W+jets background studies for dark matter searches with single top

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ATLAS EXPERIMENT

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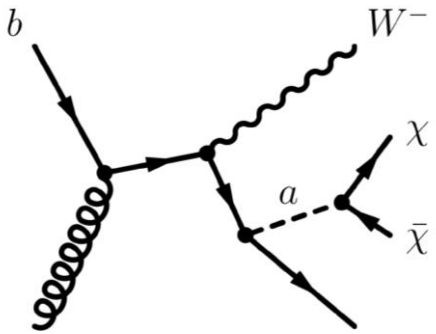
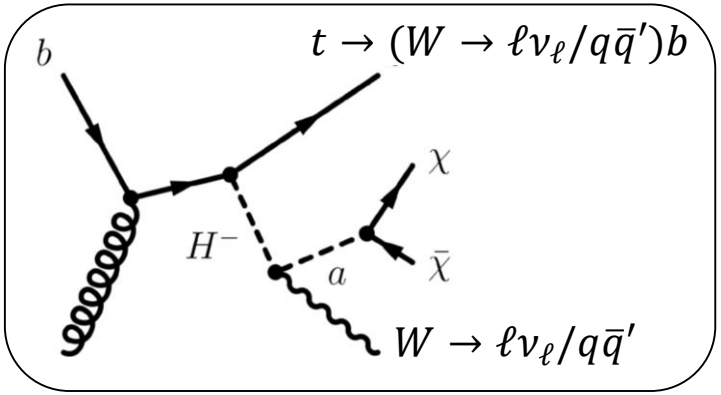
Introduction to the analysis

Benchmark model and signal signature

- Production of single top with Dark matter (DM) → Increases coverage of other analysis (example $\mathrm{DM}t\bar{t}$).
- Theoretical model → Two Higgs doublets + a pseudoscalar mediator (2HDM+a).
- Analysis focused on tW channel → Enhances cross-section due to on-shell production of $H^{\pm}$.
- Analysis → Focusing on one-lepton signature.





Signal signature

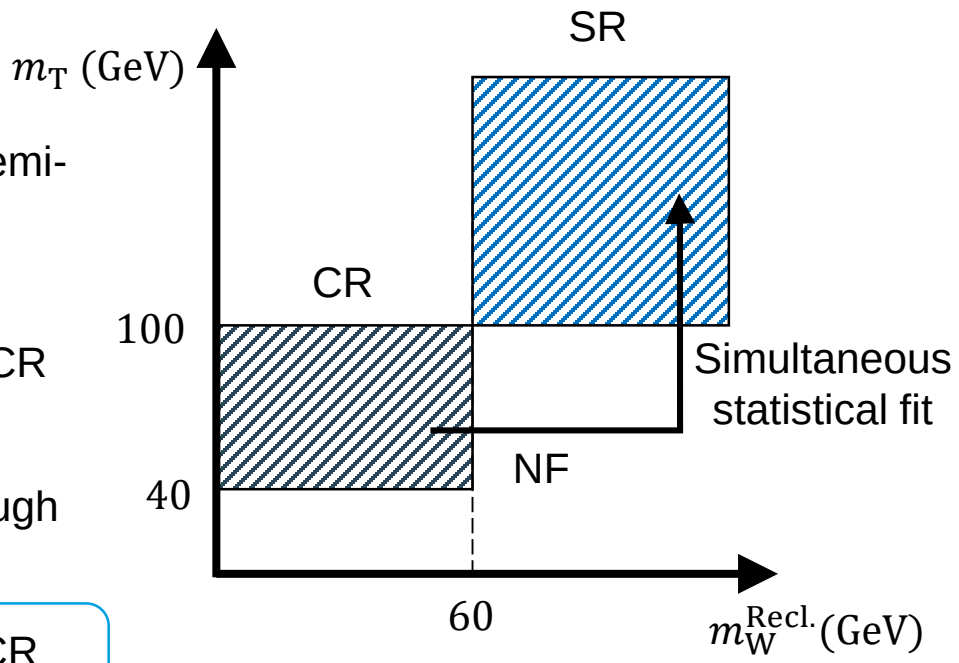
- $N_{\mathrm{lep}} = 1$
- $N_{\mathrm{jet}} \geq 3$ and $N_{\mathrm{bjet}} \geq 1$
- High $E_{\mathrm{T}}^{\mathrm{miss}}$ associated with the undetected DM and neutrino

Background events

- Top ($t\bar{t}$, single top)
- W+jets
- Small contributions (Z+jets, $t\bar{t}+V$, diboson, QCD)

