Searching for CP violation in ttH multilepton process with CMS at the LHC Run 3

Top LHC France

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Summary

Search for CP Violation in the ttH multilepton final state in CMS Run 3:

- Introduction of CP Violation and the ttH process
- ttH analysis and usage of the BDT
- Training of the Models
- Results
- Conclusions and prospects

Introduction: CP symmetry and CP violation

The SM allows for a few examples of CP-violation, which gives us η, the measure of matter-antimatter imbalance.

However, the value we observe in our universe is many orders of magnitude larger. We are interested into finding possible new sources of CP-violation.

In the Higgs sector, previous CMS and ATLAS studies have already excluded the possibility of pure CP-symmetry breaking at a 95% CL (H.Yang arXiv:2512.13226, CMS Collaboration arXiv:2208.02686). With Run3 data CMS aims at improving the precision of Run2 measurement.

$$\eta = \frac{n_B - n_{\bar{B}}}{n_\gamma}$$

$$\eta_{\text{SM CP}} \sim 10^{-20}$$

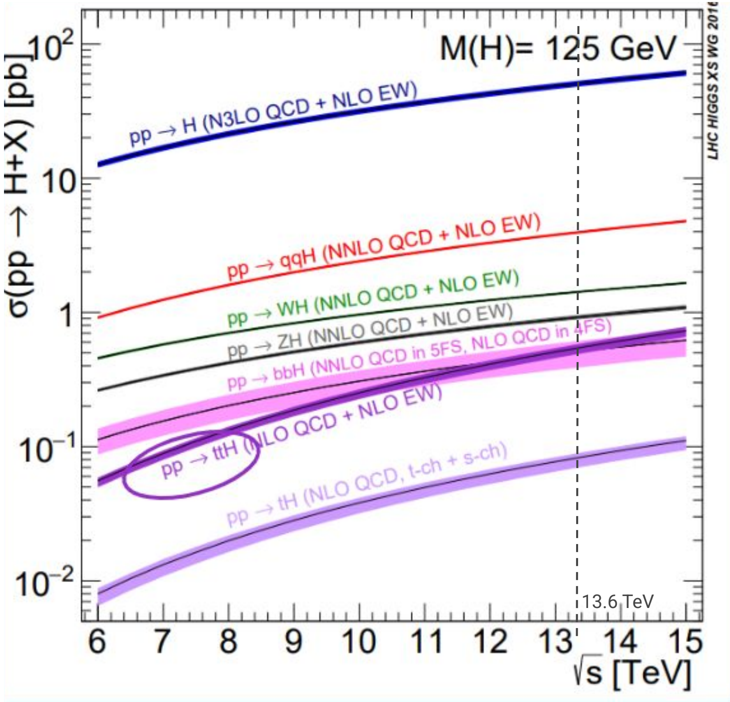
$$\eta = (6.047 \pm 0.074) \times 10^{-10}$$

Introduction: the ttH process

The top quark is the heaviest fermion of the SM, with a mass of 173.34 ± 0.76 GeV. Furthermore, its Yukawa coupling is of the order of one.

These properties may imply that is has a special role in the mechanism of electroweak symmetry breaking, making the top quark (and its coupling to the Higgs boson) a good candidate in the search for CP violation.

And, in pp collisions like in LHC, the process containing top quarks (t) and Higgs bosons (H) with highest cross section is the ttH process



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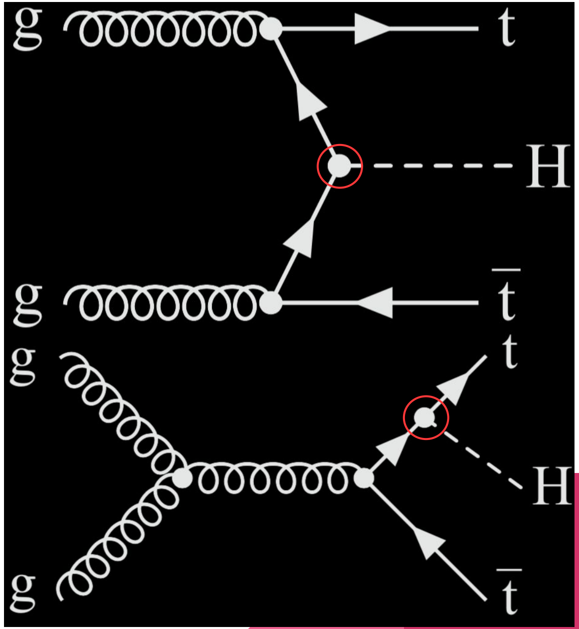
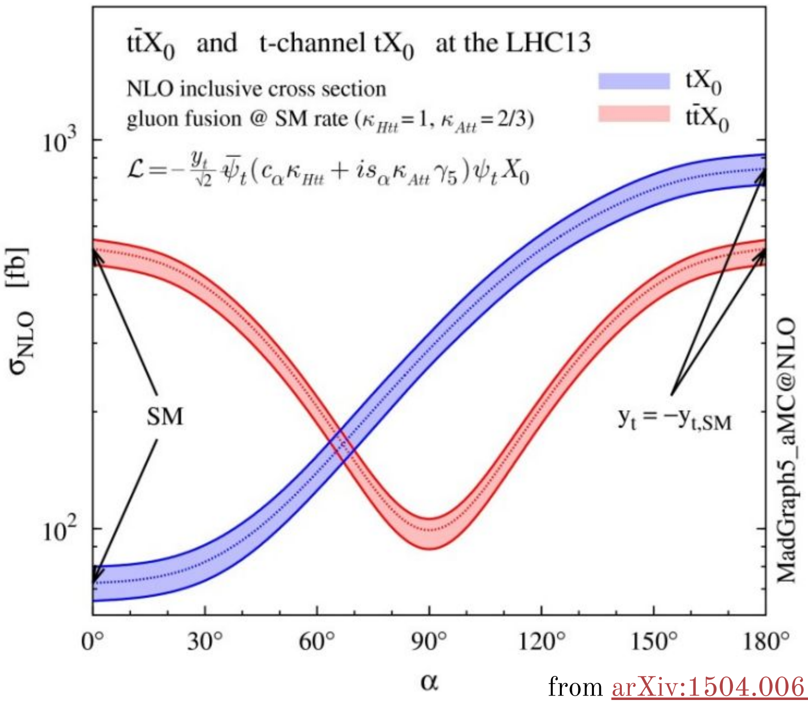


Introduction: CP symmetry in the ttH process

$$\mathcal{L} = -\frac{y_t}{\sqrt{2}}\bar{\psi}_t(\underbrace{c_\alpha \kappa_{Htt}}_{\text{CP-even}} + \underbrace{i s_\alpha \kappa_{Att}\gamma_5}_{\text{CP-odd}})\psi_t X_0$$

- **α** is the CP mixing angle (0 or 180° in SM)
- $\kappa_{\mathrm{Htt,Att}}$ are dimensionless rescaling parameters
- $\mathbf{c_\alpha}$ **and** $\mathbf{s_\alpha}$ are respectively cos(α) and sin(α), meaning the CP-even and CP-odd terms of the interaction
- y_t is the Yukawa coupling constant of the top quark to the Higgs field
- X_0 labels a generic spin-0 particle with CP-violating coupling (in this case, the Higgs boson)

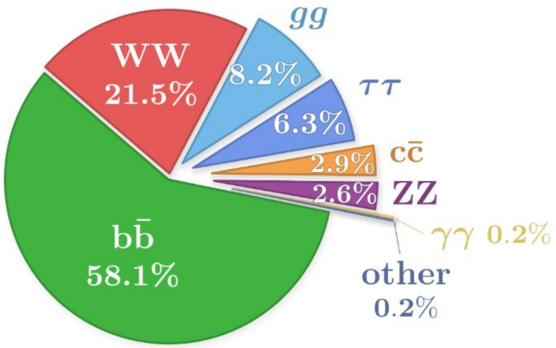
The mixing angle **α** affects not just the cross section, but also the kinematics of the process.



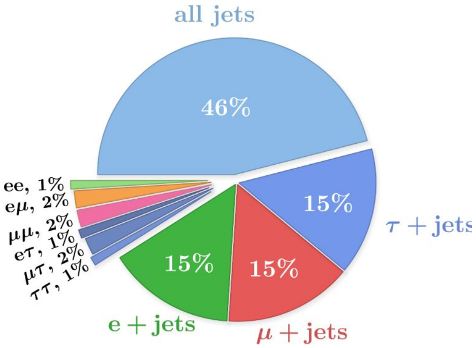
from arXiv:1504.00611

Run 3 CMS ttH Analysis: Categories

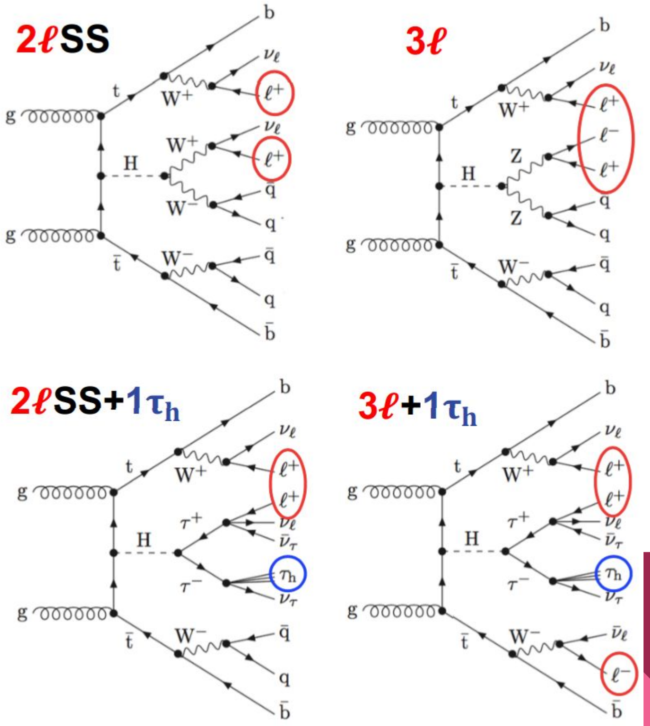
In the multilepton final state, *t* usually decays into W and b, and *H* decays in either WW, ZZ or $\tau\tau$. In CMS, we classify events into cateories defined by the number of leptons (electrons, muons) and taus.



Higgs decay products



ttbar decay products



Run 3 CMS ttH Analysis: Selections and cuts

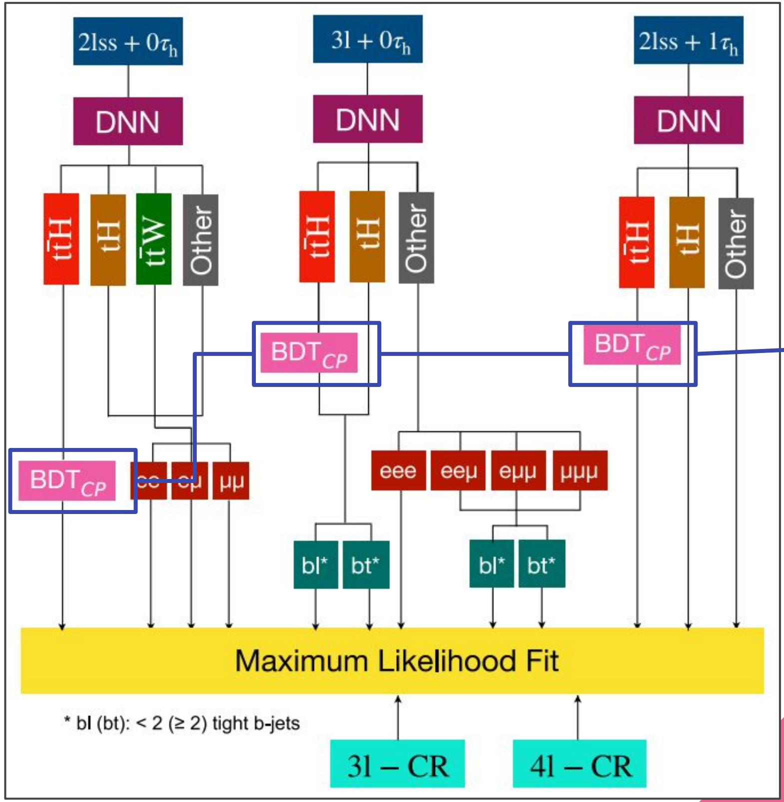
	Lepton ID WP	Lepton p_t (leading)	Lepton p_t (subleading)	$\lvert m_{ee} - m_Z \rvert$	m_{ll}	$E_{miss,t}$ LD *	number of jets	τ_H WP
2lss0tau	2 tight	>25 GeV	>15 GeV	>10 GeV	>12 GeV	>30 GeV	>=3	0 very-loose
2lss1tau	2 tight	>25 GeV	>15 GeV	-	-	>30 GeV	>=3	1 very-loose
3l0tau	3 tight	>25 GeV	>15 GeV, 15 GeV	>10 GeV	>12 GeV	>30 GeV	>=2	0 very-loose

These have remained unchanged since Run2

*the linear combination of E_t^{miss} and H_t^{miss}

Run 3 ttH Analysis: Flowchart

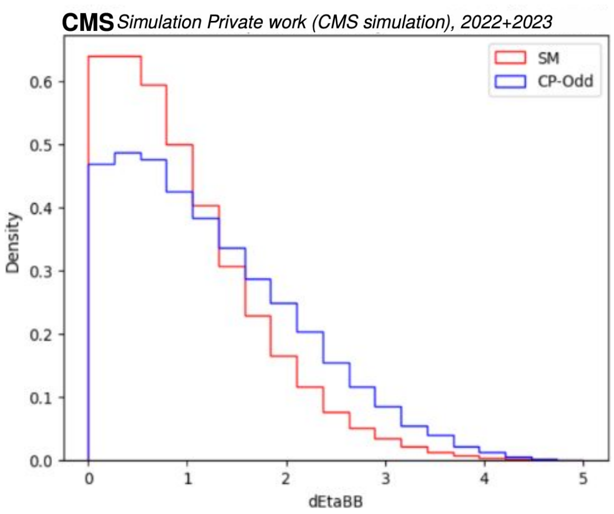
Once the DNN assigns a score to each event, to determine what process it might be, we can apply to ttH-like events another algorithm, called a Boosted Decision Tree (BDT), to determine whether it is CP-even or CP-odd.

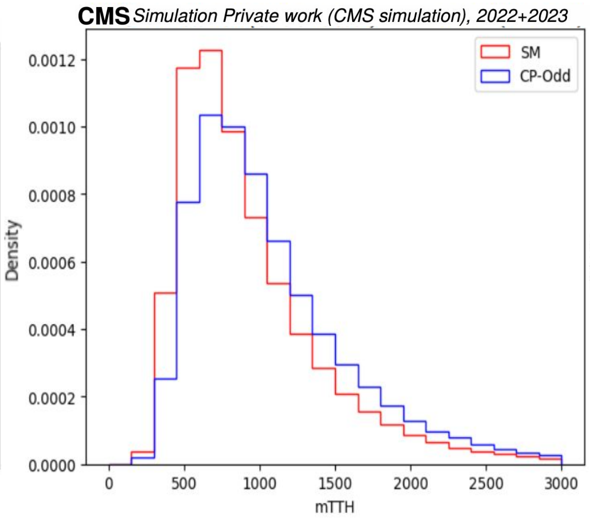


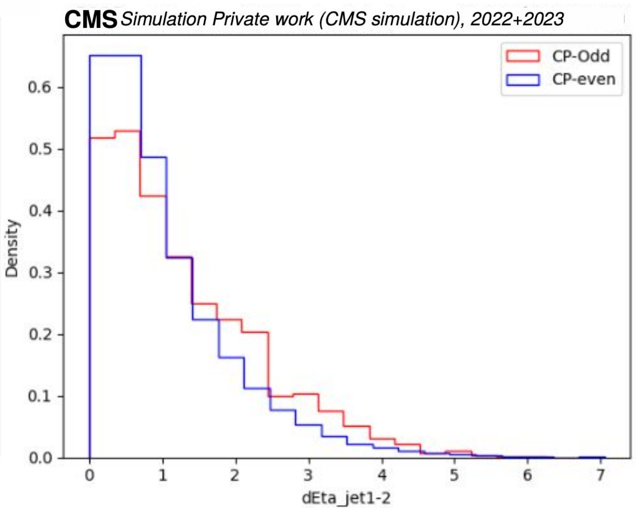
Boosted Decision Trees (BDTs) which discriminate CP-odd from CP-even events in the DNN ttH node based on the score of the CP classifiers

Diagram of the analysis process for ttH

Run 3 ttH Analysis: CP-even and CP-odd comparison







Comparison of distributions of different kinematic variables of the ttH process, for the CP-even and the CP-odd case, renormalized. dEtaBB is the difference in eta between the leading b-jets. dEta_jet1-2 is the difference in eta between the two leading jets. mTTH is the invariant mass of the Higgs, calculated as the norm of the sum of the jet and lepton 4-momenta and the missing transverse momentum.

Run 3 ttH analysis: MC and samples

- The BDT was trained on ttH Monte Carlo samples, with both CP-even and CP-odd weight.
- 2022 and 2023 MC samples, used together for the training
- The events utilized were those that passed the selections for the categories 2lss0tau, 2lss1tau and 3l0tau. In the training, all events of the signal regions were used, without selecting the ttH node of the multi-target DNN
- The signal was taken as the events with the CP-odd weight, while the background was taken as the events with the SM weight
- Split into Training and Validation in a ratio 4:1

Run 3 Training: Input Variables from Run 2 Training

2lss0tau

Tabella 5: Variables definitions 2lss0τ

Variable Name	Definition
SelJet_pt	pT of leading jet
SelJet_Eta	η of leading jet
SelJet_Phi	ϕ of leading jet
SelJet_Mass	Mass of leading jet
SelJet_isBtag	Btag class of the leading jet
SelJet_isFromHadTop	Whether the leading jet comes from the hadronic top
SelJet_BTagDeepFlavB	Deep flavour Btag of the leading jet
mindRlep1jet	dR of lep 1 to its closest jet
mindRlep2jet	dR of lep 2 to its closest jet
mTTH	invariant mass of jets+met+leptons
dEtaBB	dEta of two jets with highest b tagging score
dEtaLL_BBframe	dη of the two leptons in the B-B system frame
avg_dr_jet	average dR distance among all jets
dEtaBB_LLframe	dEta BB in the l-l system frame
Hj_tagger_hadTop	Higgs-jet tagger
HTT_score	highest BDT score of jet triplet from t
met_phi	ϕ of met
nSelJets	number of jets passing the cuts
met	missing transverse energy

2lss1tau

Tabella 6: Variables definitions 2lss1τ

Variable Name	Definition
lepton0_jetMinDR	dR of lep 1 to its closest jet
lepton1_jetMinDR	dR of lep 2 to its closest jet
dEtaBB	dη of two jets with highest b tagging score
dEtaL0L1_BBframe	dη of the two leptons in the B-B system frame
avr_dr_jet	average dR distance among all jets
dEtaB1B2_LLframe	dη BB in the l-l system frame
met_phi	ϕ of the MET
met_pt	MET
njets	number of jets passing the selection
dPhiL0L1_BBframe	dϕ of the two leptons in the B-B system frame
dPhiB1B2_LLframe	dϕ BB in the l-l system frame
HTT_score	highest BDT score of jet triplet from t
lepton1_pt	pT of the second leading lepton
lepton0_pt	pT of the leading lepton
lepton1_phi	ϕ of the second leading lepton
lepton0_phi	ϕ of the leading lepton
lepton1_eta	η of the second leading lepton
lepton0_eta	η of the leading lepton
theta_higgs_ttbar_ttHsystem	angle of $t\bar{t}$ and H in $t\bar{t}H$-system
theta_toptop_ttbarframe	angle between two t in $t\bar{t}$-frame
tau_pt	pT of the tau
tau_phi	ϕ of the tau
tau_eta	η of the tau

Run 3 Training: Input Variables from Run 2 Training

3l0tau

Tabella 4: Variables definitions $3l0\tau$

Variable Name	Definition
jetpt1	pT of leading jet
jetEta1	η of leading jet
jetPhi1	ϕ of leading jet
jetMass1	Mass of leading jet
jetpt2	pT of subleading jet
jetEta2	η of subleading jet
jetPhi2	ϕ of subleading jet
jetMass2	Mass of subleading jet
Lep1_pT	pT of lepton 1
Lep2_pT	pT of lepton 2
Lep3_pT	pT of lepton 3
mindRlep1jet	dR of lep 1 to its closest jet
mindRlep2jet	dR of lep 2 to its closest jet
mTTH	invariant mass of jets+met+leptons
dEtaBB	dEta of two jets with highest b tagging score
dEtaL1L3_BBframe	dη of leptons 1 and 3 in the B-B system frame
dEtaL1L2_BBframe	dη of leptons 1 and 2 in the B-B system frame
dRlep12	dR of lepton 1 and 2
dRlep23	dR of lepton 2 and 3
dRlep31	dR of lepton 3 and 1

What changed in Run3:
Most variables were kept. A handful needed to be removed because either unavailable yet in Run 3 or outdated in Run 2.

