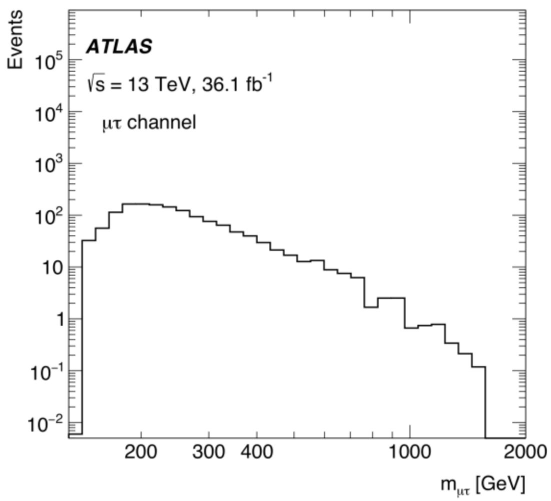
Fake background(Multijet) in eτ and μτ channel: Data-driven









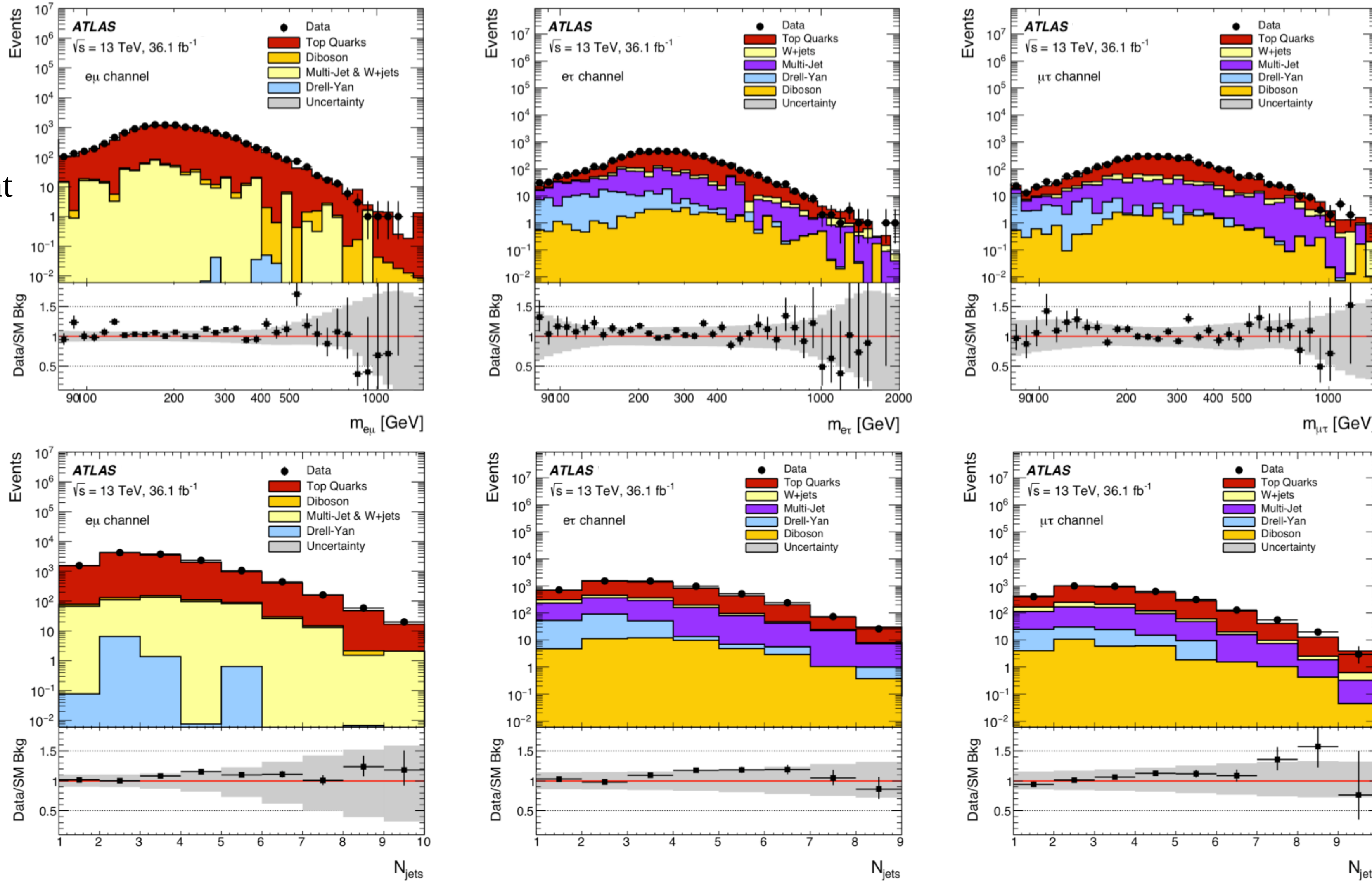


The dependency on the dilepton invariant mass is stronger for the eτ channel, while in the μτ channel $K_{Multijet}$ tends to be almost constant over the mass range.