Project objective

W+jets background studies

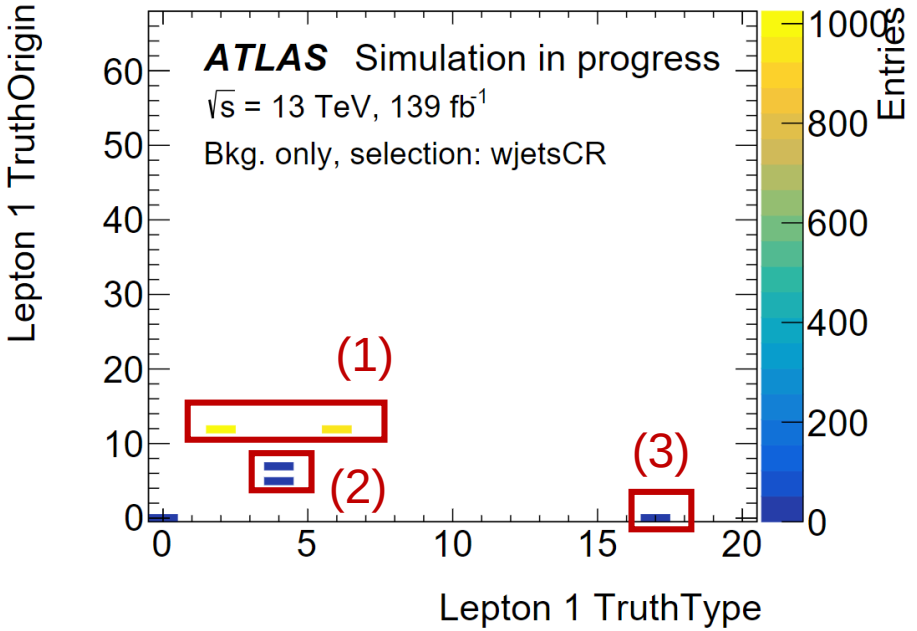


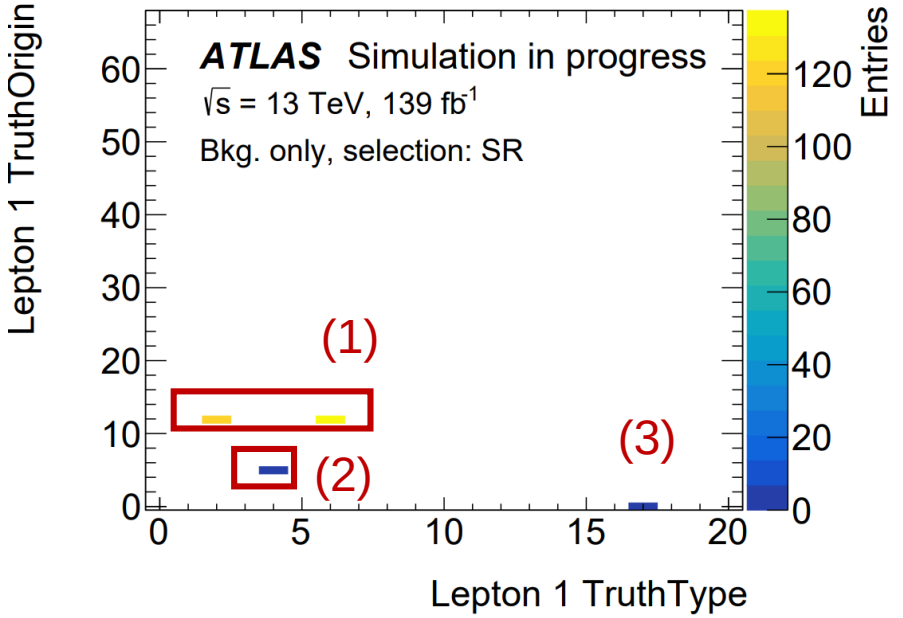
- W+jets background estimated using a semi-data-driven technique.
- Compute normalisation factor (NF) of W+jets MC prediction in control region (CR – enriched with this background)
- Propagate NF to signal region (SR) through simultaneous statistical fit.
- Study the composition of W+jets in the CR and SR
  - Truth type and origin of leptons. $W \rightarrow \tau\nu_{\tau}$ contribution.
  - Jet composition study (flavour).
- MCTruthClassifier → Tool to classify particles in MC samples → Leptons (type, origin) and jets (flavour).

Truth type and origin of leptons

W+jets CR and SR

- In both regions → Isolated (good quality) electrons and muons → >99.9 % of the leptons. (1)
- Two small contributions survive:
  - Background electrons → Photon conversion and Dalitz decay. (2)
  - Hadrons → Misidentification as lepton. (3)





$W \to e\nu_e/\mu\nu_\mu/\tau\nu_\tau$ contributions

- Check similarity of contributions both in W+jets CR and SR.
- Three decay channels → $W \to \ell\nu_\ell, \quad \ell = \{e, \mu, \tau\}$.
  - Similar branching rations (BRs): $\Gamma(W \to \ell\nu_\ell) \approx 11\%$.
- $W \to \tau\nu_\tau$ has smaller contribution → only if tau further decays into e or μ can be selected.
  - $\Gamma(\tau \to e\nu_e\nu_\tau) \approx \Gamma(\tau \to \mu\nu_\mu\nu_\tau) \approx 17.5\%$ → Comparable contributions.
- $W \to \tau\nu_\tau$ contribution suppressed in W+jets SR → cuts on m_{T}.

Contributions for each channel and selection

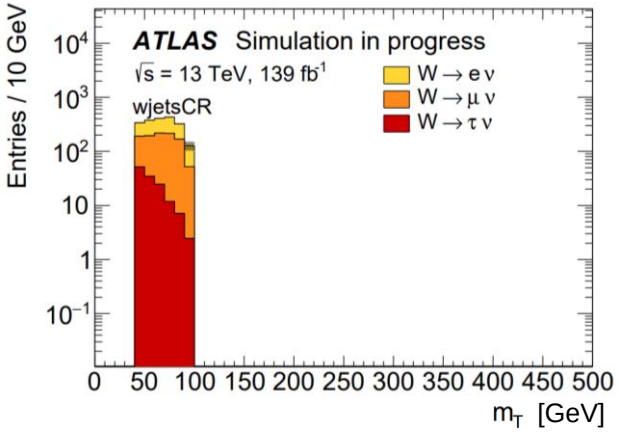
$$R^{W\to\ell\nu_\ell}_{\text{Selection}} = \frac{N^{W\to\ell\nu_\ell}_{\text{Selection}}}{N^{Total}_{\text{Selection}}}$$

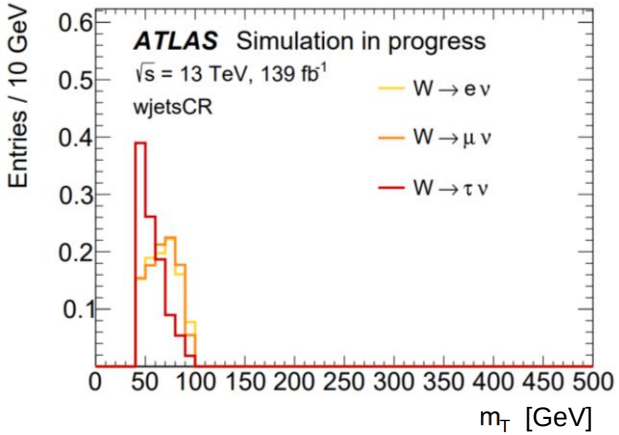
	$R^{W\to\ell\nu_\ell}_{W\text{+jets CR}}$ (%)	$R^{W\to\ell\nu_\ell}_{\text{SR}}$ (%)
$W \to e\nu$ (%)	48.27	45.75
$W \to \mu\nu$ (%)	45.16	50.49
$W \to \tau\nu$ (%)	6.57	3.76

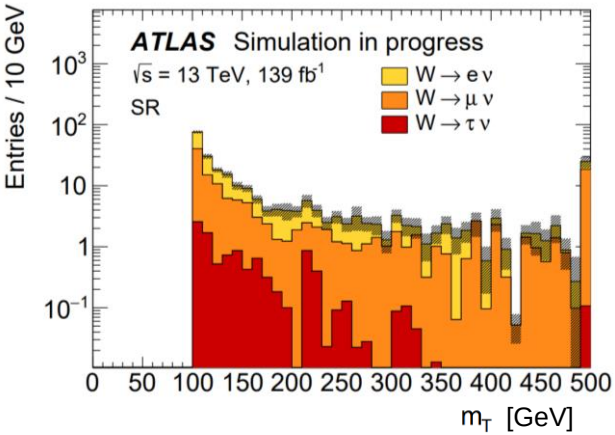
$W \to e\nu_e/\mu\nu_\mu/\tau\nu_\tau$ contributions

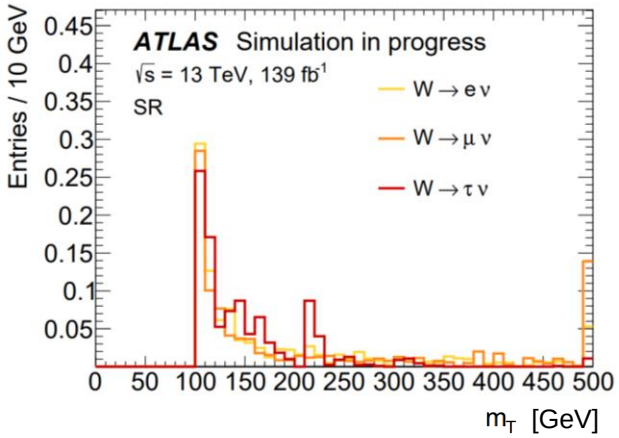
Suppression of $W \to \tau\nu_\tau$ in SR

- Cuts on m_{T} suppress contribution from $W \to \tau\nu_\tau$ on SR ($m_{\mathrm{T}} > 100$ GeV).
- Differences on m_{T} distribution due to 3-body decay of tau.