To compensate for this, new variables (sensitive to CP mixing) have been investigated.

Run 3 Training: Added Variables

In the paper from H. Bahl et al., CP-sensitive simplified template cross-sections for ttH, arXiv:2406.03950, JHEP 10 (2024) 214 new variables that would allow to optimally discriminate between ttH CP even and CP odd are discussed.

Of these, 17 were tested: |cosθ*|, and the b_1, b_2, b_3 and b_4 variables in four reference frames. The reference frames are the lab frame, the ttbar frame, the ttH frame, and the H frame.

After the optimization, only 5 were kept: |cosθ*| in the ttbar frame, meanwhile b_1, b_2, b_3 and b_4 are calculated in the ttH frame

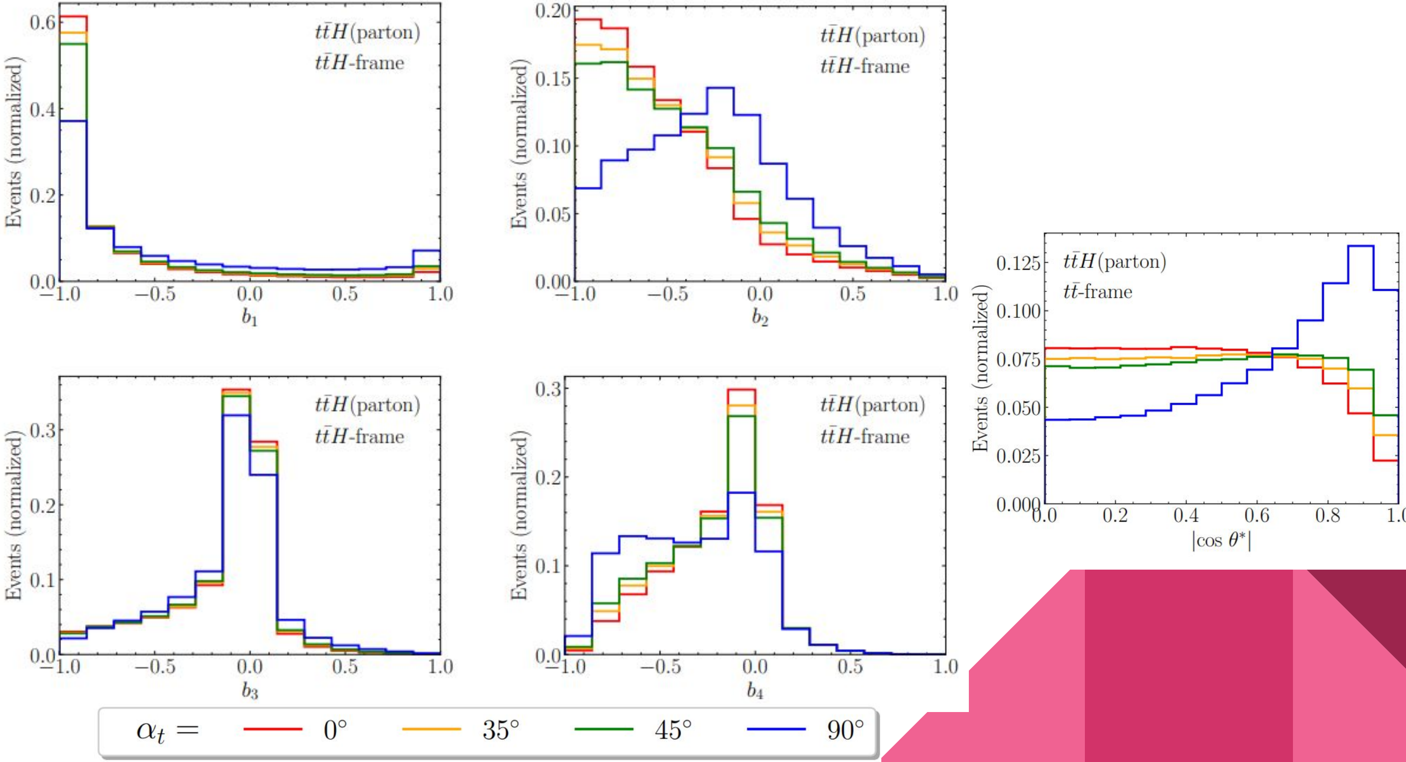
$\lvert\cos\theta^*\rvert$	$\dfrac{\lvert\boldsymbol{p}_t\cdot\boldsymbol{n}\rvert}{\lvert\boldsymbol{p}_t\rvert\cdot\lvert\boldsymbol{n}\rvert}$
b_1	$\dfrac{(\boldsymbol{p}_t\times\boldsymbol{n})\cdot(\boldsymbol{p}_{\bar{t}}\times\boldsymbol{n})}{p_{T,t}\,p_{T,\bar{t}}}$
b_2	$\dfrac{(\boldsymbol{p}_t\times\boldsymbol{n})\cdot(\boldsymbol{p}_{\bar{t}}\times\boldsymbol{n})}{\lvert\boldsymbol{p}_t\rvert\ \lvert\boldsymbol{p}_{\bar{t}}\rvert}$
b_3	$\dfrac{p_t^x\ p_{\bar{t}}^x}{p_{T,t}\,p_{T,\bar{t}}}$
b_4	$\dfrac{p_t^z\ p_{\bar{t}}^z}{\lvert\boldsymbol{p}_t\rvert\ \lvert\boldsymbol{p}_{\bar{t}}\rvert}$

Added input variables. n is the unit vector of the z-axis

Run 3 Training: Added Variables

Plots at parton-level, in ttH or ttbar frame, inclusive in the final states ($\gamma\gamma$, multilepton, bb) for multiple values of α, from the paper [H. Bahl et al., CP-sensitive simplified template cross-sections for ttH, arXiv:2406.03950, JHEP 10 (2024) 214]

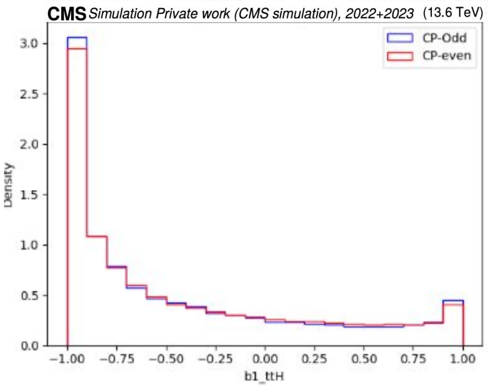
The b variables are in the ttH frame, $|\cos\theta^{*}|$ is in the ttbar frame.

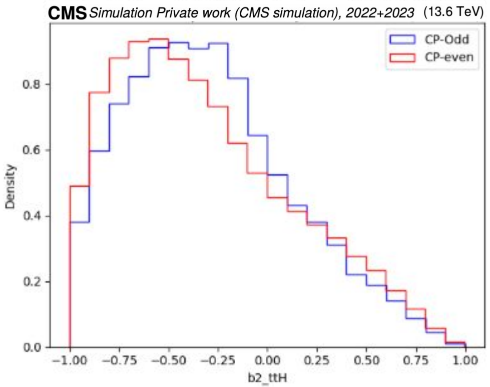


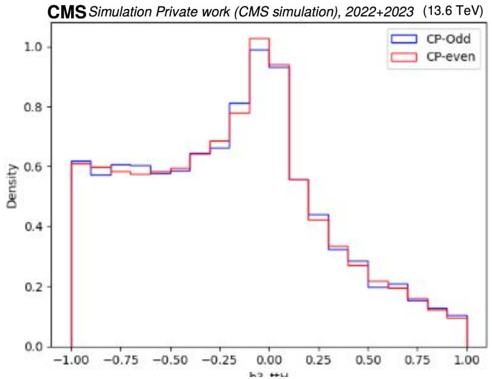
Run 3 Training: Added Variables

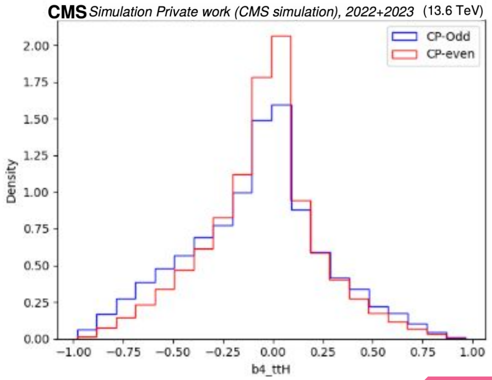
Distribution of the added variables in the multilepton final state, in the 2lss0tau category at the reconstruction level, after the full selection.
The b variables are in the ttH frame, $|\cos\theta^*|$ is in the ttbar frame.

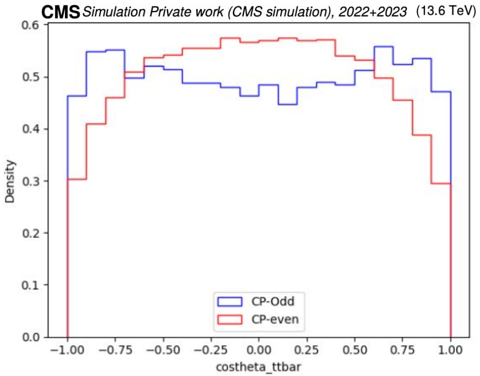
We lose discrimination at the reconstructed level, compared to the parton level



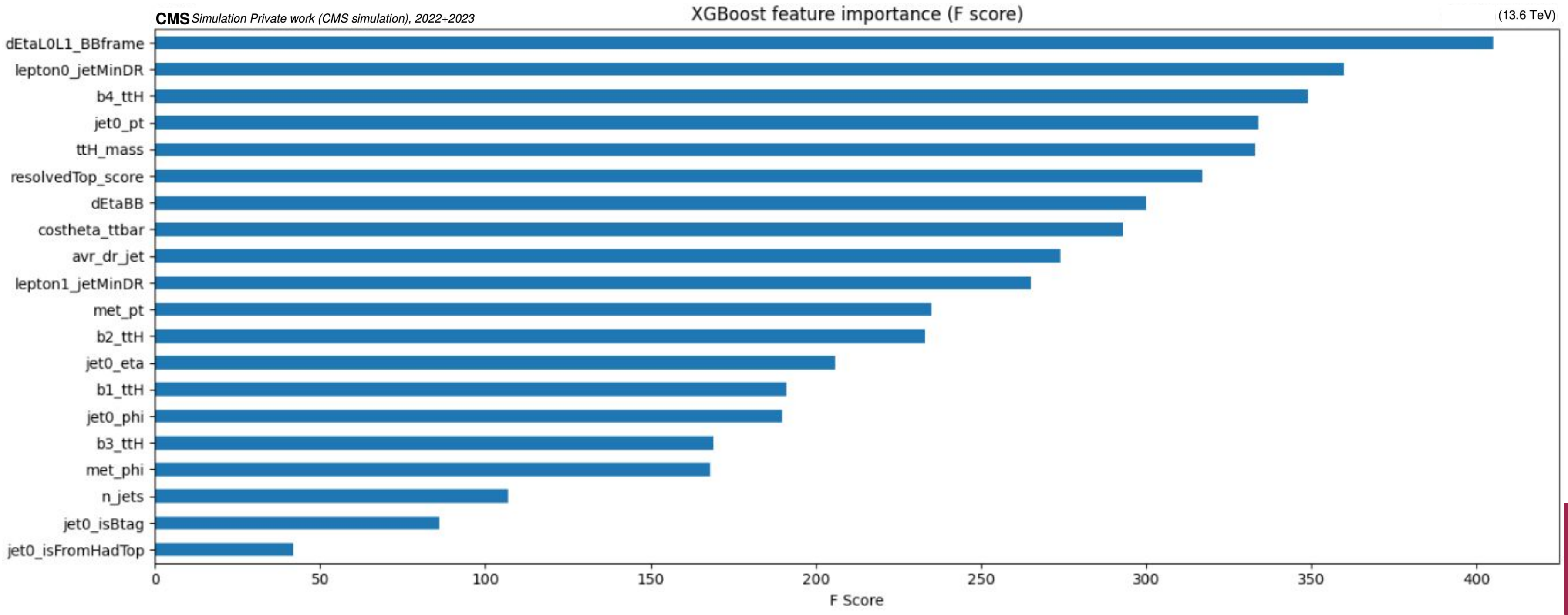








Run 3 Training: Feature importance (2lss0tau)



F-Score of the variables, in the 2lss0tau category

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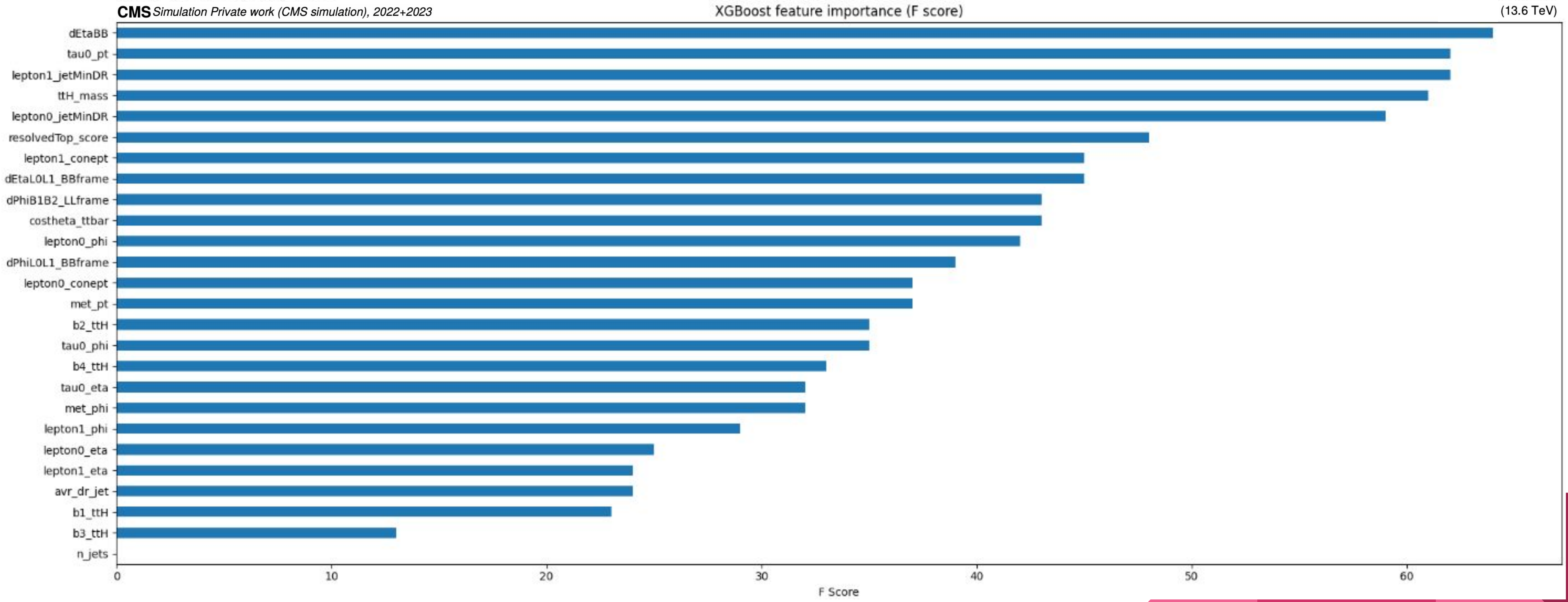

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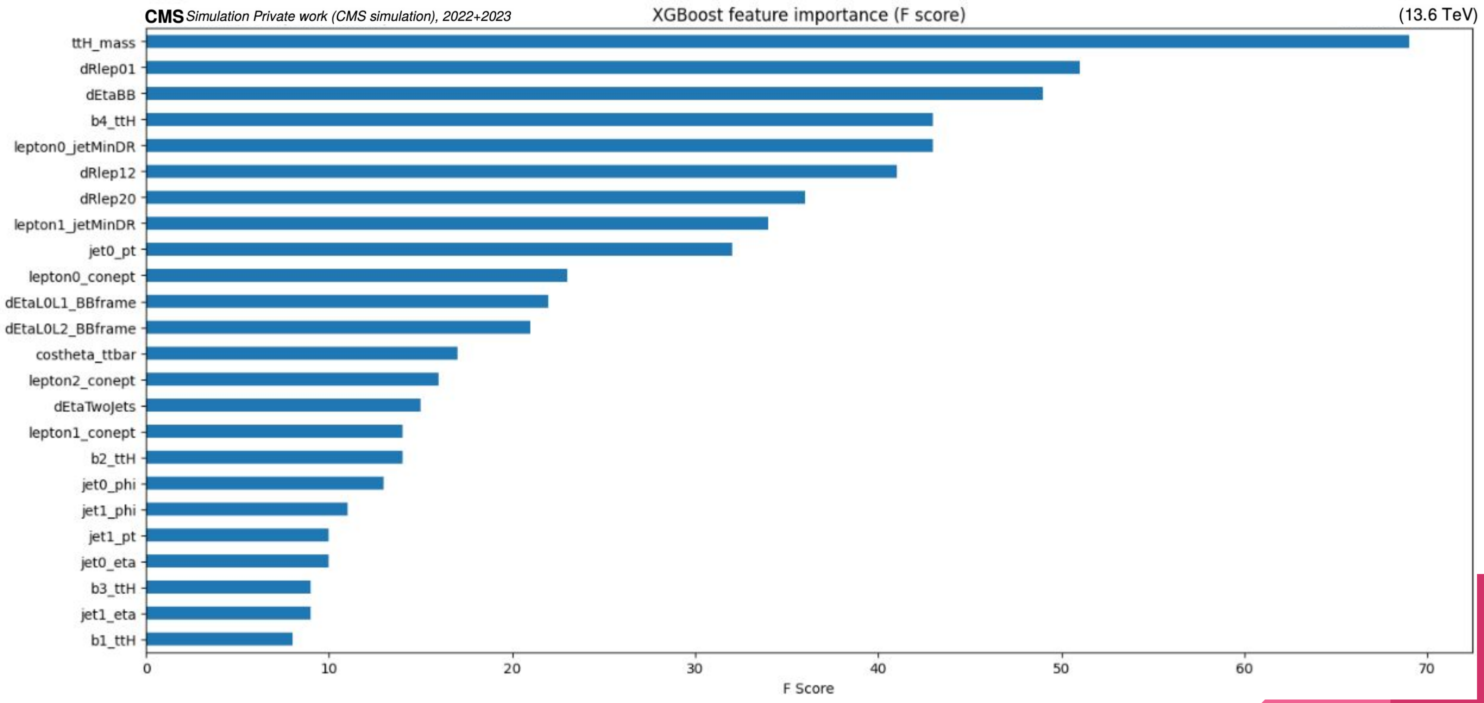


F-Score of the variables, in the 3l0tau category

Run 3 Training: Hyperparameter Optimization

When training a Machine Learning algorithm (in our case a BDT), the variables that define or constrain the properties of that algorithm are called **Hyperparameters**.

For BDTs:

- learning_rate is the weight applied to the correction from one era to the next;
- n_estimators is the number of trees;
- max_depth is the maximum number of consecutive cuts that can be present in the tree;
- subsample and colsample_bytree are the sizes of random subsection of samples or variables used;
- early_stopping interrupts the training when overtraining is detected, at least after a number of ages equal to early_stopping_rounds.