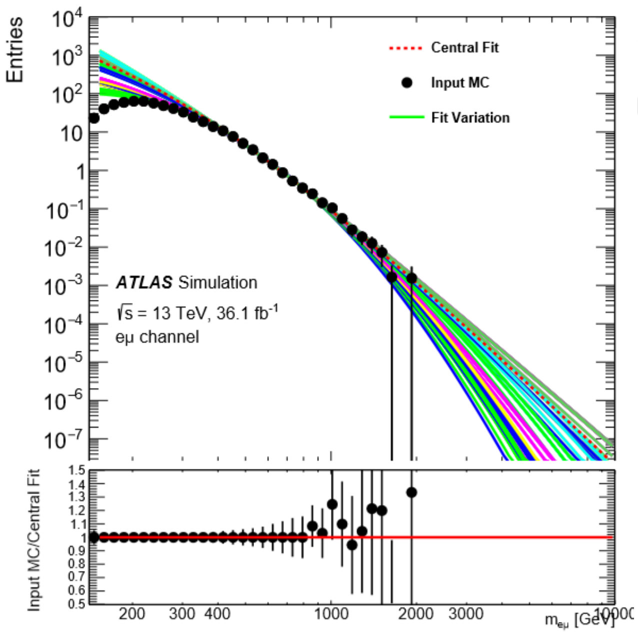
Top quarks background estimation:extrapolation

Invariant mass

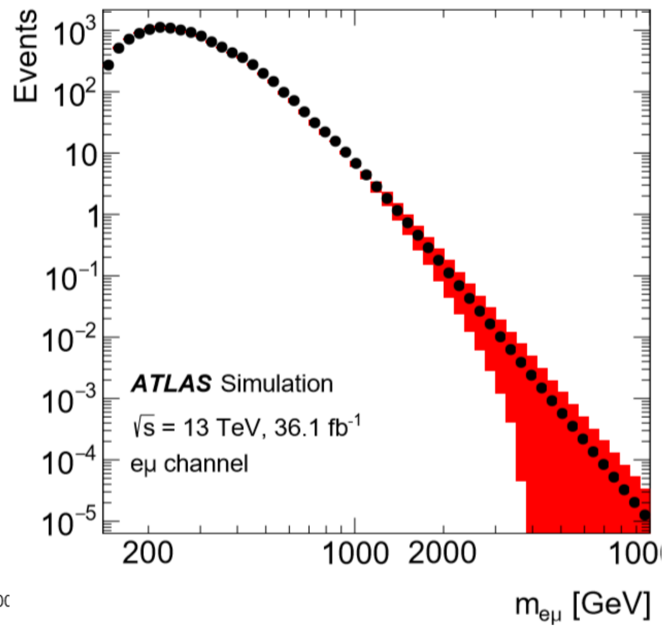
Njets



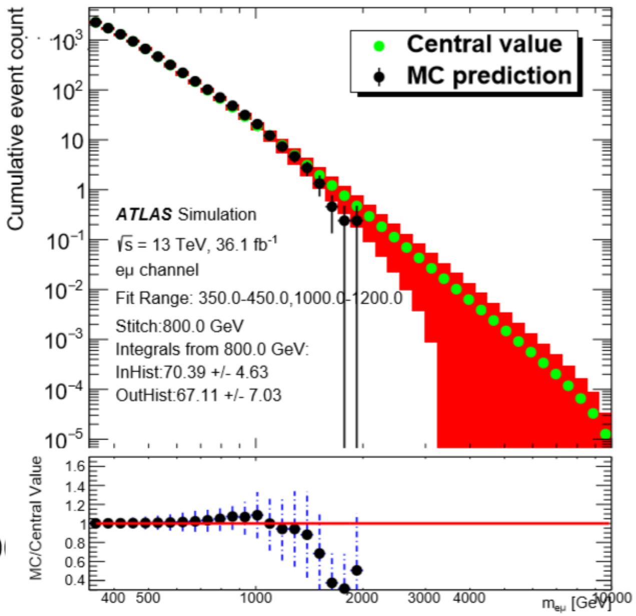
Top quarks background estimation:extrapolation