Jet composition studies

Filtered samples

- Perform jet composition study in W+jets CR and SR → Is jet composition similar? → Two approaches.
  - If not → Additional uncertainties (?)
- Filters applied to MC samples → Filters increase the statistics of each jet flavour (BFilter, CFilterBVeto, BVetoCVeto).
- Compute contribution of each of the filtered samples → Estimation of jet composition.
  - Not all the samples are filtered → Sampled with W bosons with p_{T} / total hadronic activity $> 500\ \mathrm{GeV}$ are not filtered (>50%).
- Large differences between jet composition in W+jets CR and SR are not found.

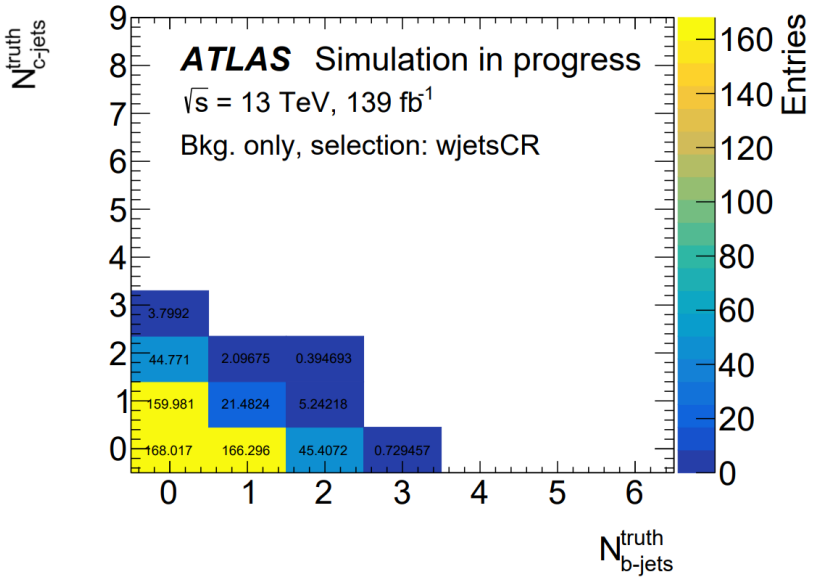
$$P^{\mathrm{Filter}}_{\mathrm{Selection}} = \frac{N^{\mathrm{Filter}}_{\mathrm{Selection}}}{N^{\mathrm{Total}}_{\mathrm{Selection}}}$$

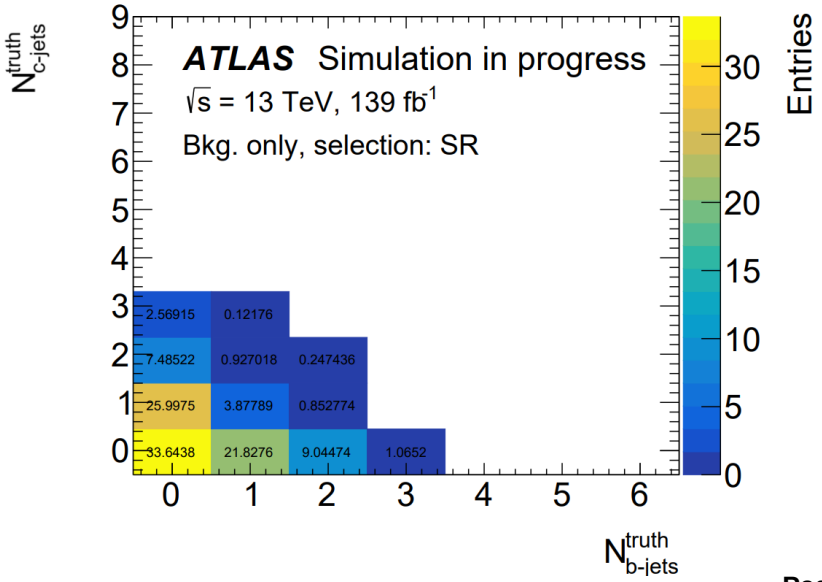
Filter	$P^{\mathrm{Filter}}_{W+\mathrm{jets\ CR}}$(%)	$P^{\mathrm{Filter}}_{\mathrm{SR}}$ (%)
BFilter	13.23	15.40
CFilterBVeto	10.76	15.16
BVetoCVeto	6.87	10.27

Jet composition studies

Validation of the results from filtered contributions

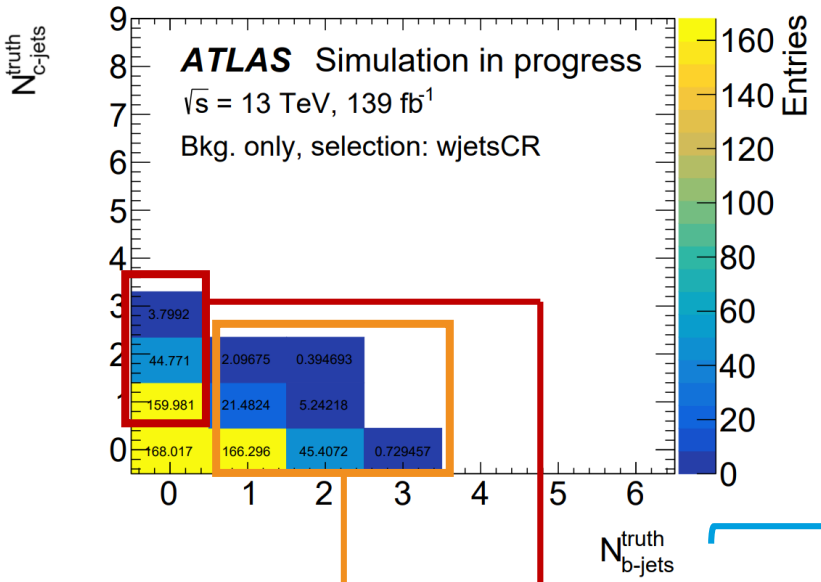
- MCTruthClassifier information → number of jets of each flavour from filtered samples.
- Validate the results obtained from filtered contributions:
  - Events with $N_b > 0$ → BFilter contribution.
  - Events with $N_c > 0,\ \ N_b = 0$ → CFilterBVeto contribution.
  - Events with $N_c = 0,\ \ N_b = 0$ → BVetoCVeto contribution.





Jet composition

Validation of the results from filtered contributions in *W*+jets CR



Information up to 6 jets. Slight differences expected.