Tabella 1: HyperParameters

Hyperparameter	Updated Range
learning_rate	[0.1, 4]
n_estimators	[1500]
max_depth	[3, 6]
subsample	[0.8, 1]
colsample_bytree	[0.8, 1]
gamma	[0, 3]
early_stopping	[True]
early_stopping_rounds	[2000]

Run 3 Training: Hyperparameter Optimization

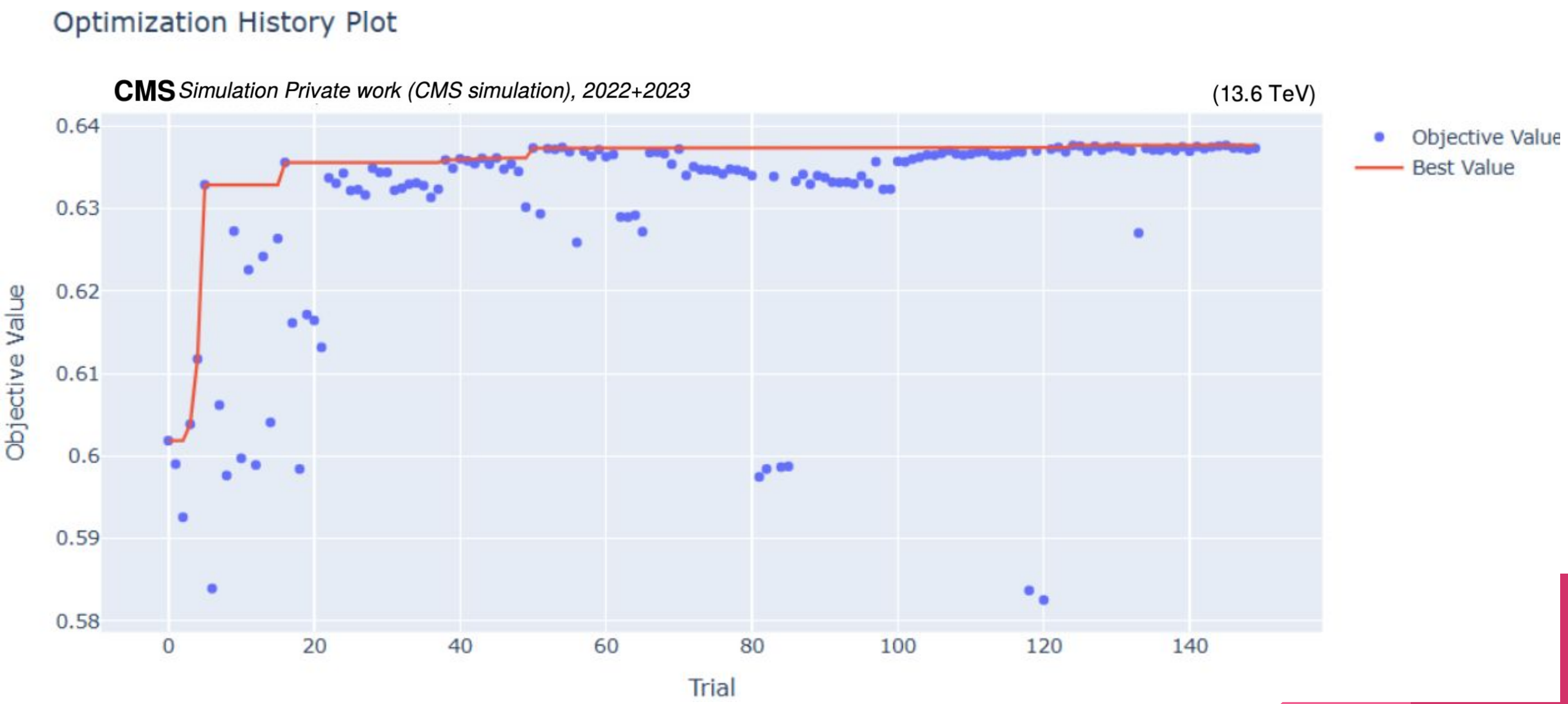
Optuna is a define-by-run tool (meaning that it allows the user to dynamically construct the search space) that uses a **Bayesian Optimization Algorithm** to either minimize or maximize an “objective” function given to it by the user.

In my case, the objective to maximize is the AUC of the ROC curve of the validation set.

The process (called “study”) is repeated for a given number of times (called “trials”), and each time the hyperparameter set is based on the results of the previous trials.

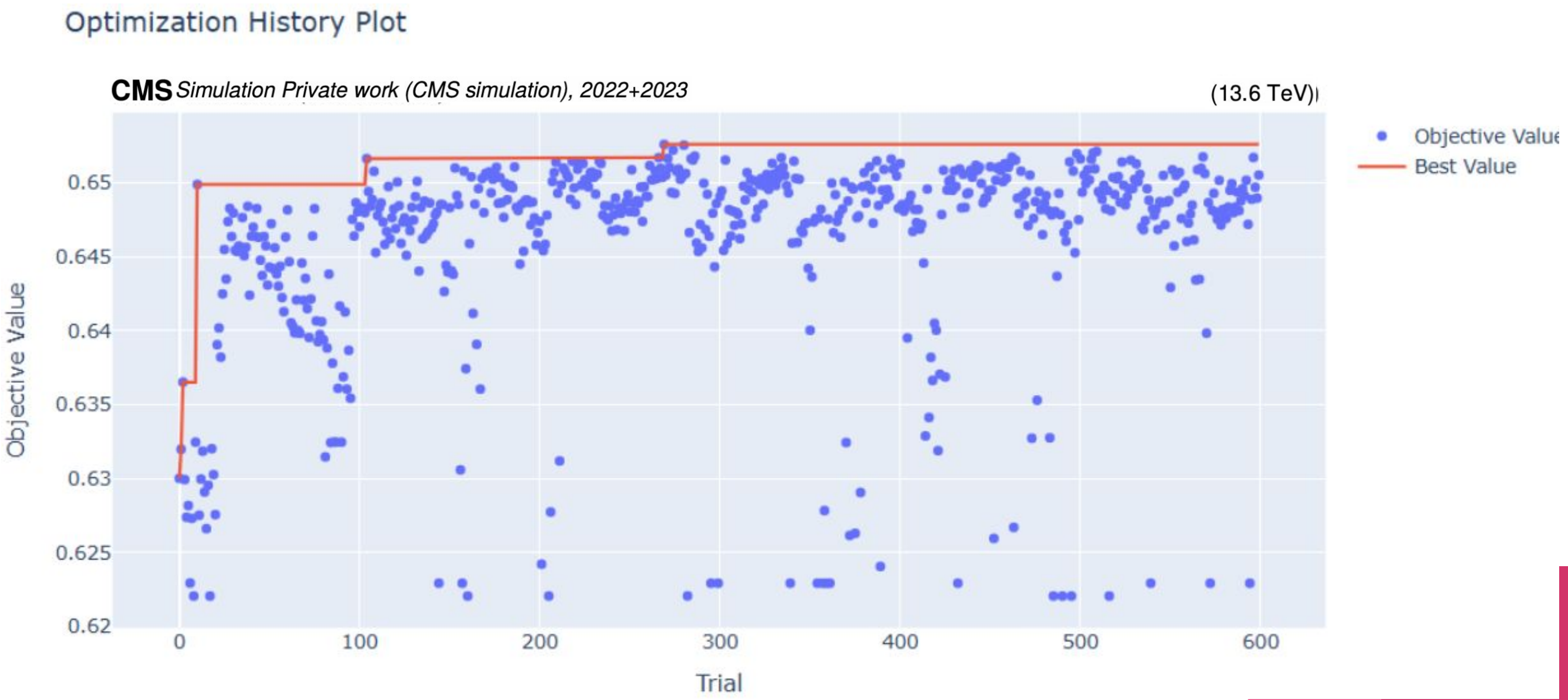
It is framework agnostic, and compatible with XGBoost.

Run 3 Training: Hyperparameter Optimization (2lss0tau)



AUC of the validation set for successive trials, for 2lss0tau

Run 3 Training: Hyperparameter Optimization (2lss1tau)



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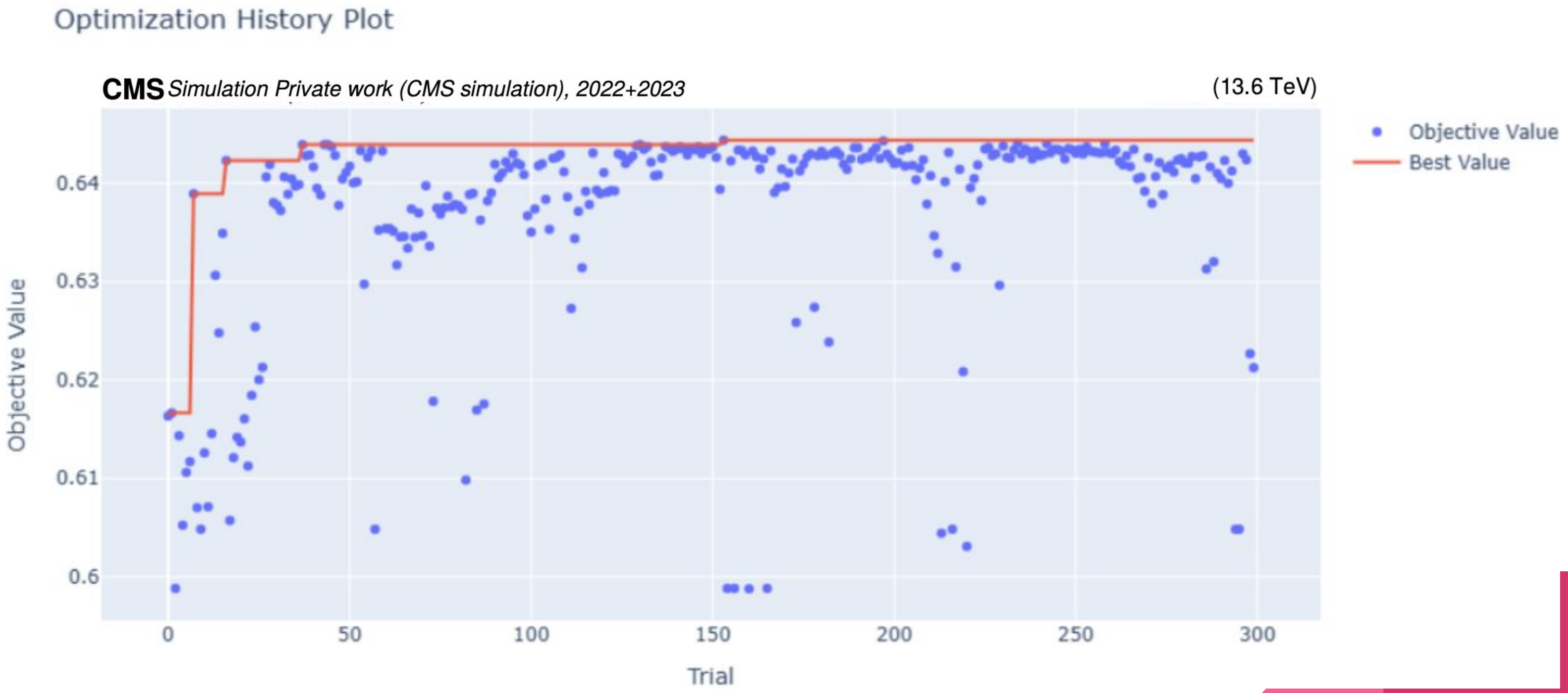
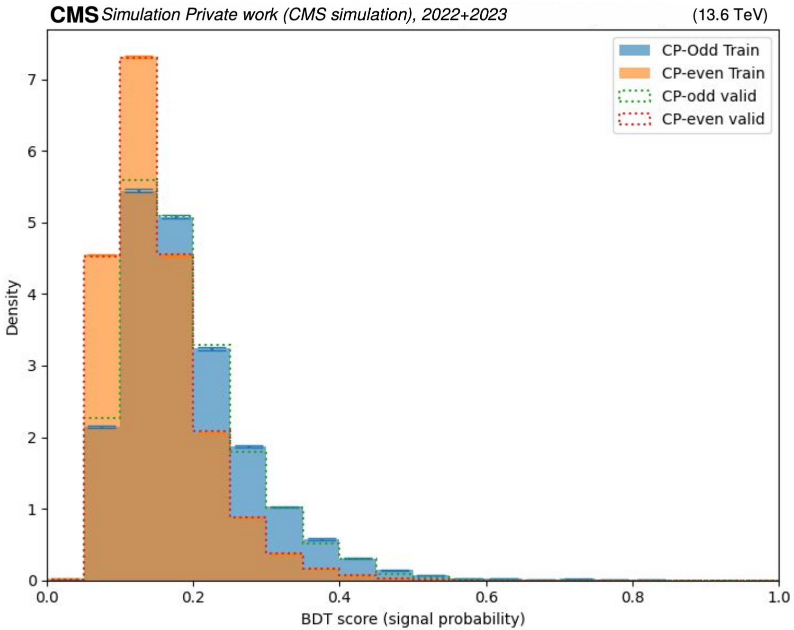
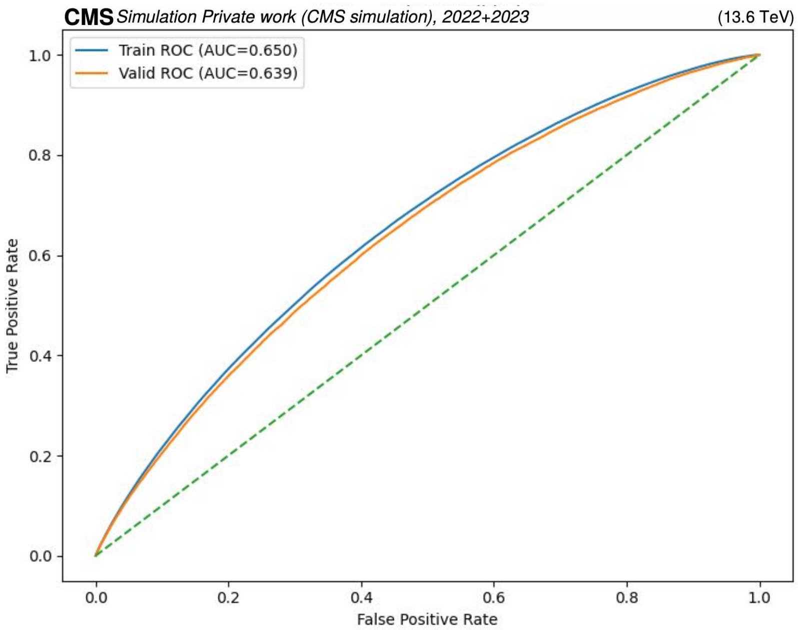


AUC of the validation set for successive trials, for 3l0tau

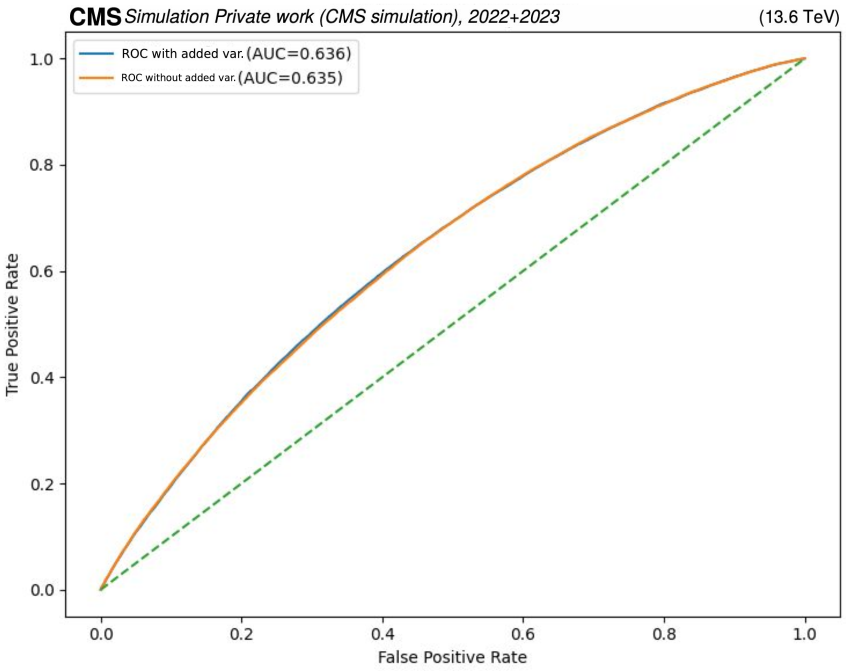
Performance: score and ROC curve (2lss0tau)

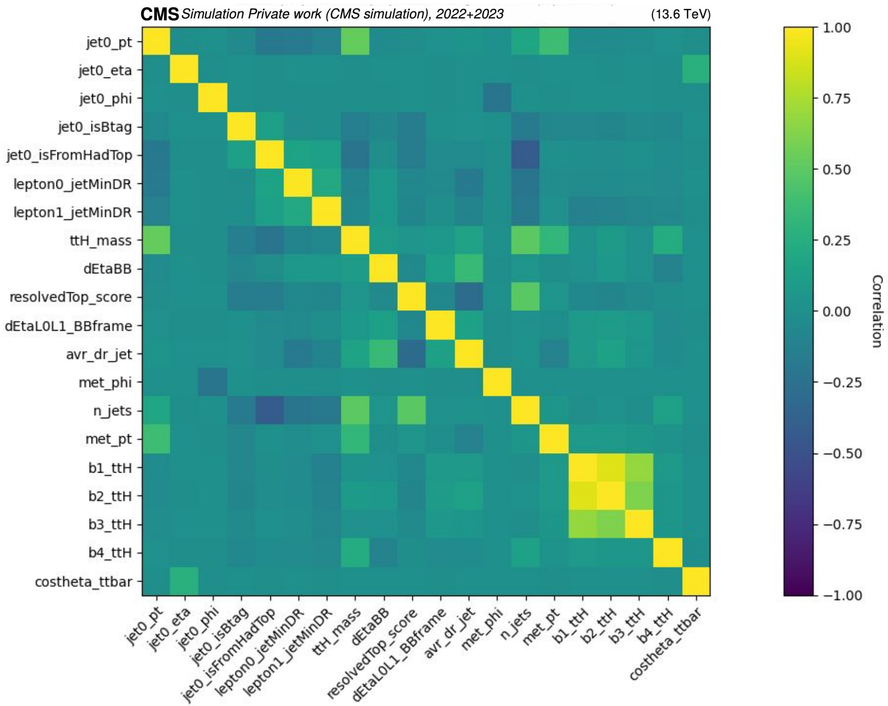




Predicted distributions for 2lss0tau for CP-even and CP-odd(left) and corresponding ROC curve with AUC=0.639 (right). In Run 2, the AUC of the ROC curve was 0.637

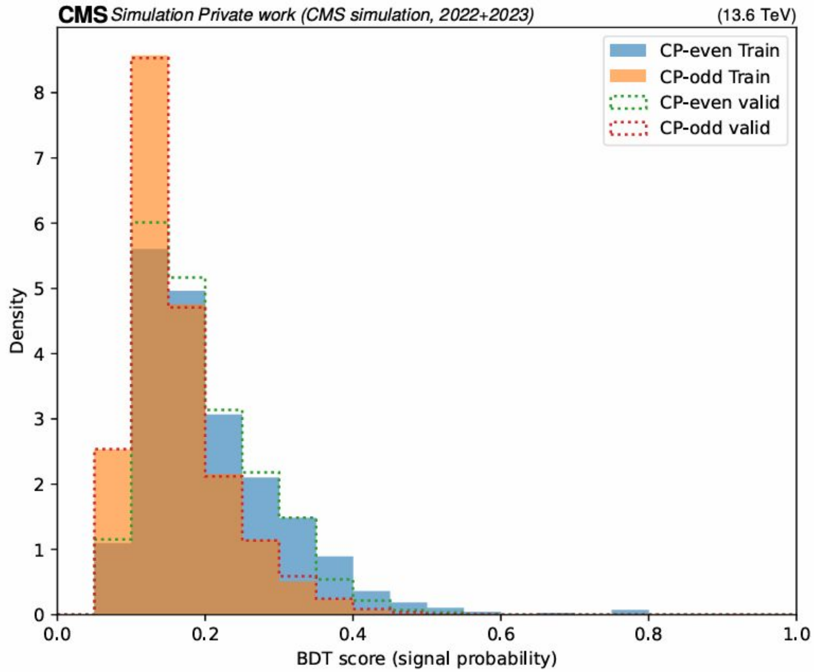
Performance: ROC curve and correlation (2lss0tau)