Top quarks background fit range variation



Top quarks background fit systematic uncertainties



Top quarks background integral bin-by-bin

Dijet function: $a \cdot x^{b} \cdot x^{c\ln(x)}$

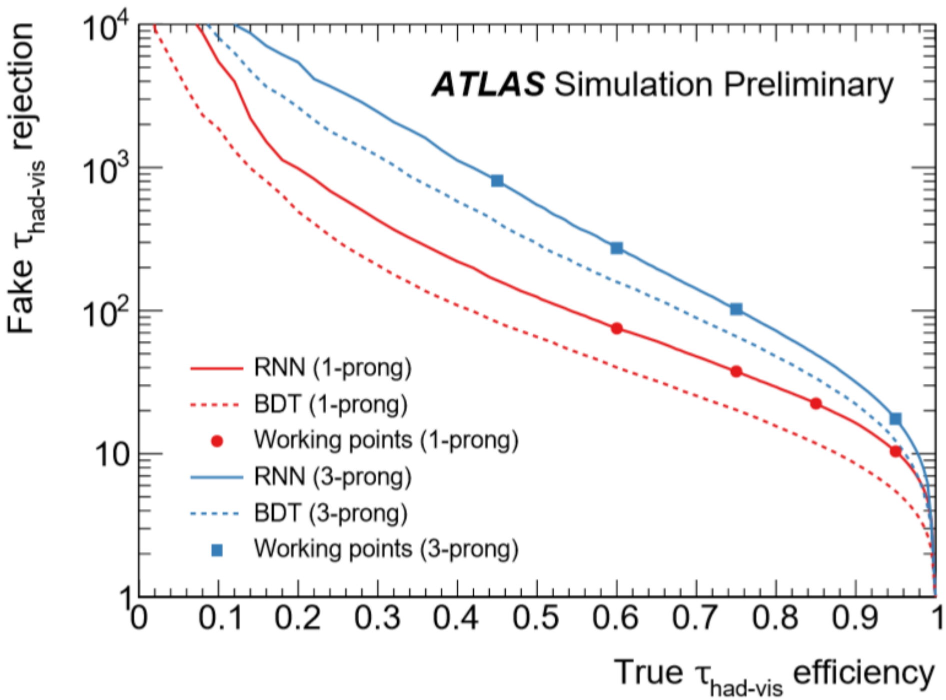
Inverse Monomial function: $\frac{a}{(x+b)^{c}}$

Systematic Uncertainties

Source	1 TeV $e\mu$	1 TeV $e\mu$ b-jet veto	1 TeV $e\tau$	1 TeV $\mu\tau$	2 TeV $e\mu$	2 TeV $e\mu$ b-jet veto	2 TeV $e\tau$	2 TeV $\mu\tau$	3 TeV $e\mu$	3 TeV $e\mu$ b-jet veto	3 TeV $e\tau$	3 TeV $\mu\tau$
Luminosity	2	2	2	2	2	2	2	2	2	2	2	2
Top-quark extrapolation	5	3	2	2	32	8	3	4	63	12	3	14
Top scale	7	6	7	8	40	15	1	14	65	15	3	27
PDF	16	15	12	14	32	34	17	20	51	69	16	53
Pile-up	1	1	3	7	9	6	3	13	32	12	2	17
Dilepton p_T modeling	7	4	2	1	11	5	0	1	15	6	0	4
Electron iden. and meas.	4	4	5	-	4	8	6	-	5	11	8	-
Muon iden. and meas.	3	4	-	4	7	7	-	16	17	10	-	18
τ iden. and meas.	-	-	2	2	-	-	1	1	-	-	1	2
τ reconstruction eff.	-	-	2	2	-	-	1	1	-	-	1	3
τ fake rate	-	-	6	9	-	-	5	12	-	-	2	12
Multijet transf. factor	-	-	31	2	-	-	53	0	-	-	64	0
Reducible $e\mu$ estimation	2	-	-	-	2	-	-	-	2	-	-	-
Jet eff. and resol.	1	4	9	8	2	12	17	42	5	17	22	48
b-tagging	-	3	-	-	-	2	-	-	-	2	-	-
E_T^{miss} resol. and scale	-	-	3	4	-	-	5	6	-	-	8	8
Total	19	20	37	25	62	45	61	62	110	79	73	91

Tau ID study: Tau RNN Identification

- The recommended Jet ID algorithm is updated to the RNN ID which claim will have better efficiency and fake rejection than BDT.
- Combination of low-level input variables for individual tracks and clusters as well as several high-level observables calculated from track and calorimeter quantities.
- Since etau channel and mutau is sensitive to the tau ID, we have a first look to see if there's any improvement for our analysis.



Summary

1. LFV search have been done using 2015-2016 data, No significant excess is found in any channel, exclusion limits for the parameter of interest of the various models searched are extracted.