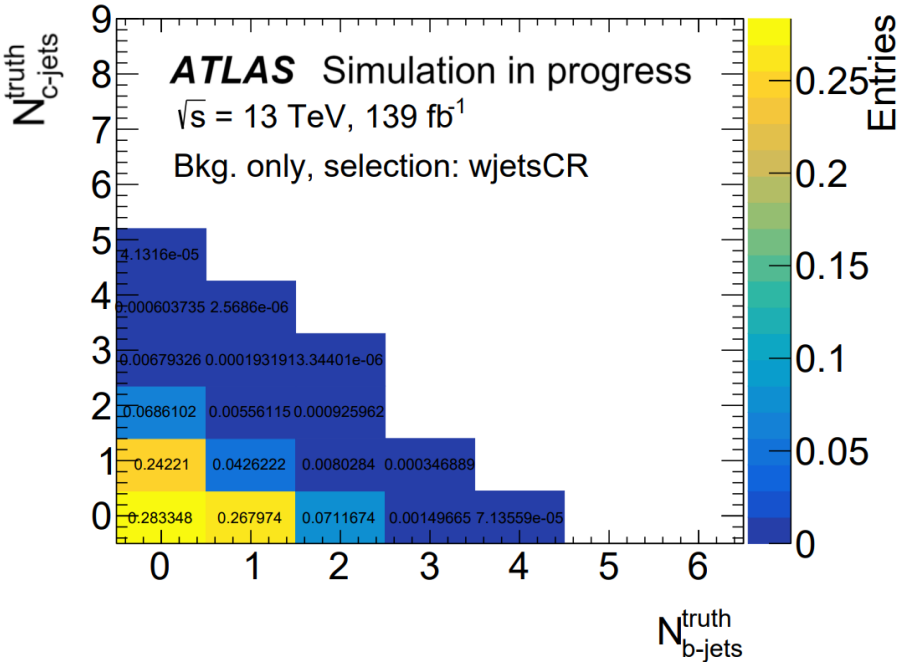
Contributions from each filtered sample (number of events) → Similar results → Validated the two methods.

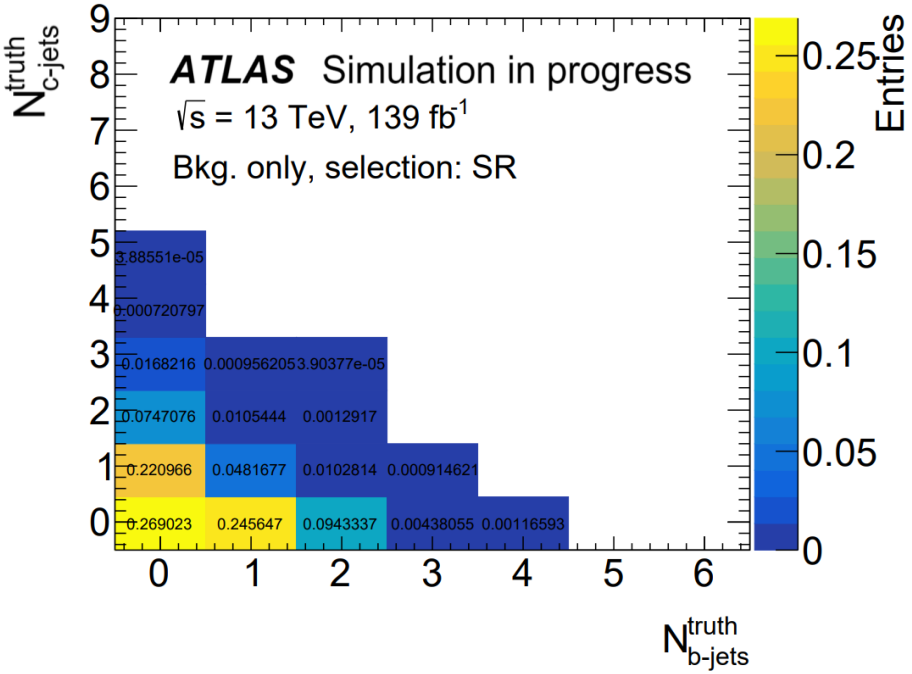
W+jets CR	Classification	BFilter	CFilterBVeto	BVetoCVeto
$N_b > 0$	241.7	265.0		
$N_c > 0$ $N_b = 0$	208.6		215.6	
$N_c = 0$ $N_b = 0$	168.0			137.6

Jet composition

Other approach → Final results on jet compositions

- Compute number of truth b jets and c jets in the events in both regions (CR and SR) using Truth Classifier.
- Advantage → Takes into account all contributions (filtered and non-filtered).
- Normalised distributions shown in W+jets CR and SR to compare compositions.
- Similar composition in both regions.





Conclusions

- Dominant leptons → Isolated electrons and muons → from W decay.
- Background from $W \rightarrow \tau\nu_\tau$ contribution suppressed in SR → m_{T} cuts.
- Jet composition has been studied with different approaches:
  - Filtered samples contribution.
  - Classification of events using the number of truth jets from each flavour → Validation of previous approach. Alternative study.
- So far studies show similar compositions in both W+jets CR and SR → NF can be propagated from CR to SR through simultaneous statistical fit.