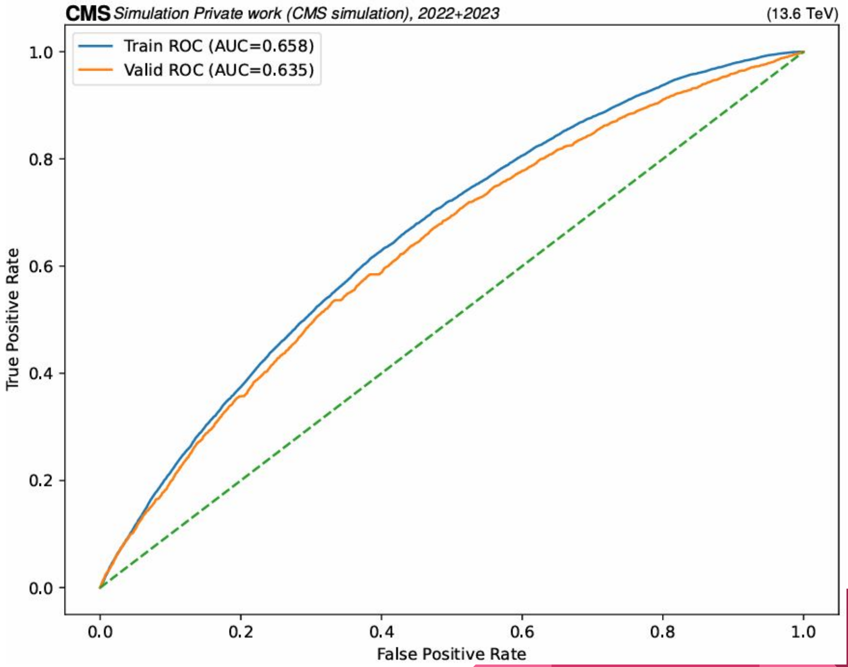




Comparison of ROC curve with or without the added variables for 2lss0tau (left) and correlation matrix (right). In the comparison, the optimization was run separately for both

Performance: score and ROC curve (2lss1tau)





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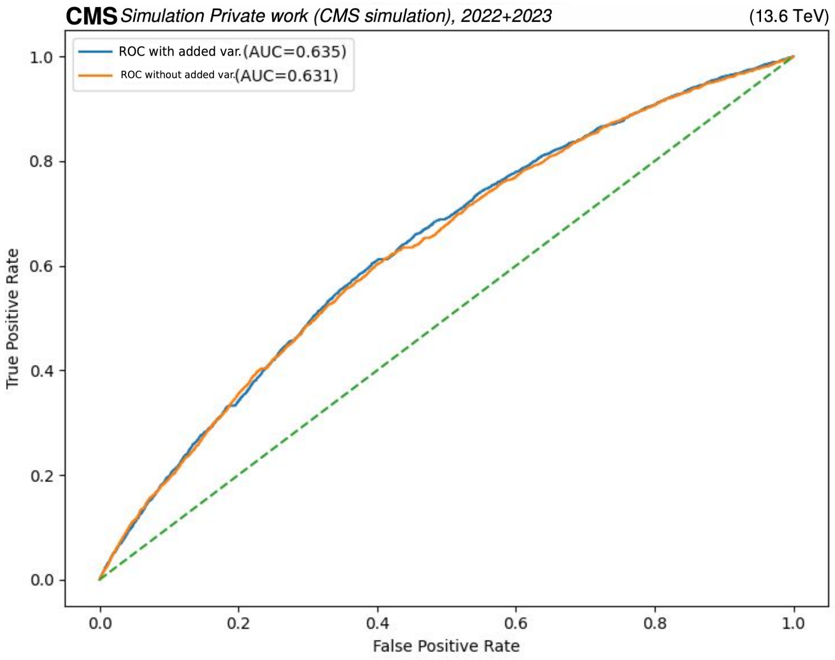

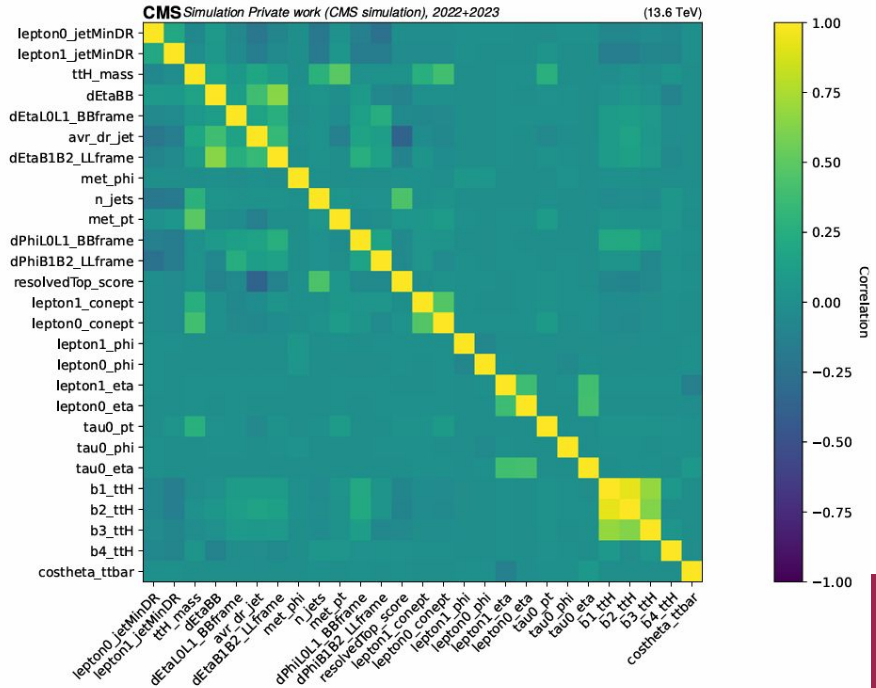

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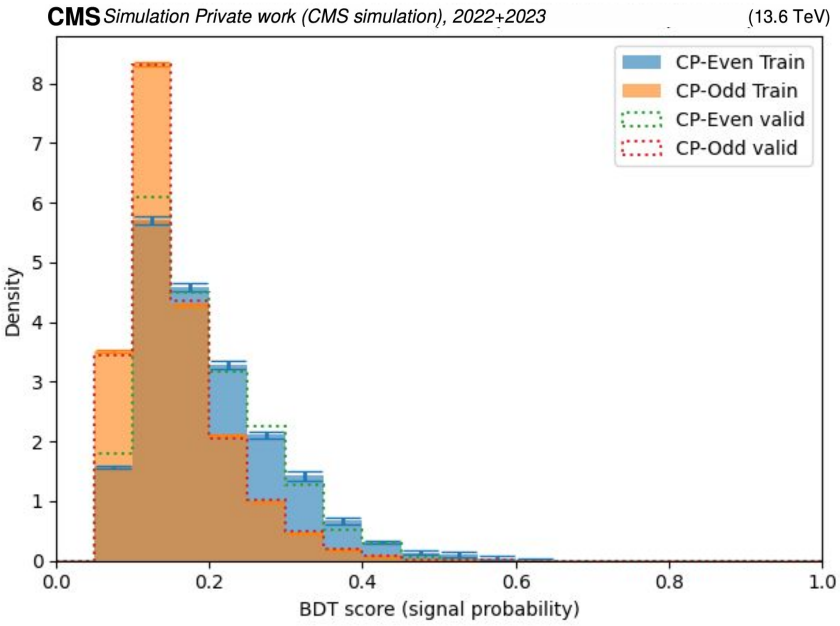
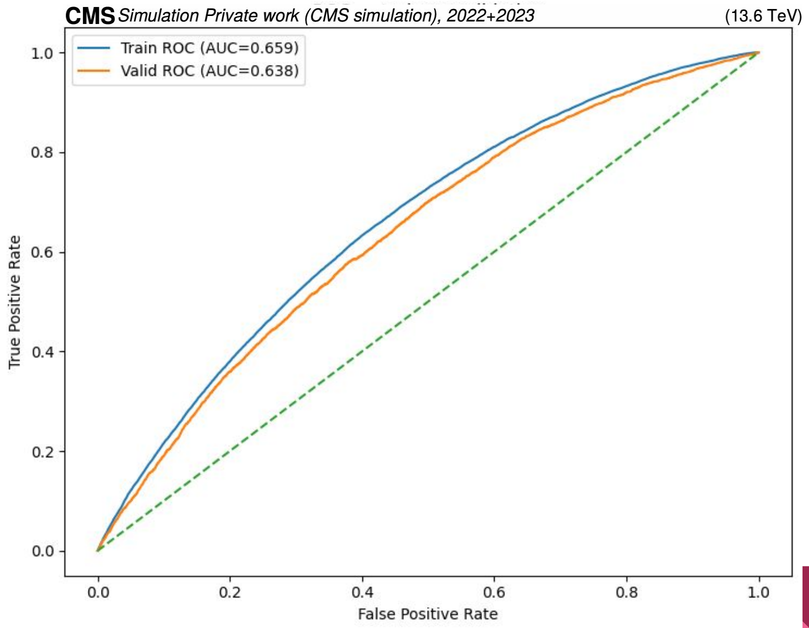
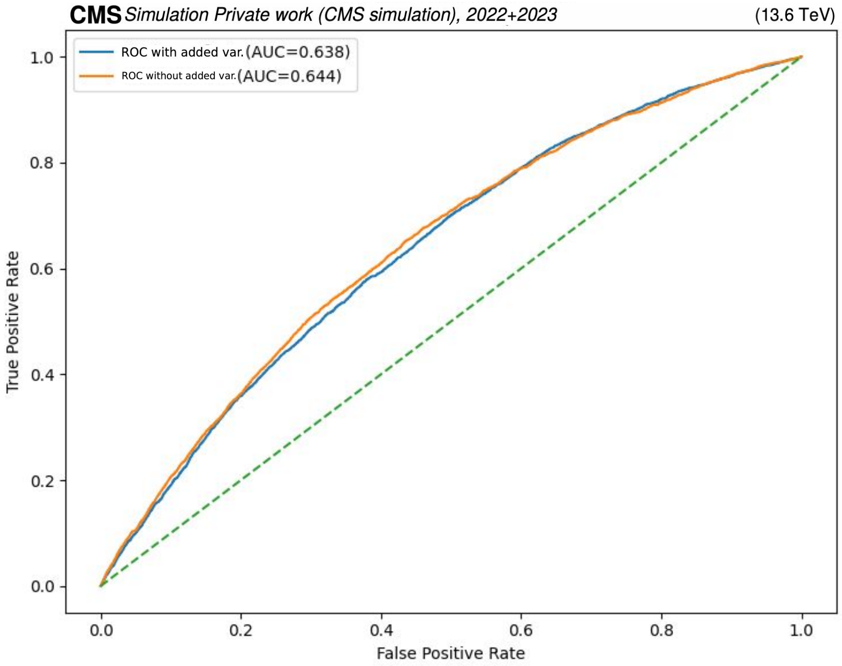
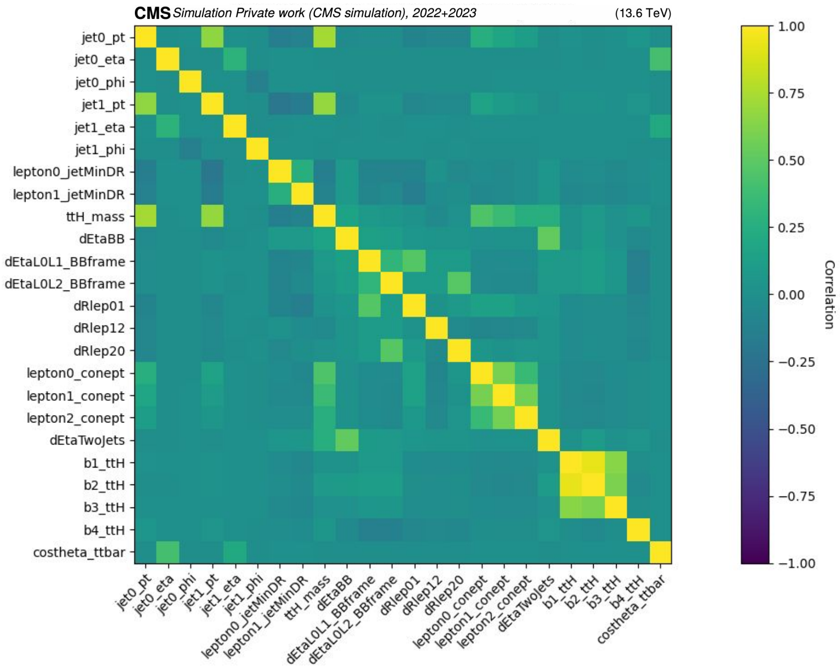




Predicted distributions for 3l0tau for CP-even and CP-odd(left) and corresponding ROC curve with AUC=0.638 (right). In Run 2, the AUC of the ROC curve was 0.637

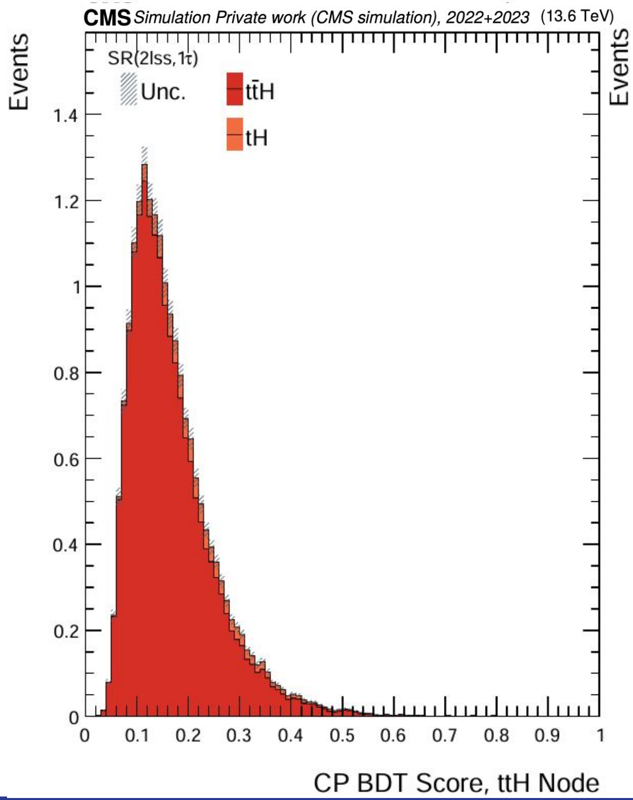
Performance: ROC curve and correlation (3l0tau)

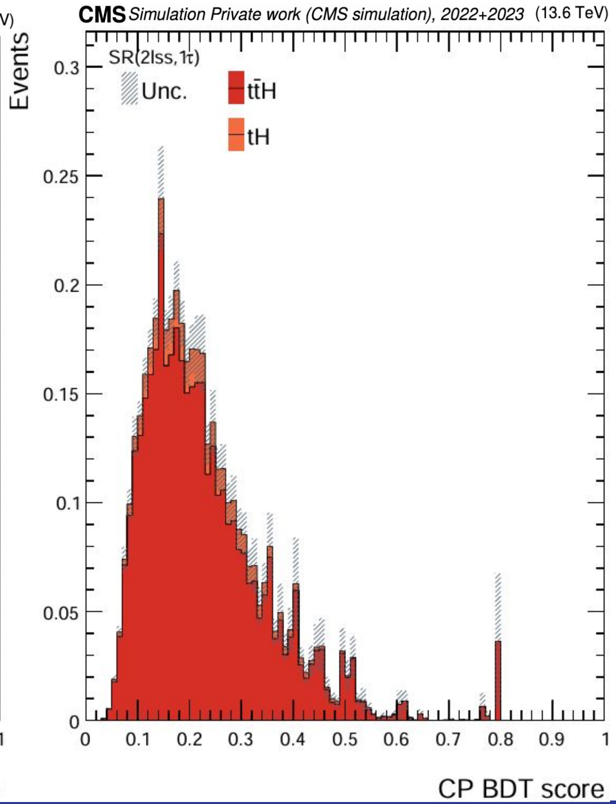




Comparison of ROC curve with or without the added variables for 3l0tau (left) and correlation matrix (right). In the comparison, the optimization was run separately for both

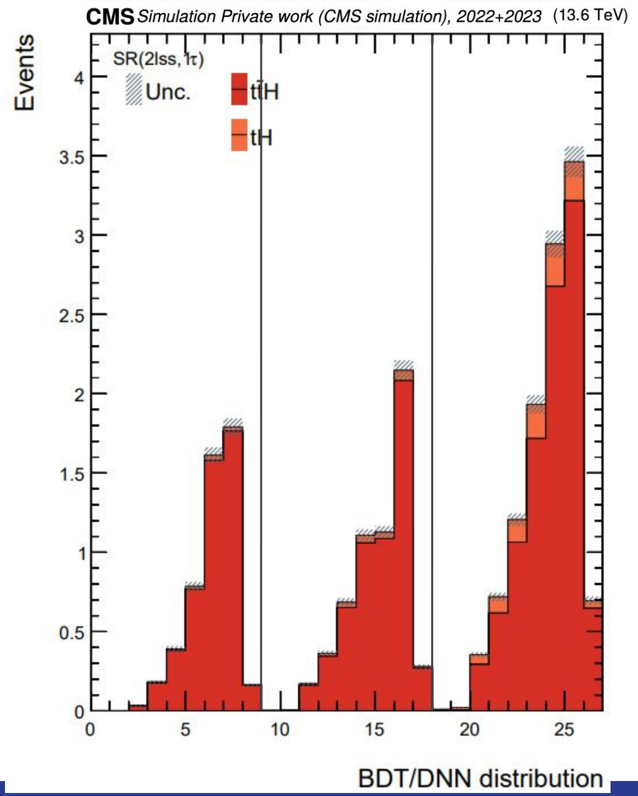
Performance: BDT score in the ttH node (2lss1tau)





Comparison of the BDT score distribution in the ttH node, for the 2lss1tau channel. On the left, the CP-even distribution, on the right, the CP-odd distribution

Performance: usage in the analysis



Once the model is trained, it is then applied to the ttH-like events in the ttH node. For the likelihood scan, what is used is not the BDT score directly, but the combined distribution of the scores of the BDT and of the DNN.

To do so, we first split the events into a first set of bins based on their BDT score. For example, in the 2lss1tau channel (left) we have three bins.

We then further split the events in each region based on the score assigned by the DNN. The binnings are chosen to maximize the following z-score

$$Z = \frac{n_s}{N_s} z_s + \frac{n_b}{N_b} z_b$$

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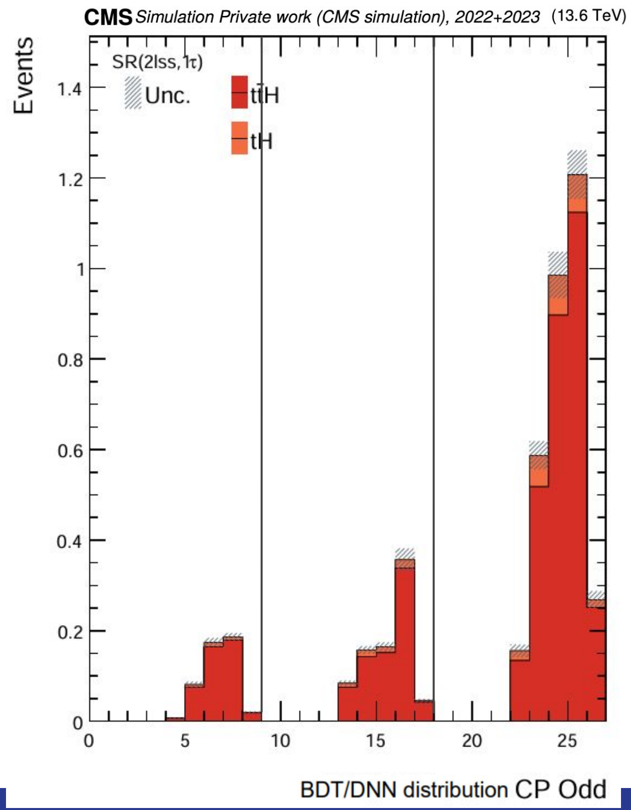

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Conclusions and prospects

Summary:

- The Run 3 AUC is comparable with the Run 2 AUC
- The added variables improved slightly the results
- We might have reached a plateau with what we can get with a BDT

Future prospects:

- Finalize the signal extraction with the likelihood scan
- Test different ML methods (DNNs, transformers) to replace the BDT

Thank you for the Attention!