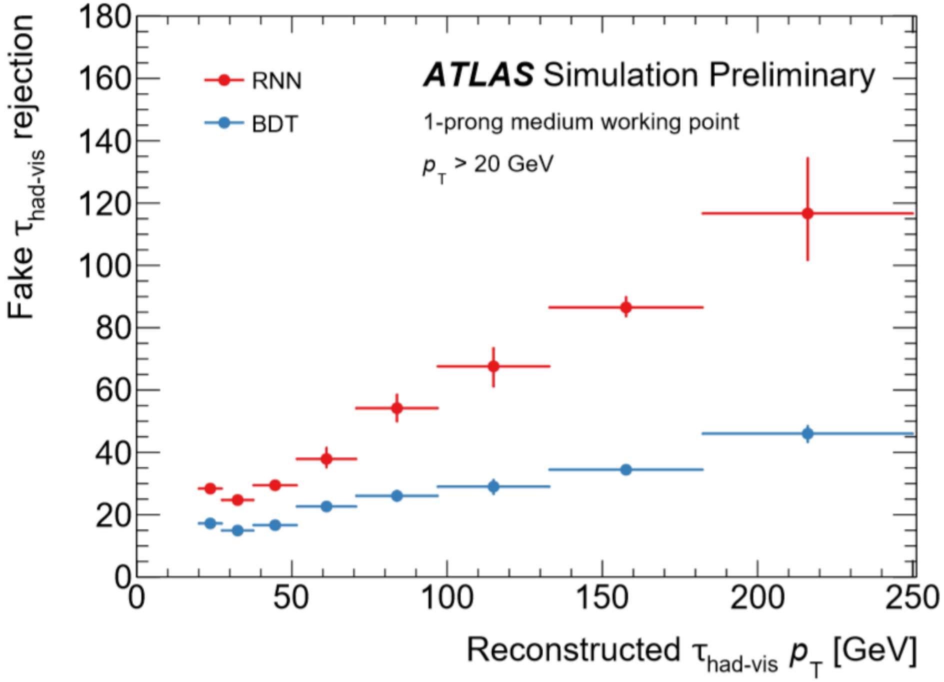
2. For the reducible background matrix method and data-driven method are used to calculate objects efficiency and fake rate, top quarks background is estimated by using extrapolation .

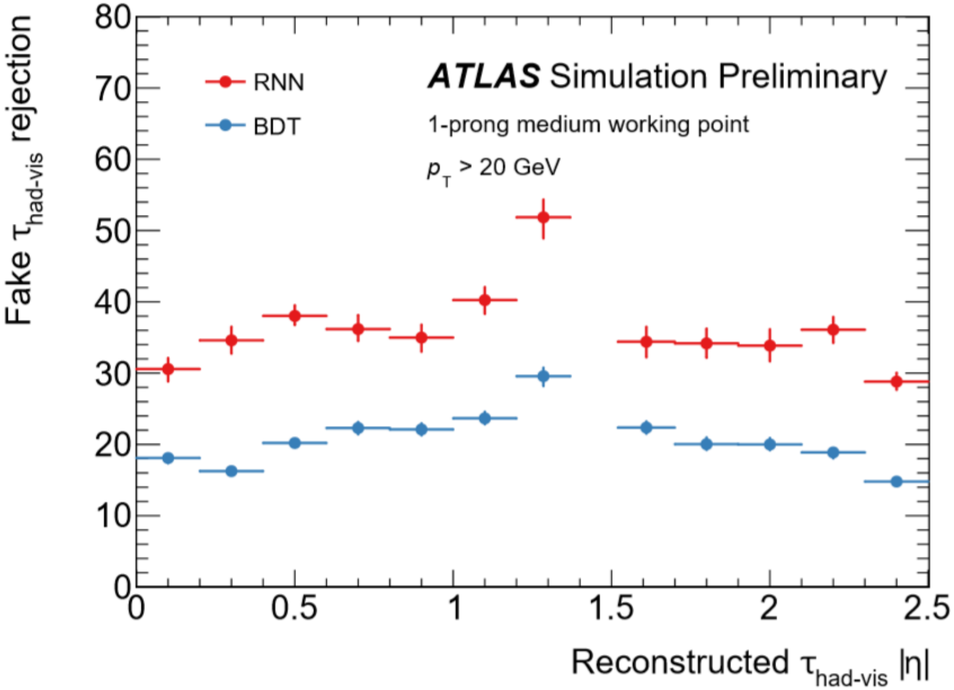
3. Full run-2 data and some new methods like RNN will be used for this study, hope to get better results than before, it’s on going now.

Thank you !!!

Back up

Fake hadronic tau rejection





Rejection power for quark and gluon jets misidentified as $\tau_{had-vis}$ for 1-prong, $\tau_{had-vis}$ candidates depending on the transverse momentum pT and the absolute pseudorapidity |η|.