Thank you

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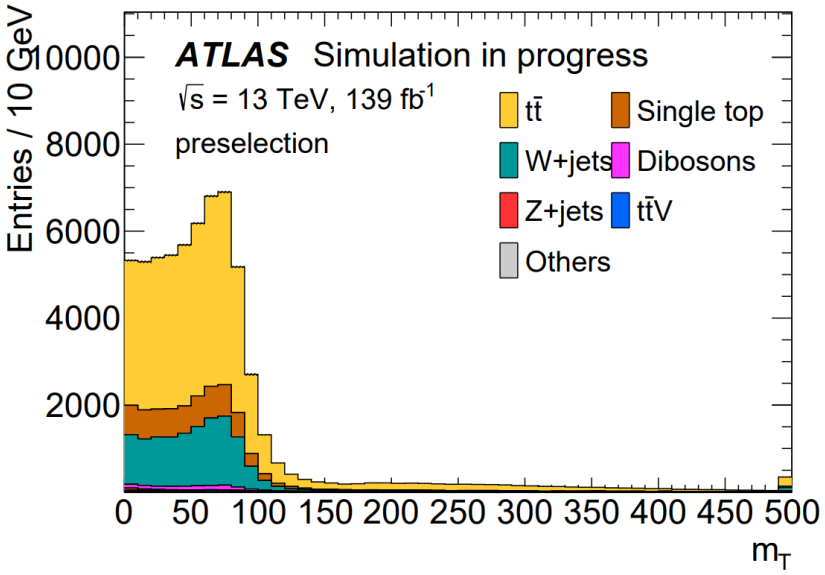
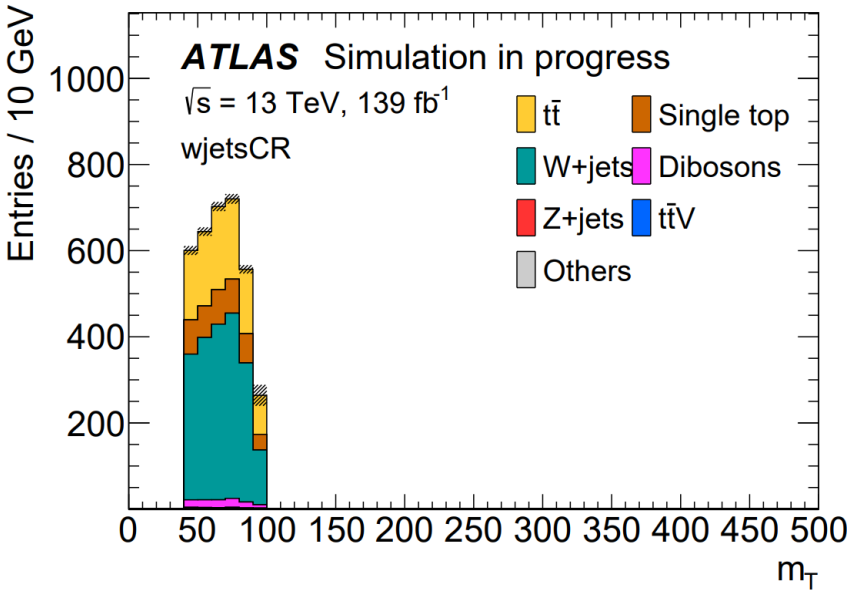
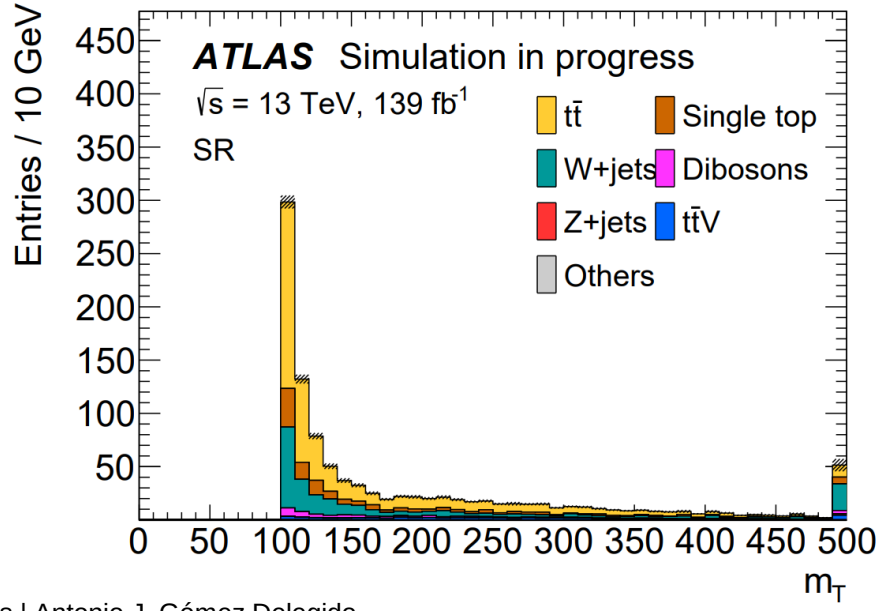
Backup slides

Backgrounds in the analysis







Backgrounds in the analysis

	Preselection (%)	W+jets CR (%)	SR (%)
W+jets	20.24	57.43	24.69
ttbar	65.67	27.34	41.64
Singletop	11.15	11.92	13.59
Diboson	1.57	2.75	4.97
Z+jets	0.26	0.28	0.35
ttV	0.93	0.23	4.14
Others	0.17	0.04	0.22

MCTruthClassifier

Legend

Type	Label	Type	Label	Type	Label
Unknown	0	NonIsoTau	11	SUSY particle	22
UnknownElectron	1	BkgTau	12	BBbarMesonPart	23
IsoElectron	2	UnknownPhoton	13	BottomMesonPart	24
NonIsoElectron	3	IsoPhoton	14	CCbarMesonPart	25
BkgElectron	4	NonIsoPhoton	15	CharmedMesonPart	26
UnknownMuon	5	BkgPhoton	16	BottomBaryonPart	27
IsoMuon	6	Hadron	17	CharmedBaryonPart	28
NonIsoMuon	7	Neutrino	18	StrangeBaryonPart	29
BkgMuon	8	NuclFrag	19	LightBaryonPart	30
UnknownTau	9	NonPrimary	20	StrangeMesonPart	31
IsoTau	10	GenParticle	21	LightMesonPart	32

Table 11: MCTruthClassifier particle type labels

MCTruthClassifier

Legend

Type	Label	Type	Label	Type	Label
NonDefined	0	HeavyBoson	16	CharmedBaryon	32
SingleElec	1	WBosonLRSM	17	BottomBaryon	33
SingleMuon	2	NuREle	18	PionDecay	34
SinglePhot	3	NuRMu	19	KaonDecay	35
SingleTau	4	NuRTau	20	BremPhot	36
PhotonConv	5	LQ	21	PromptPhot	37
DalitzDec	6	SUSY	22	UndrPhot	38
ElMagProc	7	LightMeson	23	ISRPhot	39
Mu	8	StrangeMeson	24	FSRPhot	40
TauLep	9	CharmedMeson	25	NucReact	41
top	10	BottomMeson	26	PiZero	42
QuarkWeakDec	11	CCbarMeson	27	DiBoson	43
WBoson	12	JPsi	28	ZorHeavyBoson	44
ZBoson	13	BBbarMeson	29	QCD	45
Higgs	14	LightBaryon	30		
HiggsMSSM	15	StrangeBaryon	31		