Tight-loose-very loose definitions

Electrons			
Observable	Loose	Fakeable	Tight
Cone-p_T	> 7 GeV	> 10 GeV	> 10 GeV
$\|\eta\|$	< 2.5	< 2.5	< 2.5
$\|d_{xy}\|$	< 0.05 cm	< 0.05 cm	< 0.05 cm
$\|d_z\|$	< 0.1 cm	< 0.1 cm	< 0.1 cm
d/σ_d	< 8	< 8	< 8
I_e	$< 0.4 \times p_T$	$< 0.4 \times p_T$	$< 0.4 \times p_T$
$\sigma_{i\eta i\eta}$	—	$< \{ 0.011 / 0.030 \}^1$	$< \{ 0.011 / 0.030 \}^1$
H/E	—	< 0.10	< 0.10
1/E - 1/p	—	> -0.04	> -0.04
Conversion rejection	—	✓	✓
Missing hits	≤ 1	$= 0$	$= 0$
EGamma POG MVA	>WP-loose[2]	>WP-80 (>WP-loose)[2]†	>WP-loose[2]
Deep Jet of nearby jet	—	<WP-medium[3]	<WP-medium[3]
Jet relative isolation[4]	—	< 0.7 (—) †	—
Prompt-e MVA	—	< 0.80 (> 0.80)	> 0.80

Tight-loose-very loose definitions

Muons			
Observable	Loose	Fakeable	Tight
p_T	> 5 GeV	> 10 GeV	> 10 GeV
$\|\eta\|$	< 2.4	< 2.4	< 2.4
$\|d_{xy}\|$	< 0.05 cm	< 0.05 cm	< 0.05 cm
$\|d_z\|$	< 0.1 cm	< 0.1 cm	< 0.1 cm
d/σ_d	< 8	< 8	< 8
I_μ	$< 0.4 \times p_T$	$< 0.4 \times p_T$	$< 0.4 \times p_T$
PF muon	>WP-loose[1]	>WP-loose[1]	>WP-medium[1]
Deep Jet of nearby jet	—	<WP-interp. (<WP-medium)[2]	<WP-medium[2]
Jet relative isolation[3]	—	<0.5 (—) †	—
Prompt-μ MVA	—	< 0.85 (> 0.85)	> 0.85

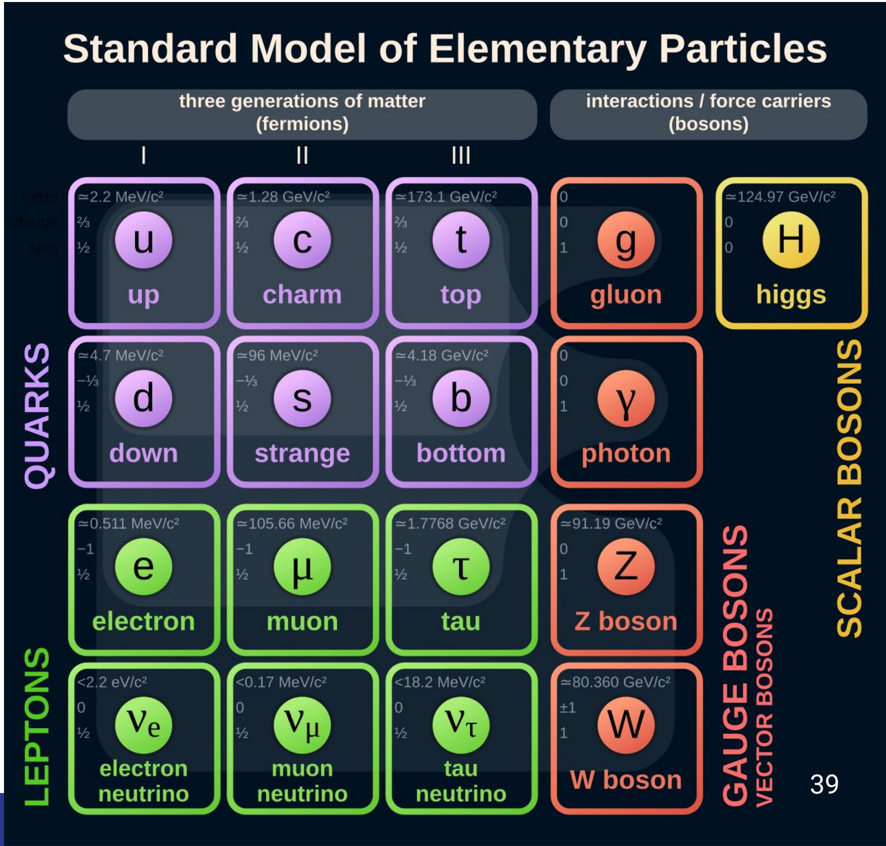
Tight-loose-very loose definitions

Hadronic τ			
Observable	Loose	Fakeable	Tight
p_T	> 20 GeV	> 20 GeV	> 20 GeV
$\lvert\eta\rvert$	< 2.3	< 2.3	< 2.3
$\lvert d_z\rvert$	< 0.2 cm	< 0.2 cm	< 0.2 cm
Decay mode finding	New	New	New
Decay modes	All	All except 2-prong$(+\pi^0)^1$	All except 2-prong$(+\pi^0)^1$
DeepTau vs. jets	> WP-VVLoose	> WP-VVLoose	WP-VLoose
DeepTau vs. muons	—	> WP-VLoose	> WP-VLoose
DeepTau vs. electrons	—	> WP-VVVLoose	> WP-VVVLoose

Introduction: the Top Quark

The top quark (*t*) has unique properties when compared to the other quarks:

1. It has a mass of **171,77±0,38 GeV**, over 2 orders of magnitude larger than that of all other quarks;



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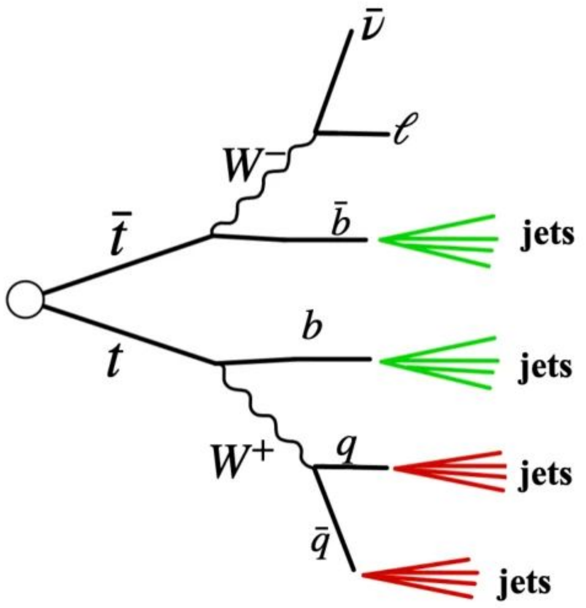

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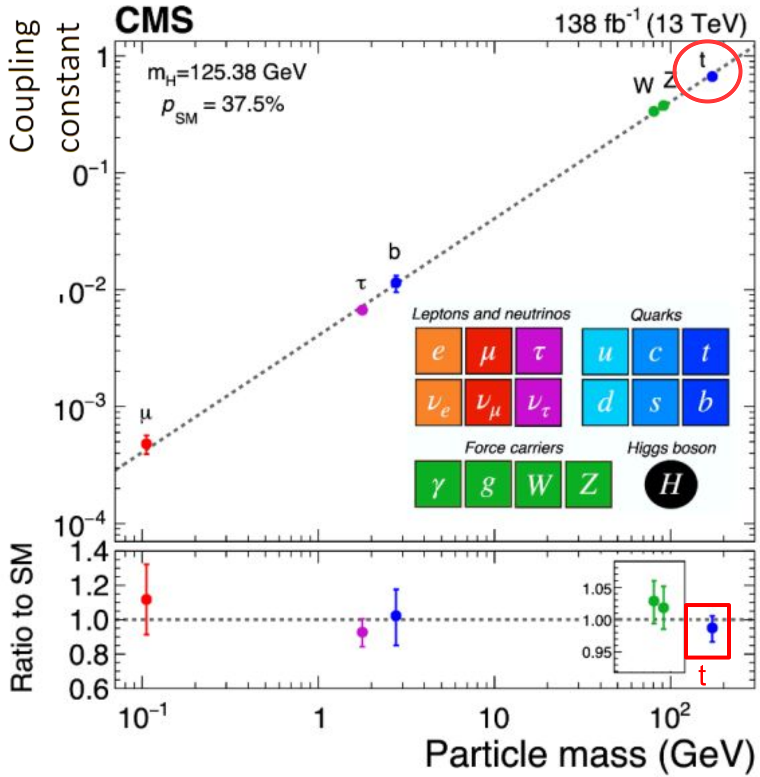
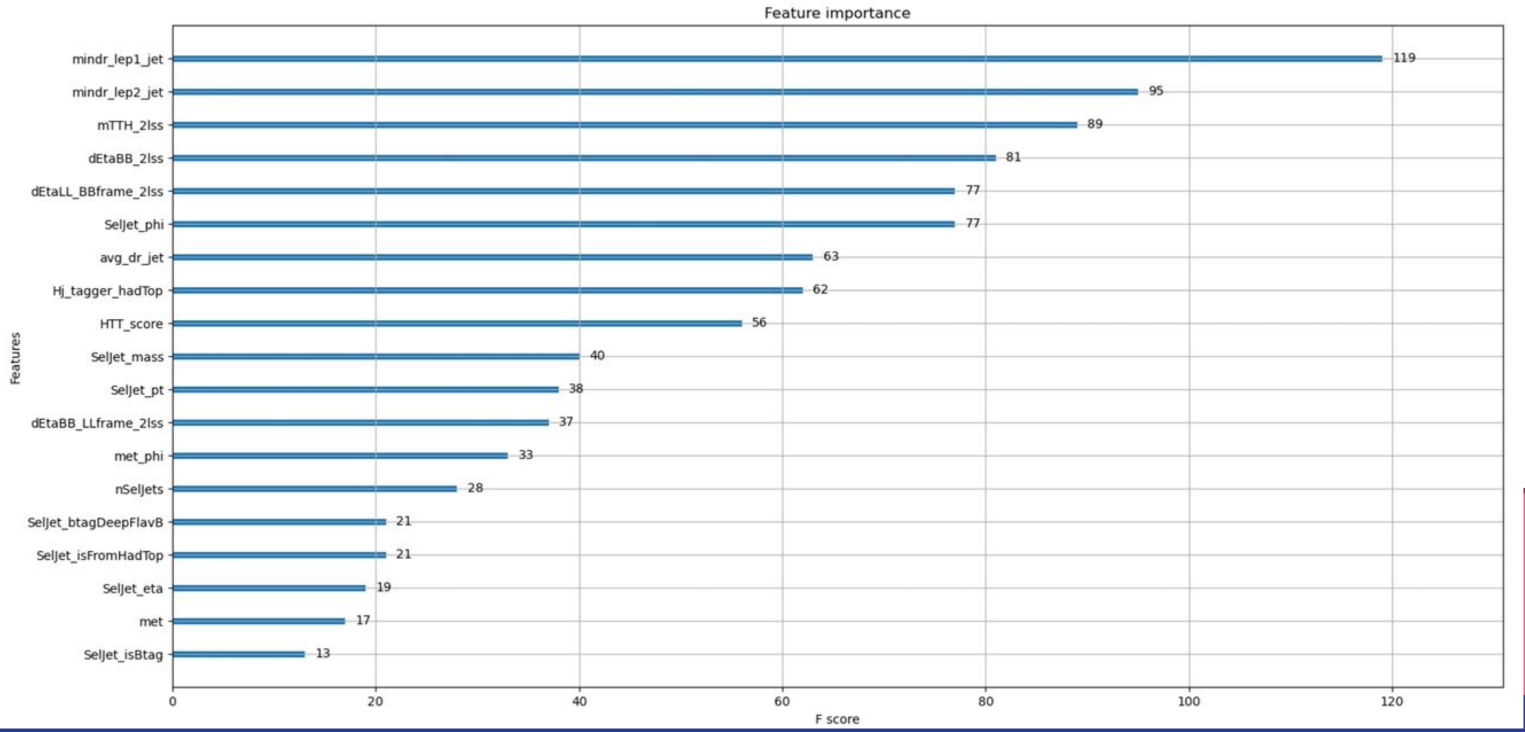
3. It has an unusually high coupling to the Higgs field, measured in CMS Run 2 to be **0.95 ±0.08**. Predictions for HL-LHC foresee that the precision on this measurement will increase to 4%

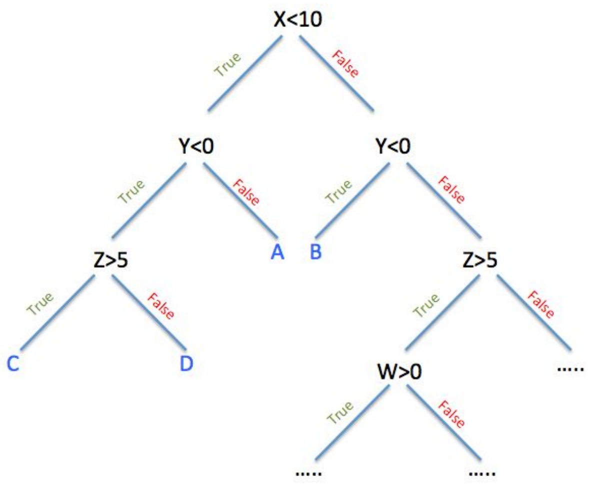


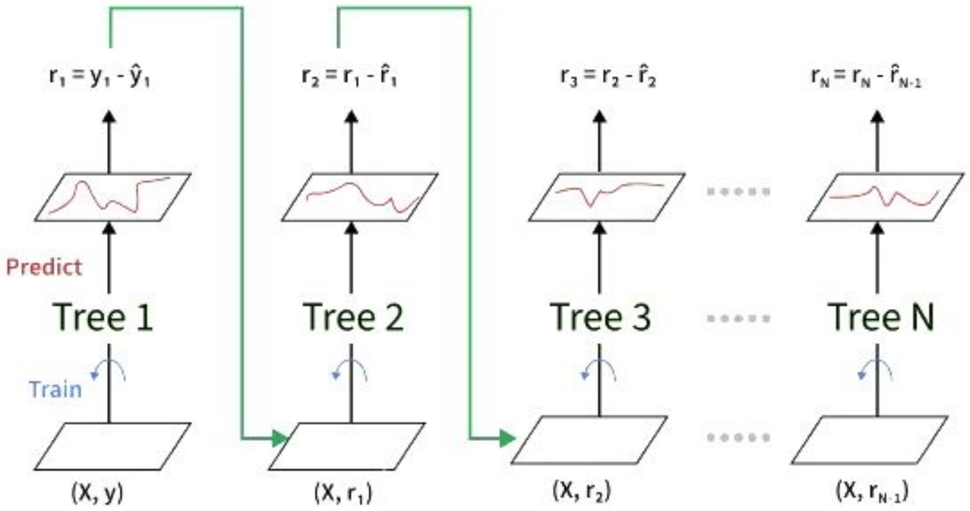
The Input Variables: Variable ranking in Run 2 (2lss0tau)

All features used for the 2lss0tau CP-BDT, with relative importance (from the CMS AN-20-241):



ttH Analysis and usage of the CP-BDT

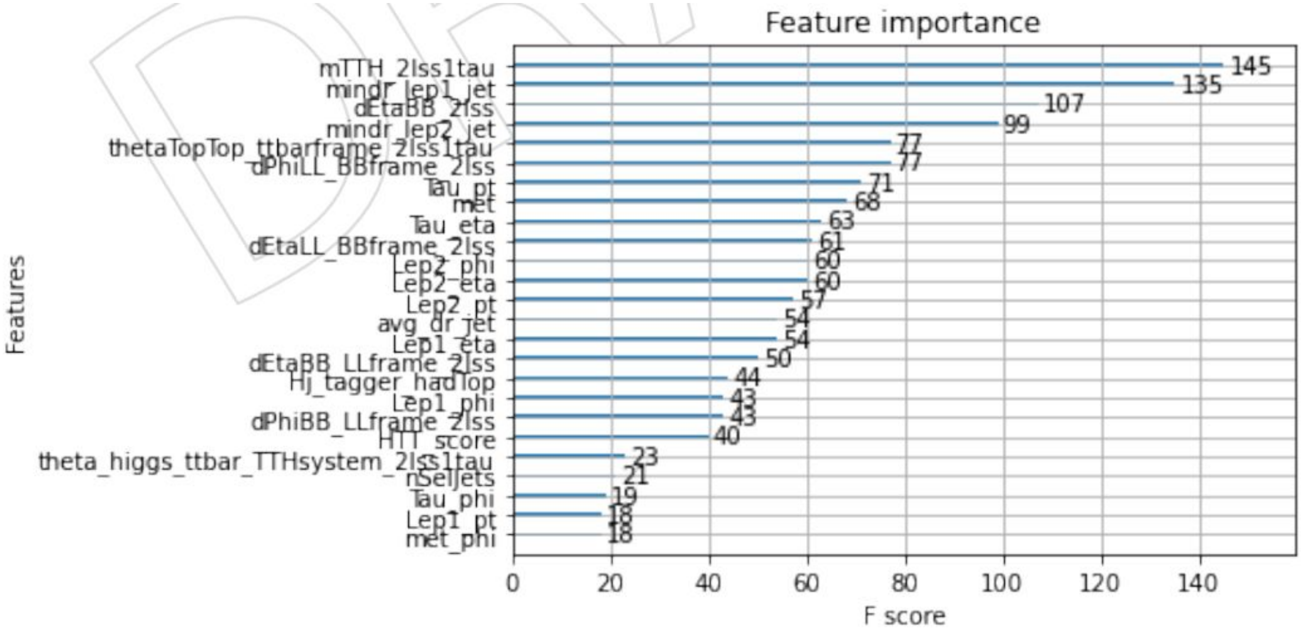




Example of a Binary Decision Tree

Example of a Boosted Decision Tree (BDT). When creating the training data for the second tree, we apply to misidentified events a weight α = (1 - r_1)/r_1

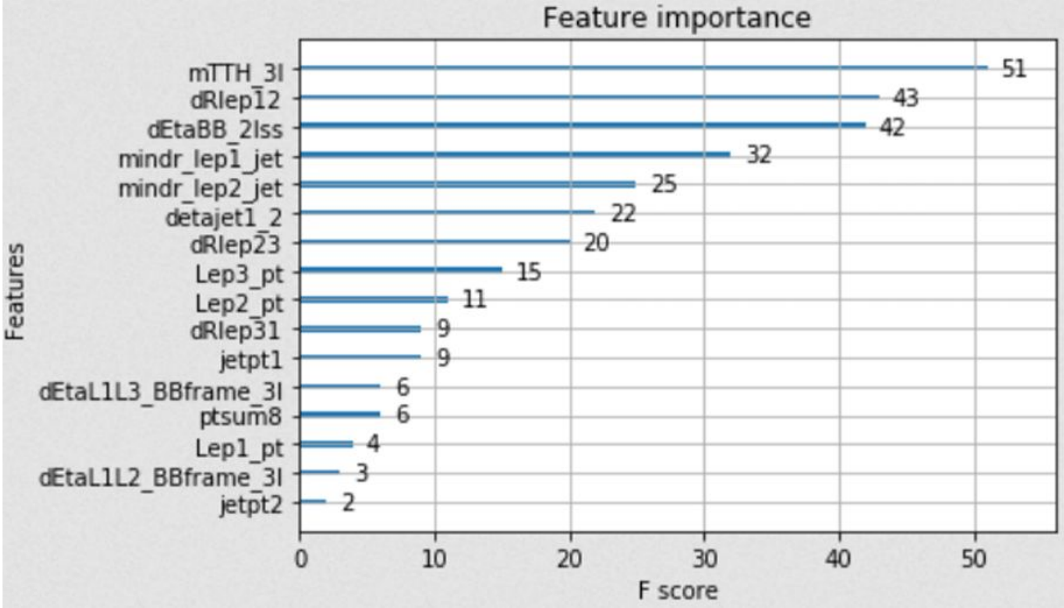
Features in Run 2



These are the input features of the CP-BDT in the Run2 AN. Of these, I have only avoided the HJet-tagger, and I have added the variables from here

The Input Variables: Variable ranking in Run 2 (3l0tau)

All features used for the 3l0tau CP-BDT in Run2, with relative importance (from the CMS AN-20-241):



Training Method

The BDT is trained using XGBoost, with the following functions:

The evaluation metric is the AUC of the validation set

The number of rounds has been increased to 2000, but the best iteration is still picked

```
param = {
    "verbosity": 0,
    "objective": "binary:logistic",
    "eval_metric" : "auc",
    "tree_method": "hist",
    #"callbacks" : pruning_callback,
    #fixed parameters
    "n_estimators" : 2500,
    "reg_lambda" : 1.0,
    "reg_alpha" : 0.1,
    "min_child_weight" : 2.0,
    "scale_pos_weight" : 1.055,
    "random_state" : 723575,
    "early_stopping_rounds" : 2000,
    # Hyperparameters to exploit
    "learning_rate" : trial.suggest_float("learning_rate", 0.1, 4.0),
    "subsample": trial.suggest_float("subsample", 0.8, 1.0),
    "colsample_bytree": trial.suggest_float("colsample_bytree", 0.8, 1.0),
    "gamma" : trial.suggest_int("gamma", 0., 3.0),
    "max_depth" : trial.suggest_int("max_depth", 3, 6)
}
clf = xgb.XGBClassifier(**param)
clf.fit(Xtr, ytr, sample_weight=wtr,
    eval_set=[(Xva, yva)],
    sample_weight_eval_set=[(wva)], verbose=100)
```

Updated Output: Error bars

Since last time, error bars have been added to both the score distribution and the ROC curve.

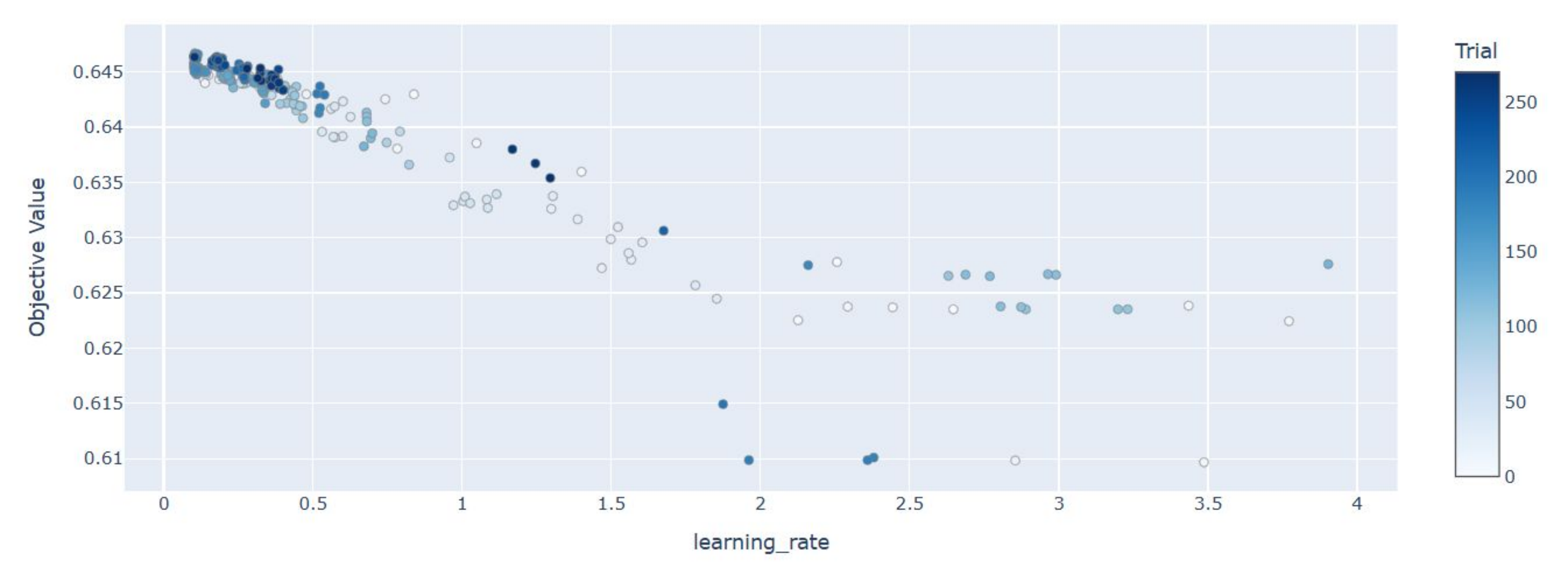
For the score distribution, each channel was assigned the following error:

$$\Delta n = \sqrt{n}$$

For the ROC curve, we assigned to the TPR (True Positive Rate) the following error:

$$\Delta tpr = \sqrt{\frac{tpr \cdot (1 - tpr)}{N}}$$

2lss0tau optimization plots



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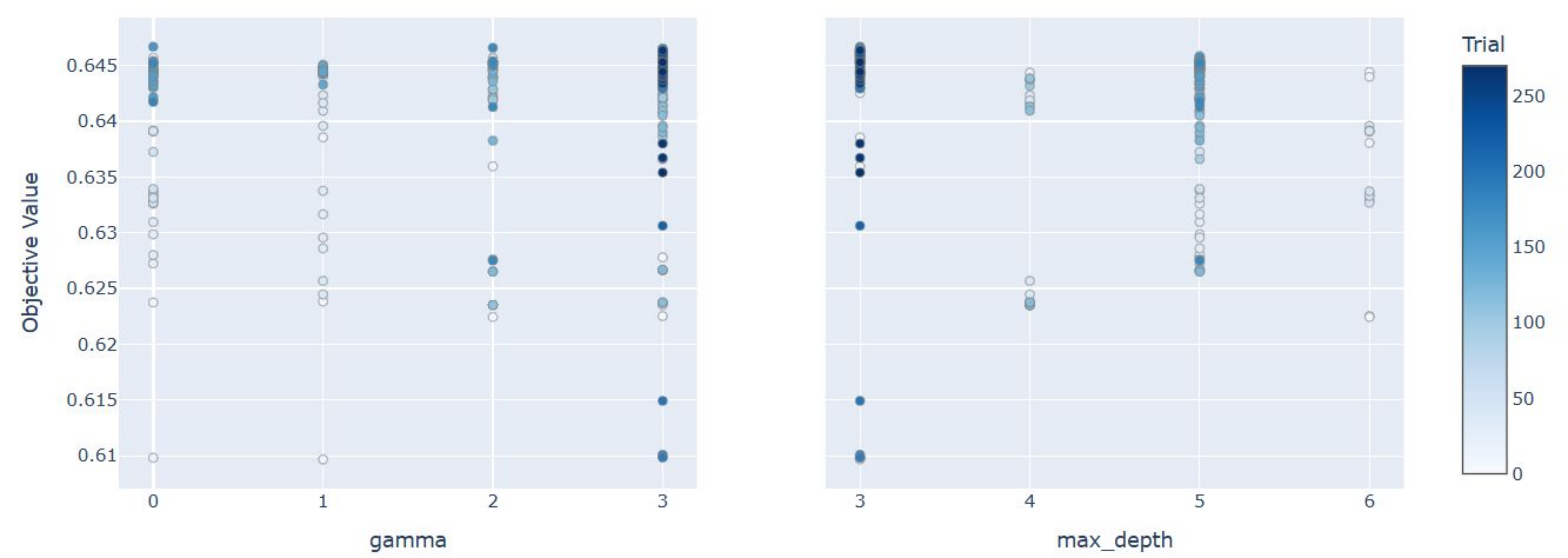

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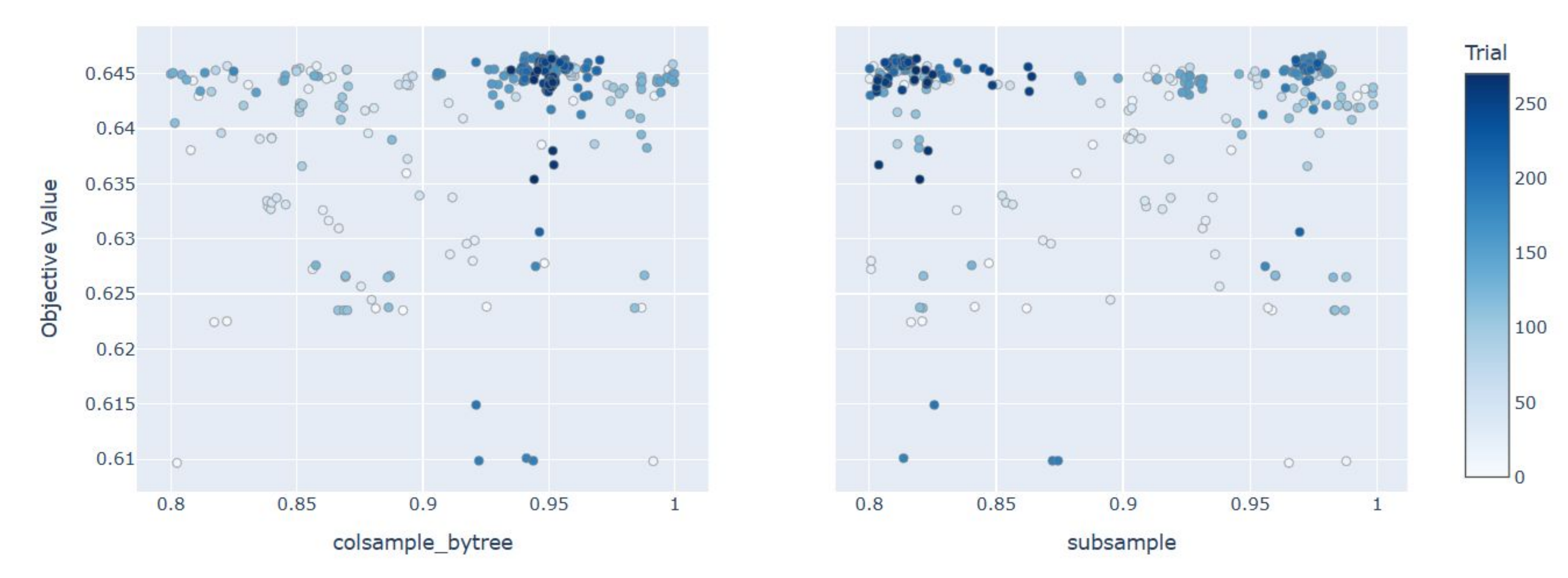
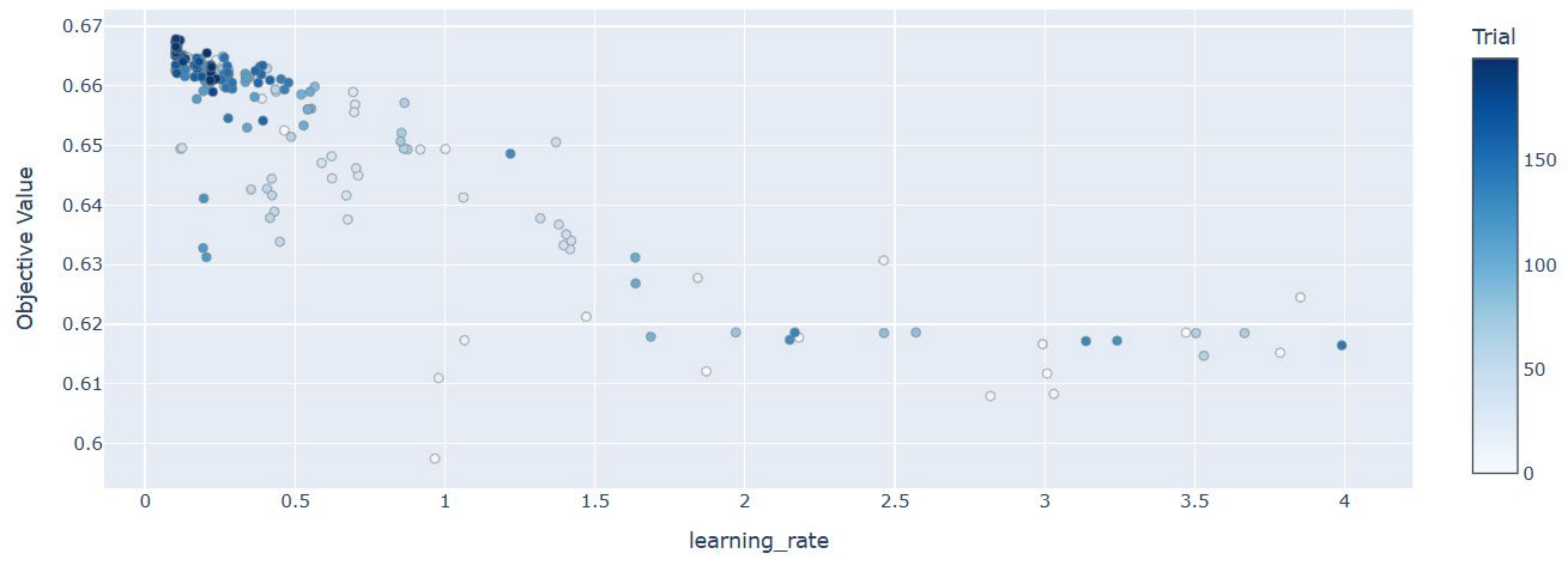


3l0tau optimization plots



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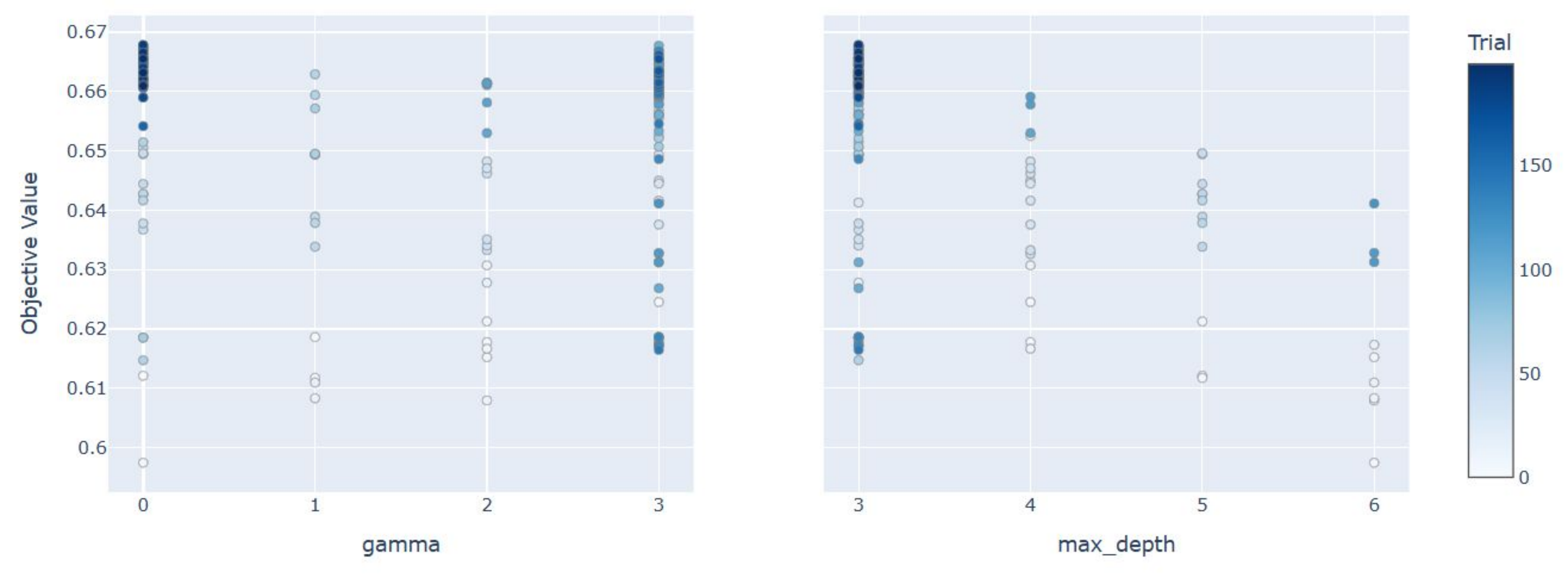

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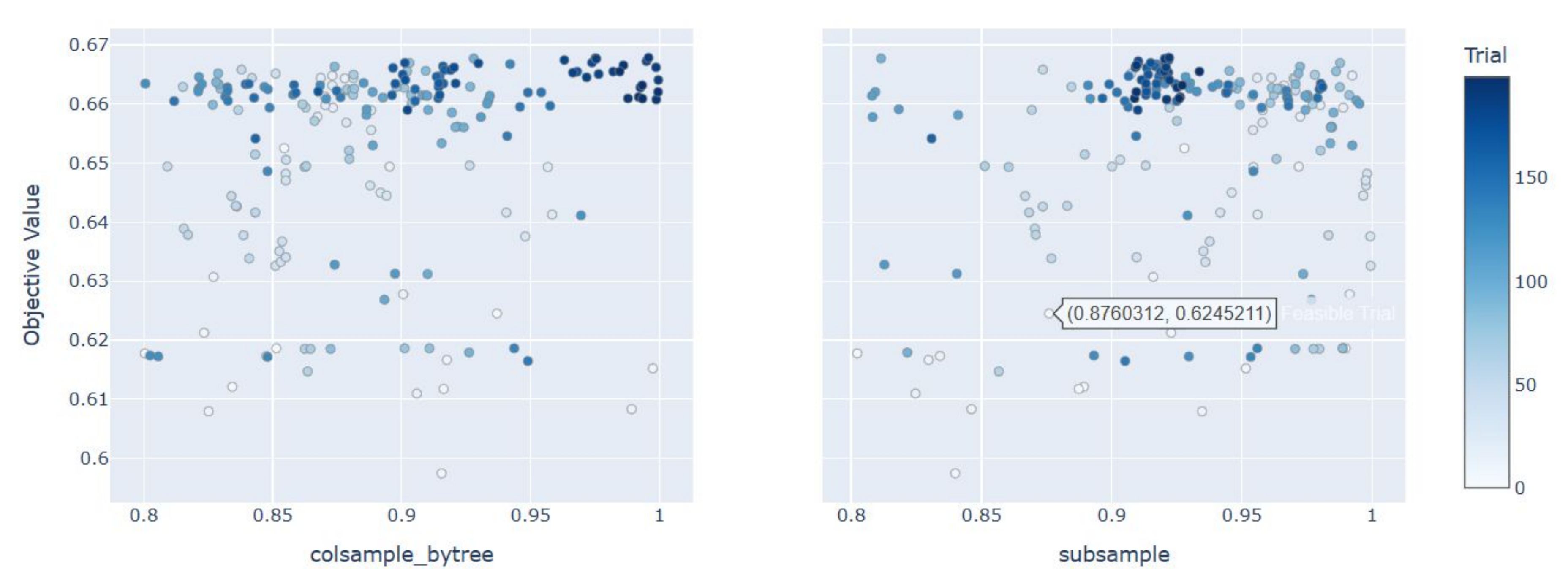
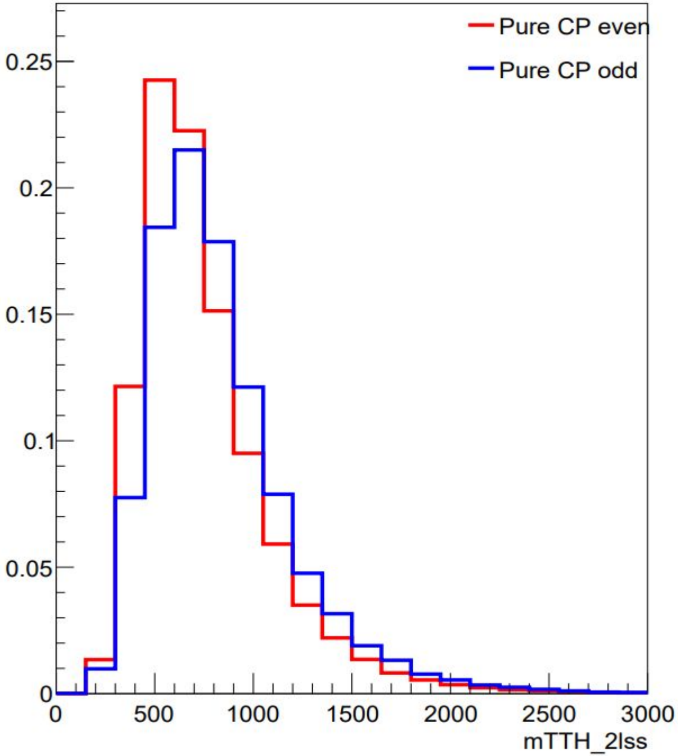