Table 12: MCTruthClassifier particle origin labels

MCTruthClassifier

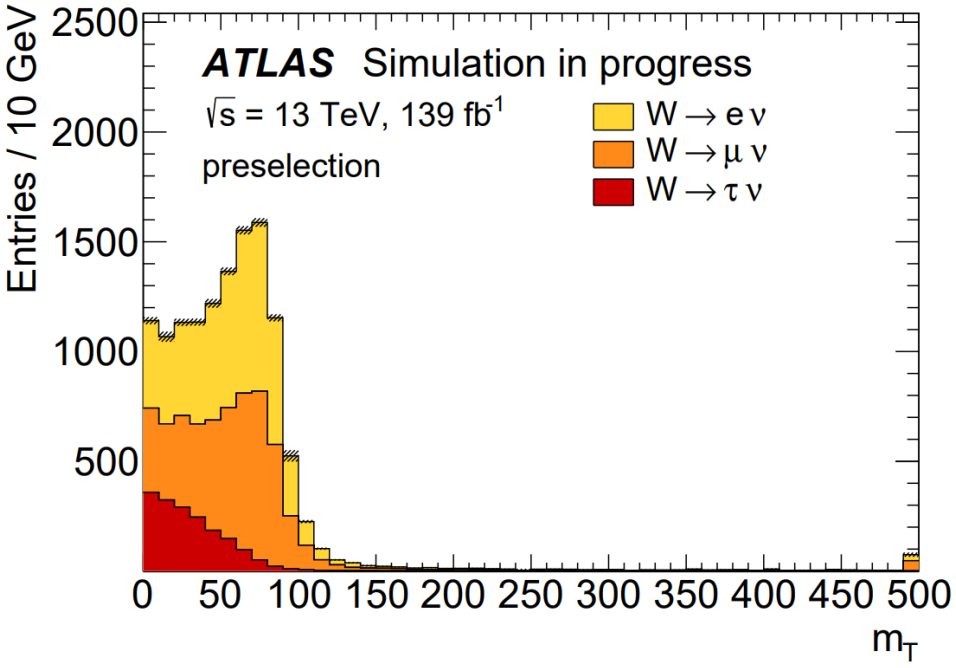
Legend

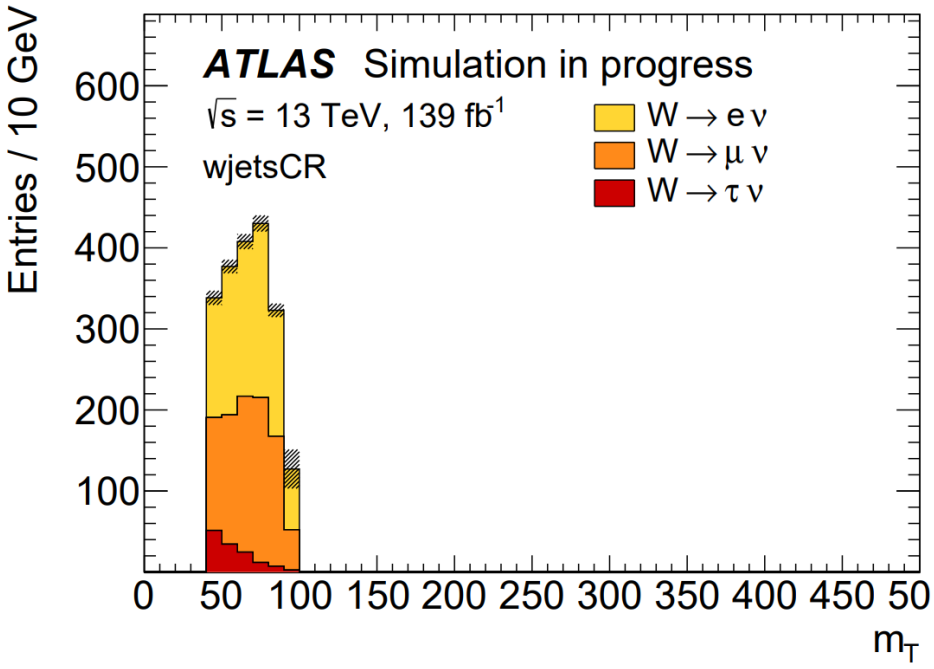
Quark	PDGId	Quark	PDGId
d	1	b	5
u	2	t	6
s	3	b'	7
c	4	t'	8

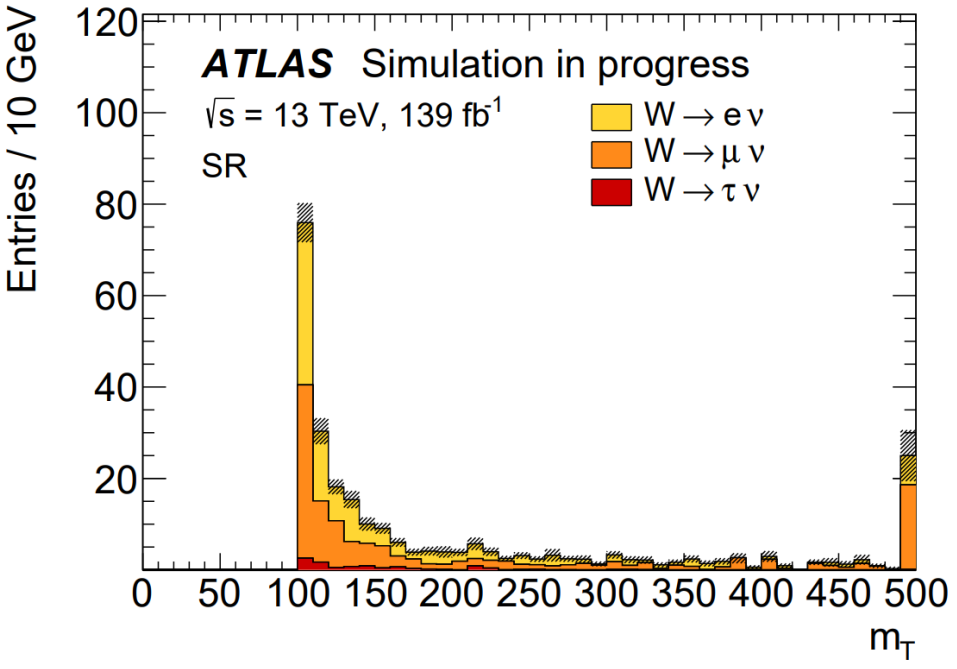
Table 13: Monte Carlo particle numbering scheme

m_T distributions

Preselection, W+jets CR and SR



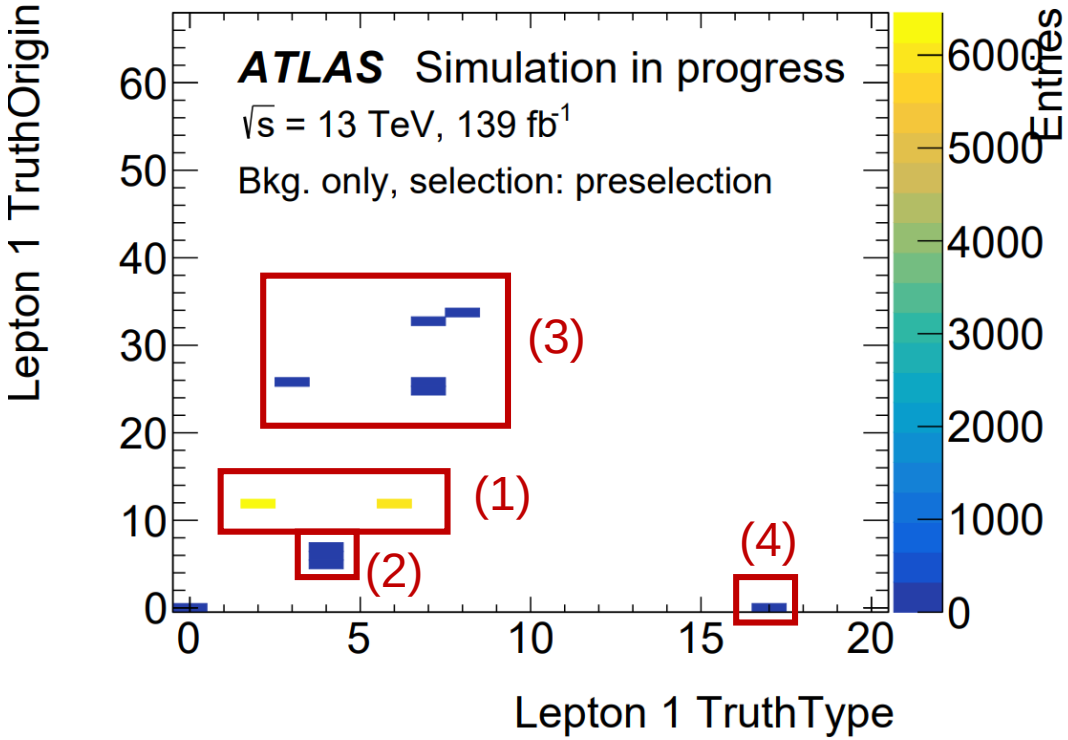




Truth type and origin

Preselection

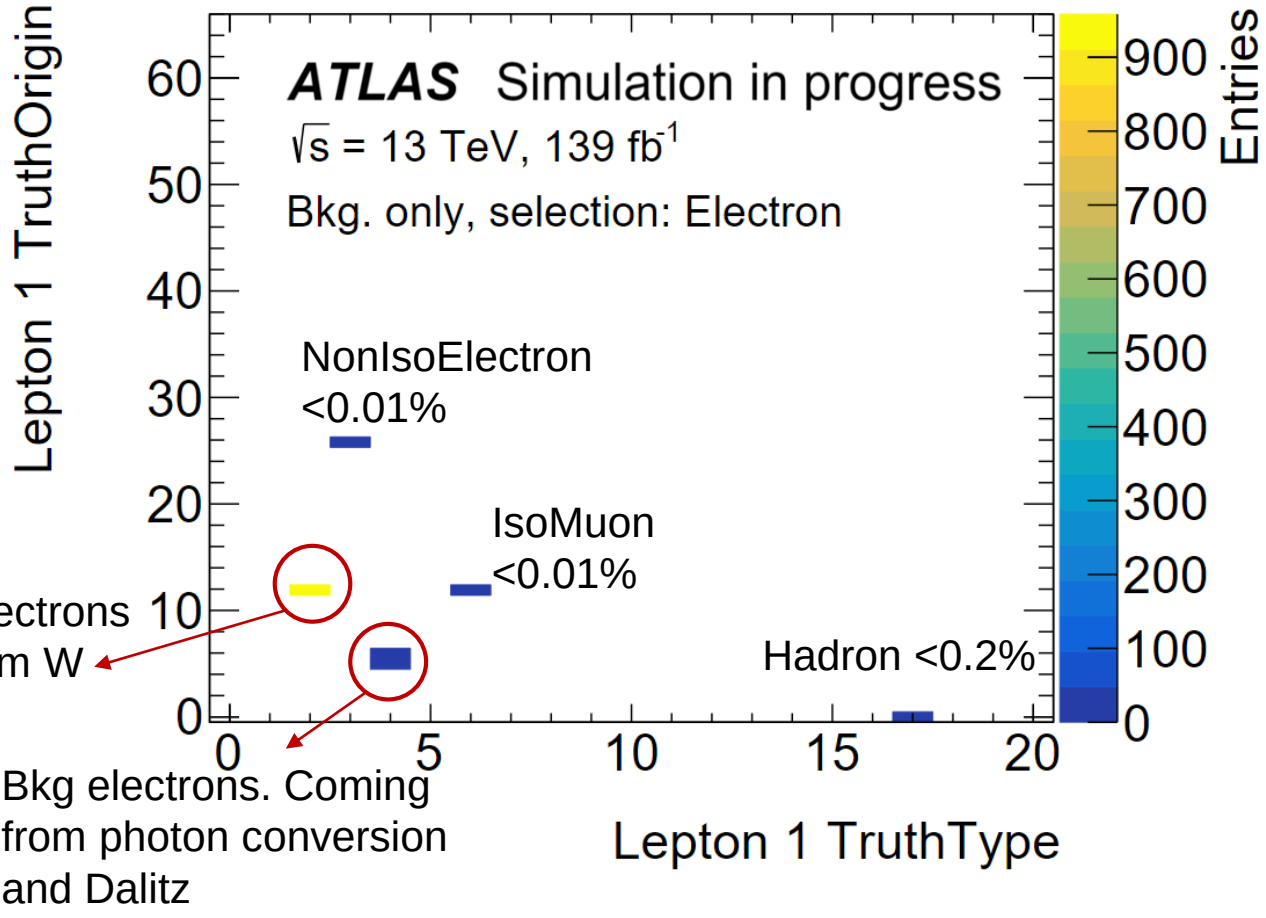
- Dominant type and origin → isolated electrons and muons from W decay. (1)
- Other contributions:
  - Background electrons → Photon conversion and Dalitz decay. (2)
  - Non isolated leptons → Baryon and meson decays. (3)
  - Hadrons → Misidentification. (4)



Tau contribution

Electron preselection

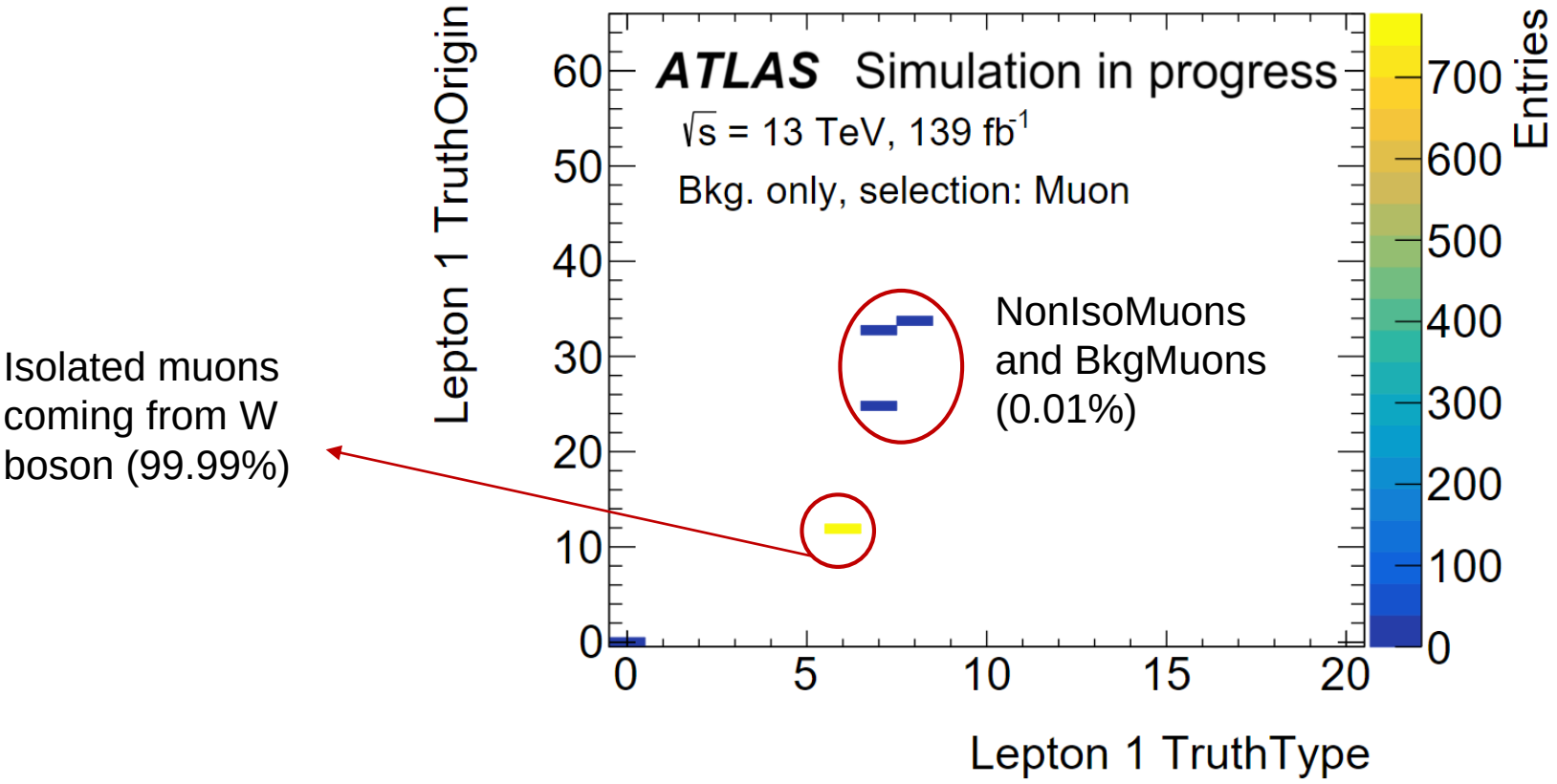
- The plot shown only contains electrons coming from $W \rightarrow \tau\nu$ decays.
- Electrons coming from $W \rightarrow \tau\nu$ are mainly isolated electrons (97%), the rest are non isolated electrons (1%), isolated muons (1%). BkgElectrons and hadrons are <1%.
- Electrons from $W \rightarrow \tau\nu$ samples have as main truth origin a W boson.
- Contribution of hadrons faking leptons <0.2 %.