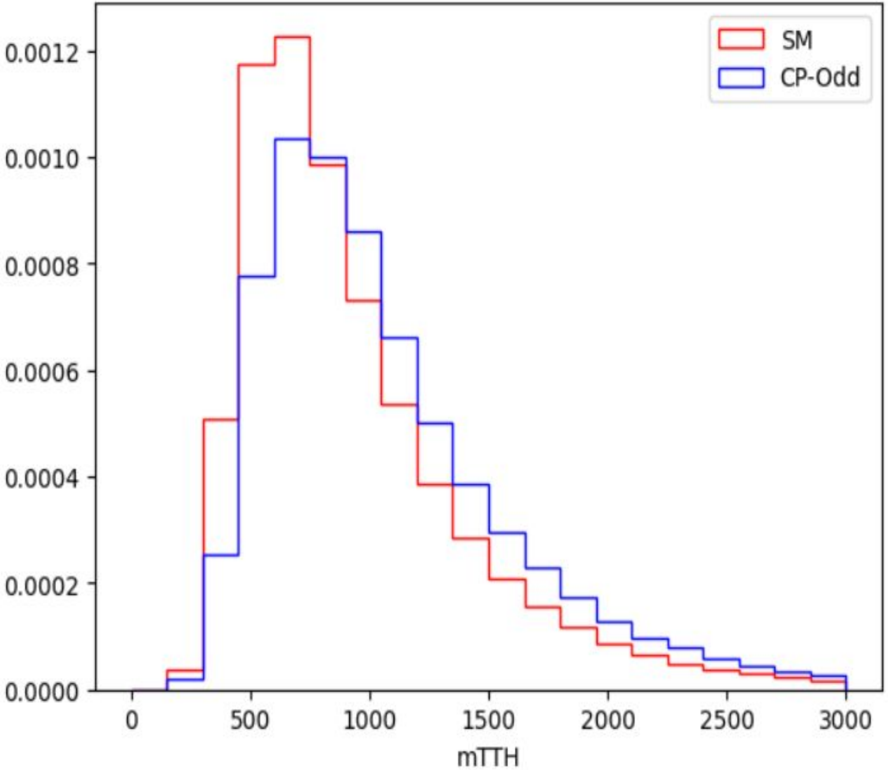
Variables from arXiv:2406.03950v2

observable	definition	frame
$p_{T,H}$	-	lab, $t\bar{t}$, $t\bar{t}H$
$\Delta\eta_{t\bar{t}}$	$\lvert\eta_t - \eta_{\bar{t}}\rvert$	lab, H, $t\bar{t}H$
$\Delta\phi_{t\bar{t}}$	$\lvert\phi_t - \phi_{\bar{t}}\rvert$	lab, H, $t\bar{t}H$
$m_{t\bar{t}}$	$(p_t + p_{\bar{t}})^2$	frame-invariant
$m_{t\bar{t}H}$	$(p_t + p_{\bar{t}} + p_H)^2$	frame-invariant
$\lvert\cos\theta^*\rvert$	$\frac{\lvert\boldsymbol{p}_t \cdot \boldsymbol{n}\rvert}{\lvert\boldsymbol{p}_t\rvert \cdot \lvert\boldsymbol{n}\rvert}$	$t\bar{t}$
b_1	$\frac{(\boldsymbol{p}_t \times \boldsymbol{n}) \cdot (\boldsymbol{p}_{\bar{t}} \times \boldsymbol{n})}{p_{T,t} p_{T,\bar{t}}}$	all
b_2	$\frac{(\boldsymbol{p}_t \times \boldsymbol{n}) \cdot (\boldsymbol{p}_{\bar{t}} \times \boldsymbol{n})}{\lvert\boldsymbol{p}_t\rvert \ \lvert\boldsymbol{p}_{\bar{t}}\rvert}$	all
b_3	$\frac{p_t^x \ p_{\bar{t}}^x}{p_{T,t} p_{T,\bar{t}}}$	all
b_4	$\frac{p_t^z \ p_{\bar{t}}^z}{\lvert\boldsymbol{p}_t\rvert \ \lvert\boldsymbol{p}_{\bar{t}}\rvert}$	all
ϕ_C	$\arccos\left(\frac{\lvert(\boldsymbol{p}_{p_1} \times \boldsymbol{p}_{p_2}) \cdot (\boldsymbol{p}_t \times \boldsymbol{p}_{\bar{t}})\rvert}{\lvert\boldsymbol{p}_{p_1} \times \boldsymbol{p}_{p_2}\rvert \ \lvert\boldsymbol{p}_t \times \boldsymbol{p}_{\bar{t}}\rvert}\right)$	H

Except this one

2lss0tau Input variables comparison: Run2 vs Run3





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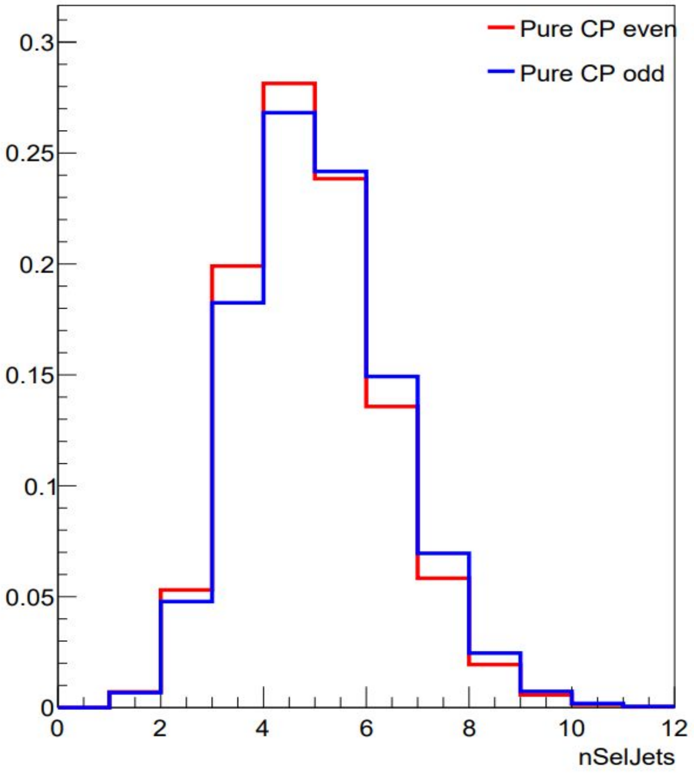

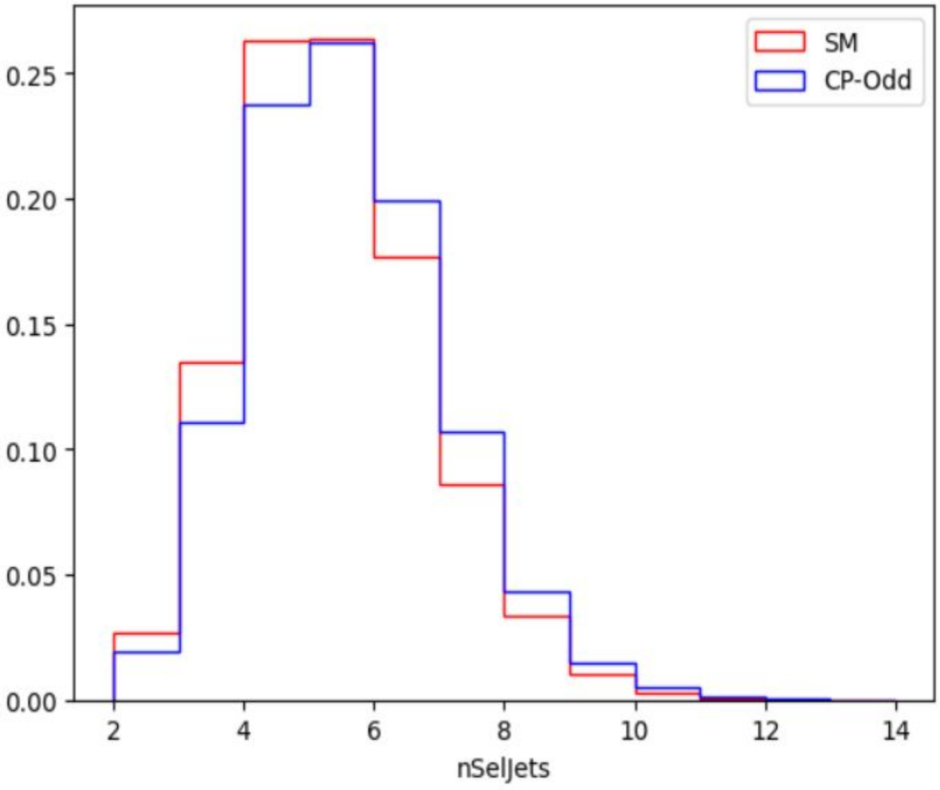

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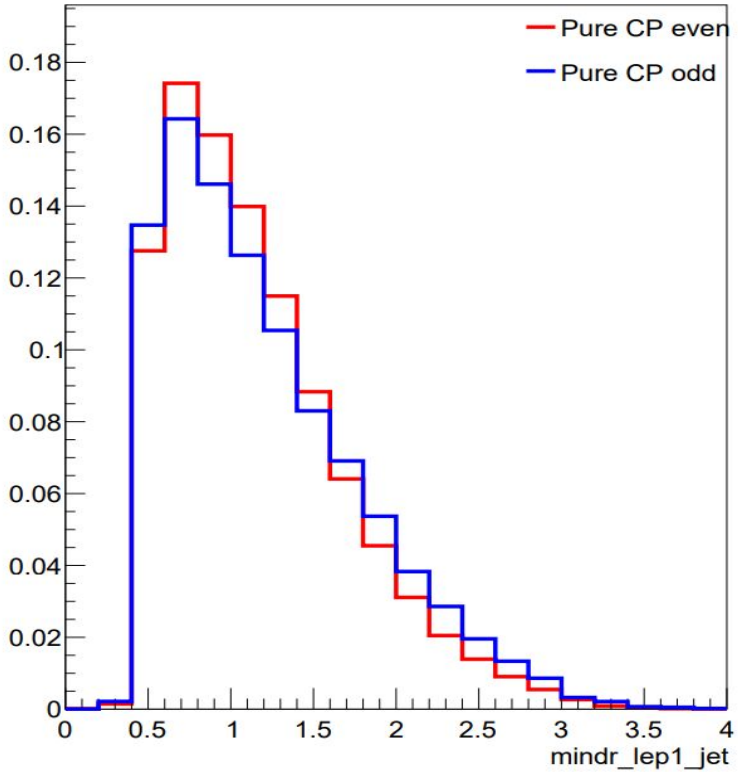

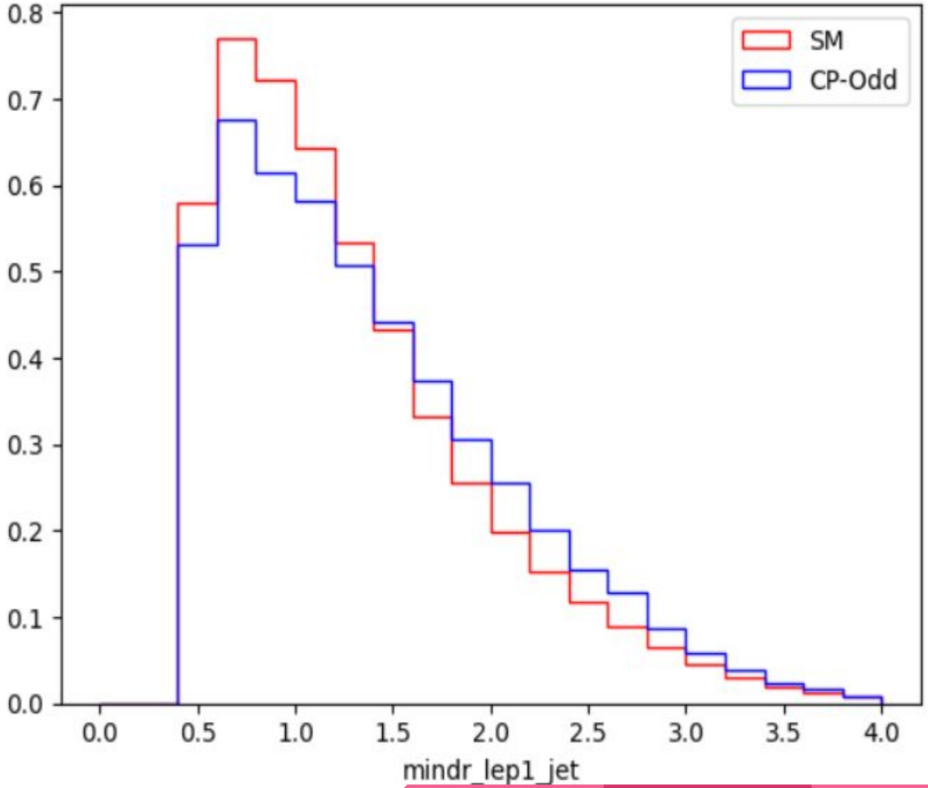

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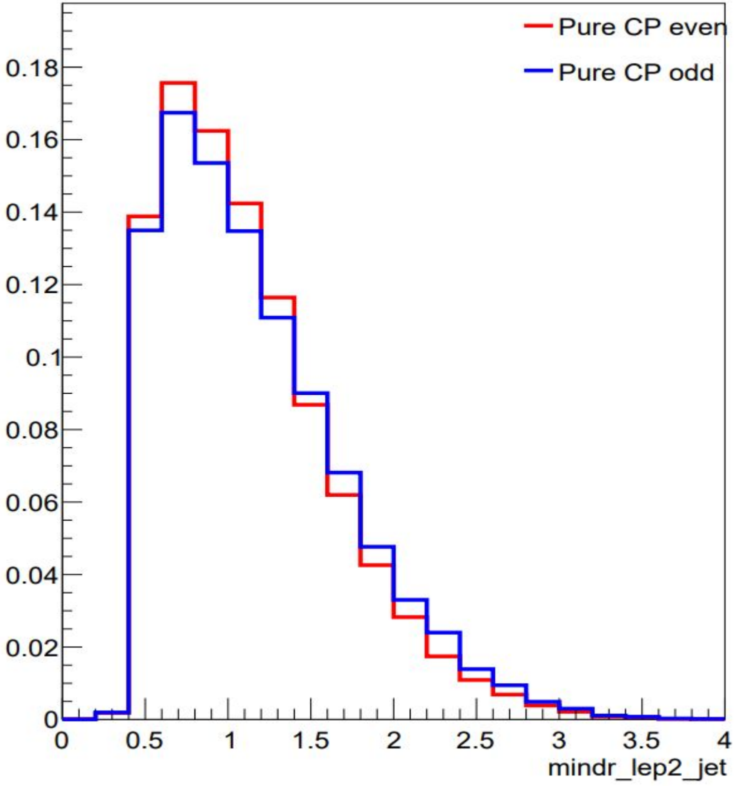

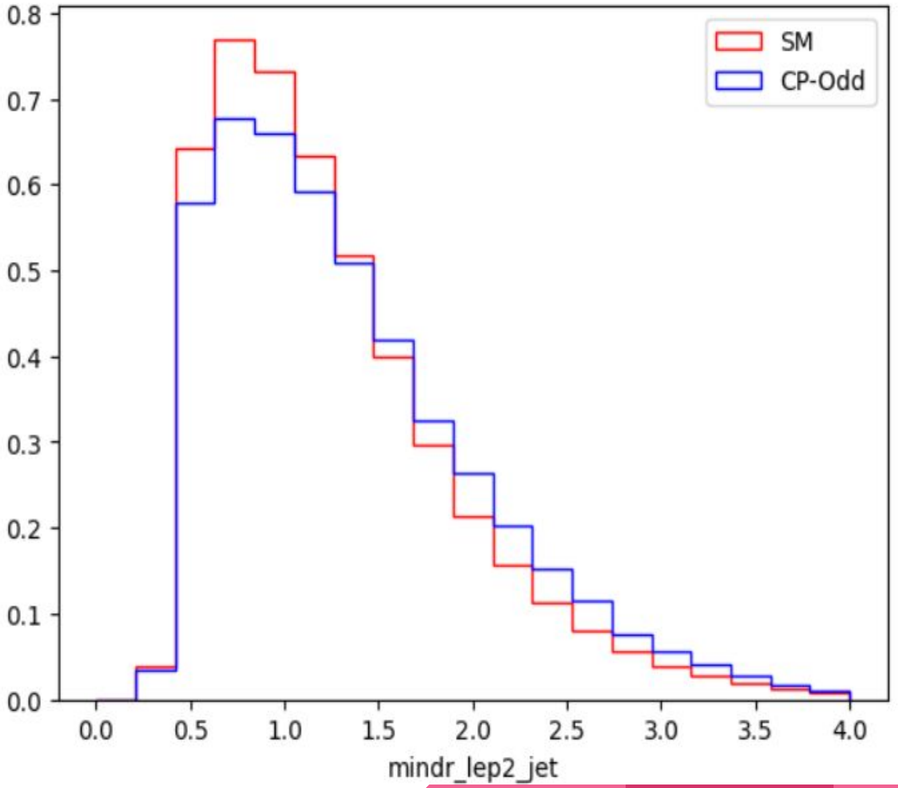

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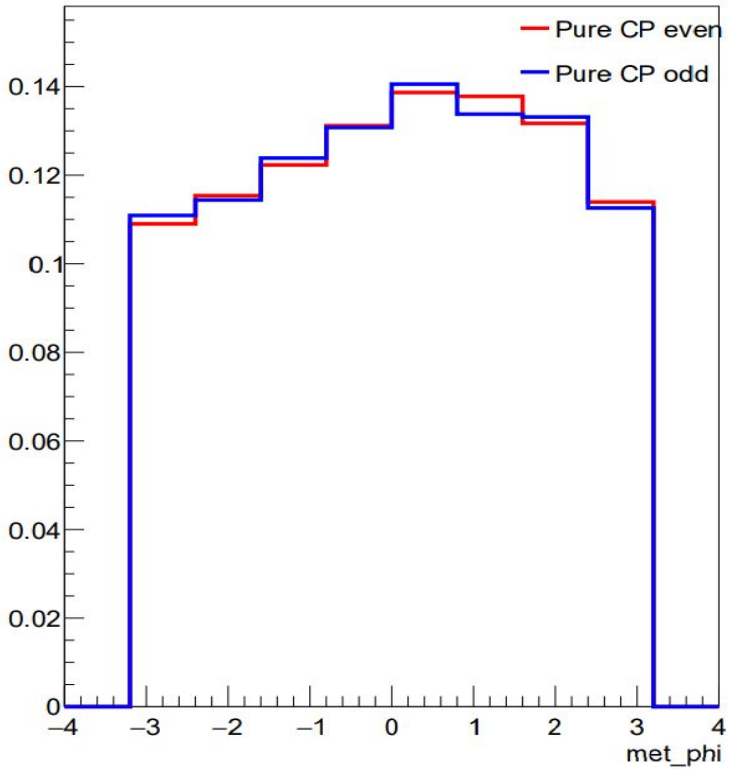