Tau contribution

Muon preselection

- Muons coming from $W \rightarrow \tau\nu$ decays are mainly isolated muons (99.99%).
- The truth origin of muons in $W \rightarrow \tau\nu$ files is in the 99.99% of the cases a W boson.



Validation of filtered sample computations

Preselection and SR

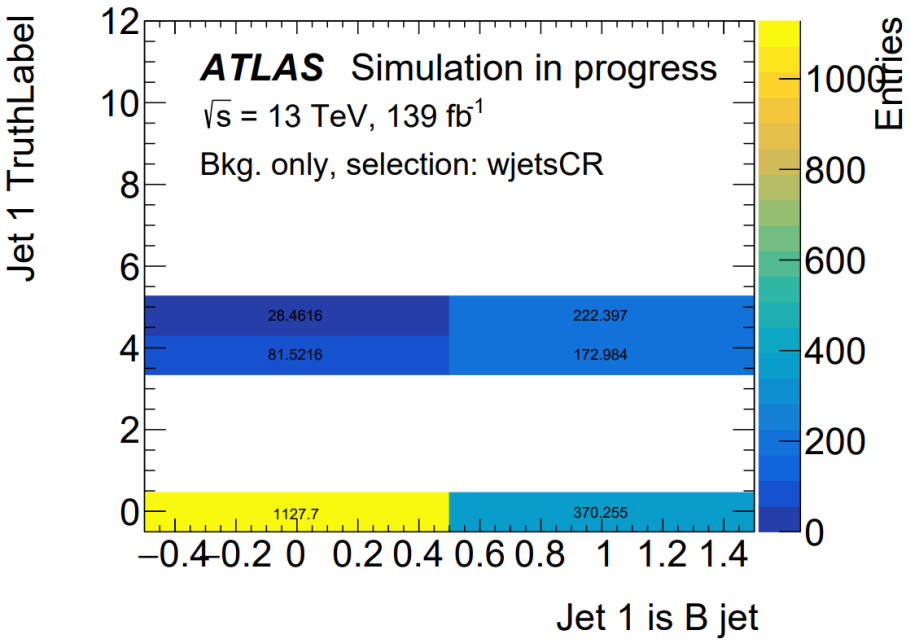
Preselection	Classification	BFilter	CFilterBVeto	BVetoCVeto
$N_b \geq 0$	2127.3	2298.4		
$N_c > 0$ $N_b = 0$	1523.80		1592.8	
$N_c = 0$ $N_b = 0$	1193.61			953.5

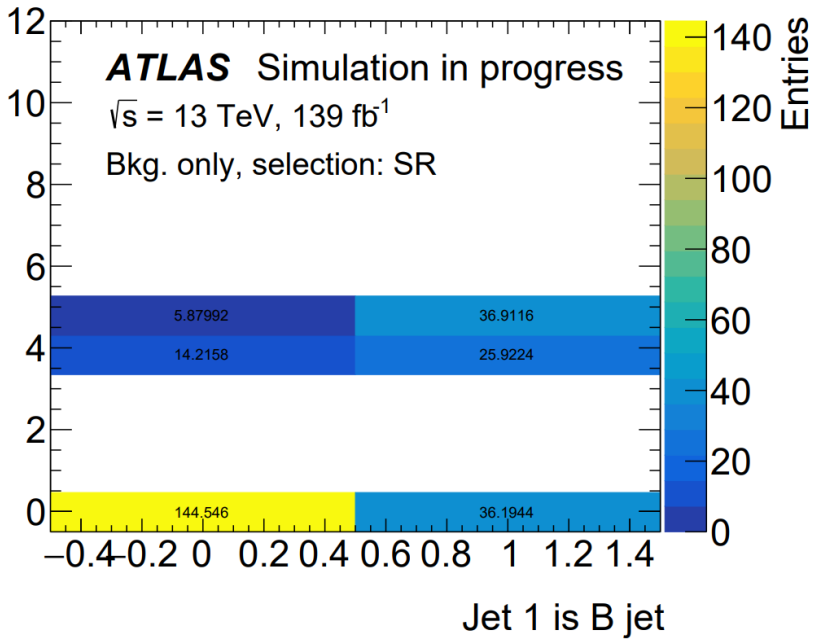
SR	Classification	BFilter	CFilterBVeto	BVetoCVeto
$N_b \geq 0$	38.0	40.6		
$N_c > 0$ $N_b = 0$	36.1		40.0	
$N_c = 0$ $N_b = 0$	33.6			27.1

Truth vs. reco

A comparison of truth b jets and b-tagged jets

- b-tagging algorithm → Efficiency of 77%.
- Two reasons to compare truth b jets vs. b-tagging decision:
  - Study if truth b jets are properly tagged.
  - If cuts do not bias → Percentage of tagging similar in all the regions.





Truth vs. reco

A comparison of truth b jets and b-tagged jets

$$\eta^{\text{tag (non-tag)}}_{\text{truth bjet}} = \frac{N^{\text{tag (non-tag)}}_{\text{truth bjet}}}{N^{\text{tag}}_{\text{truth bjet}} + N^{\text{non-tag}}_{\text{truth bjet}}}$$

Jet		W+jets CR	SR
Jet 1	$\eta^{\text{tag}}_{\text{bjet}}$ (%)	90.08	89.43
	$\eta^{\text{non-tag}}_{\text{bjet}}$ (%)	9.92	10.57
Jet 2	$\eta^{\text{tag}}_{\text{bjet}}$ (%)	94.56	86.22
	$\eta^{\text{non-tag}}_{\text{bjet}}$ (%)	5.44	13.78
Jet 3	$\eta^{\text{tag}}_{\text{bjet}}$ (%)	72.85	78.57
	$\eta^{\text{non-tag}}_{\text{bjet}}$ (%)	27.15	21.43