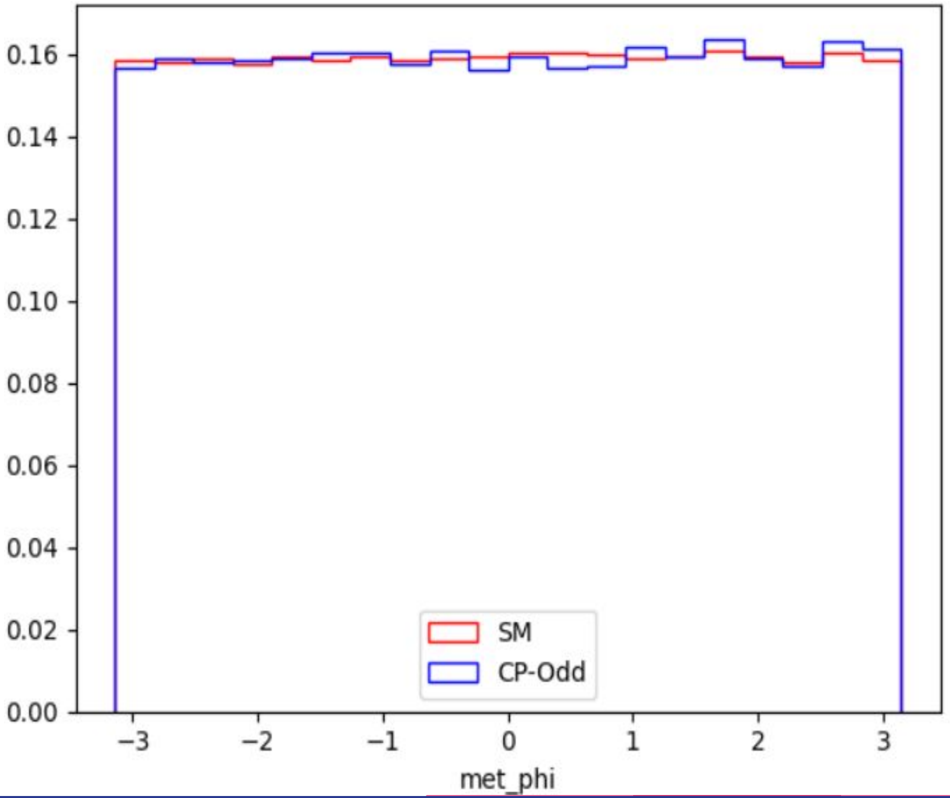

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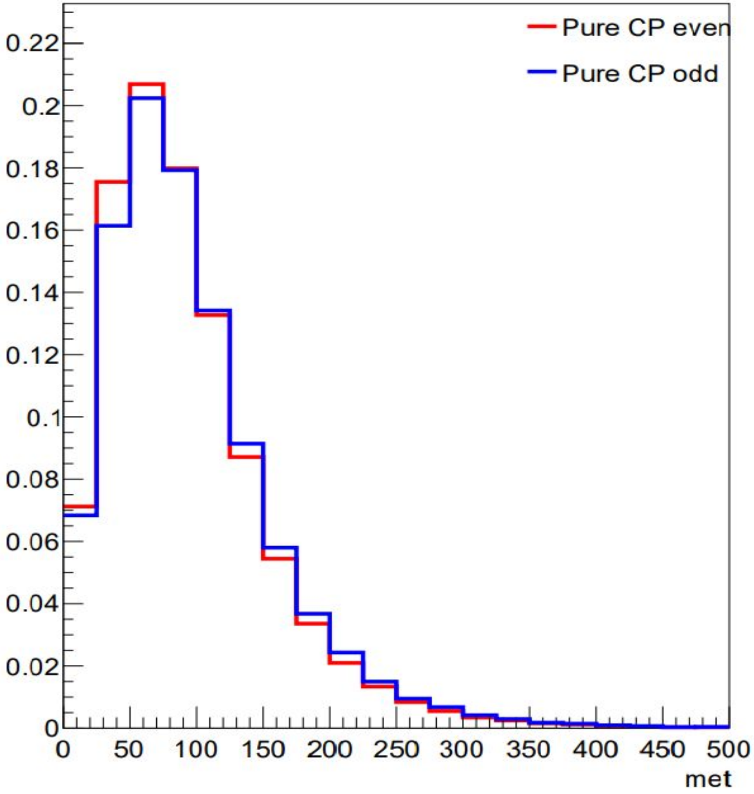

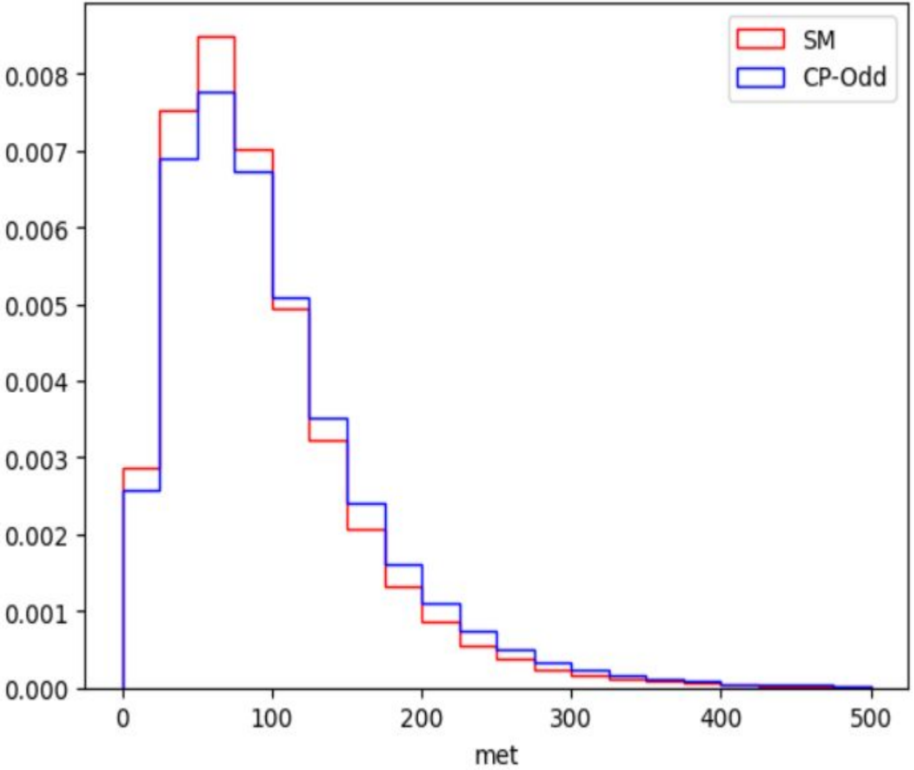

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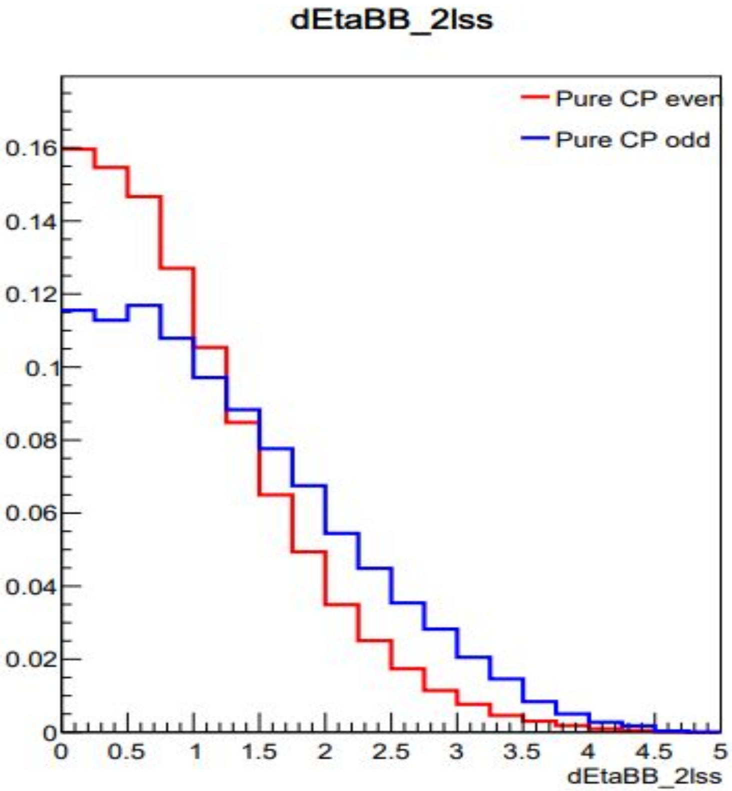

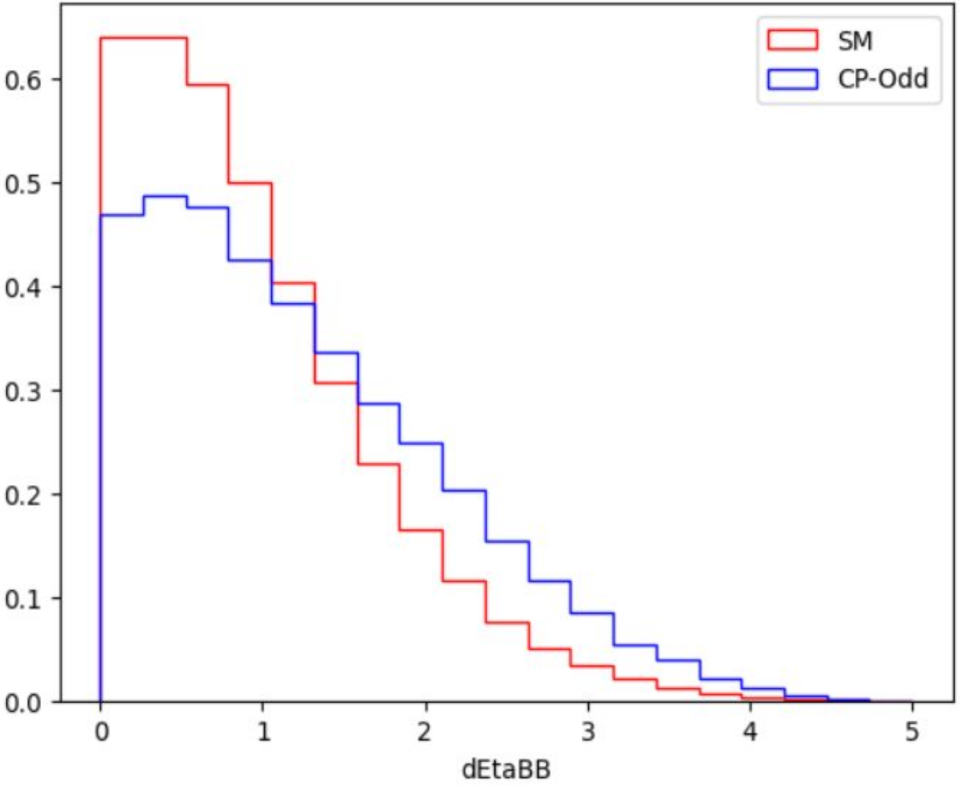

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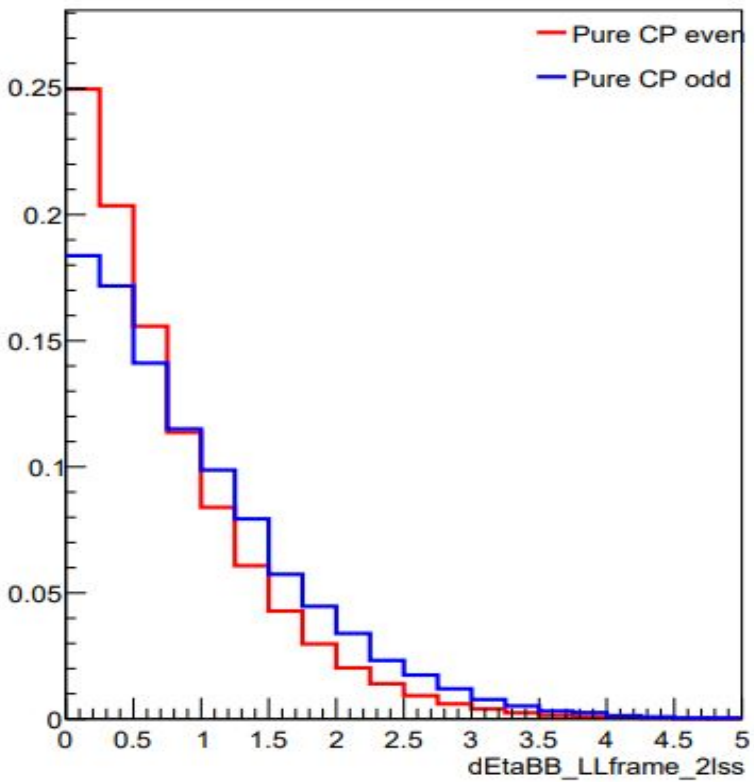

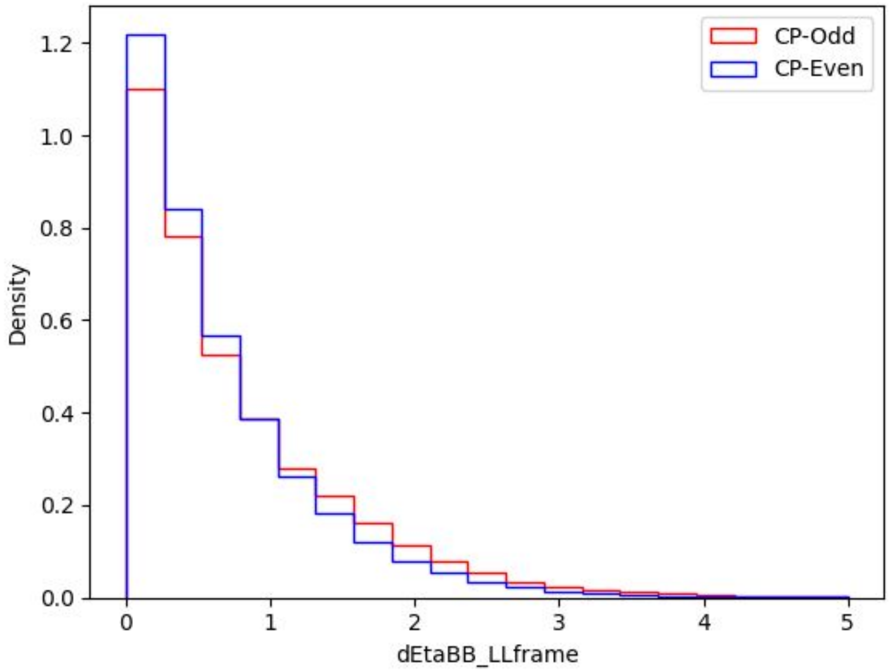

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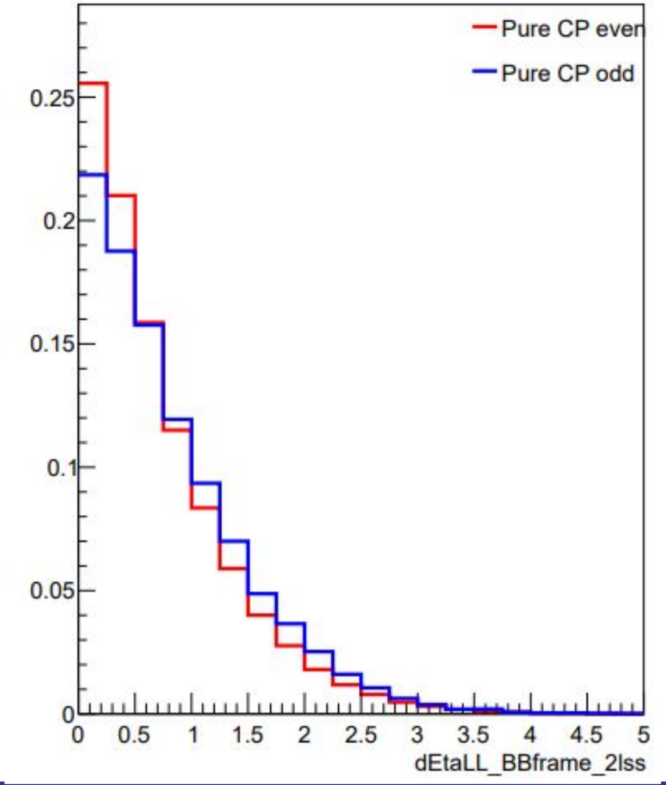

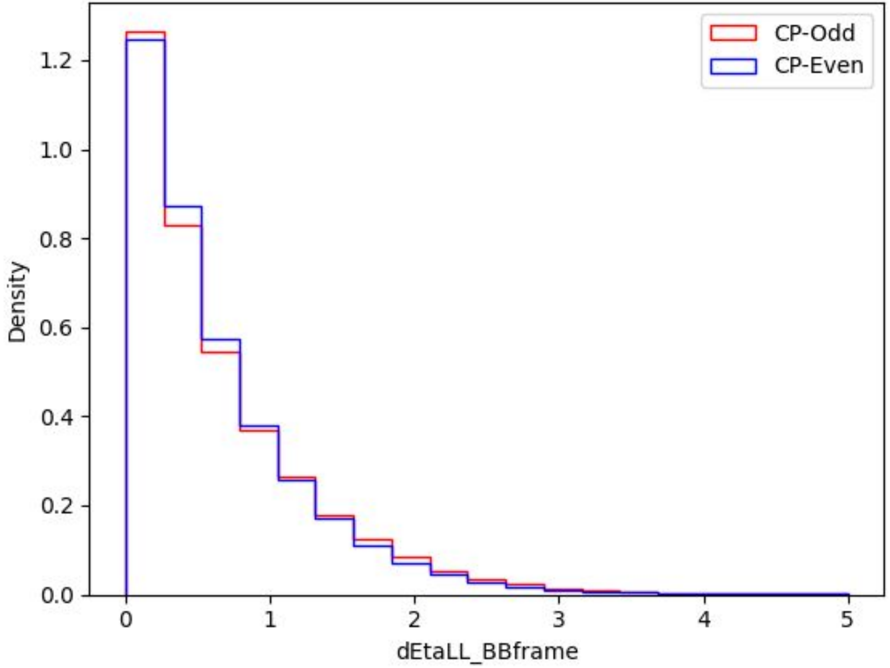

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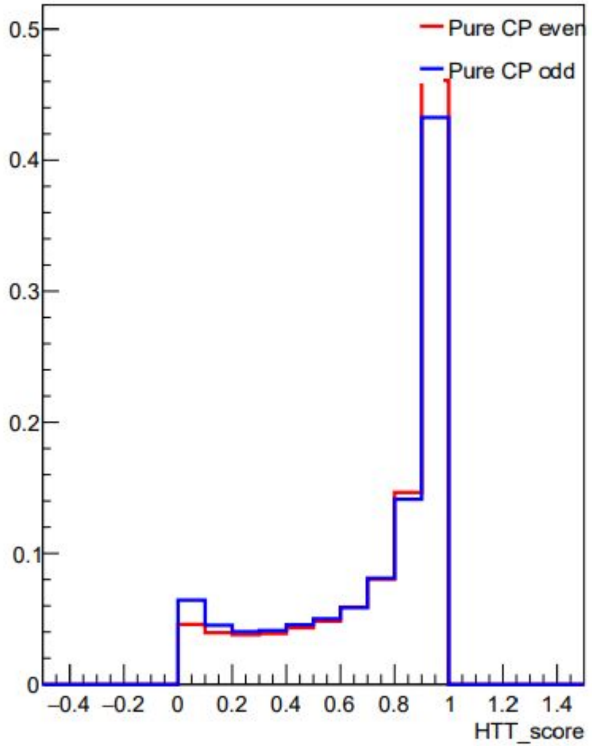

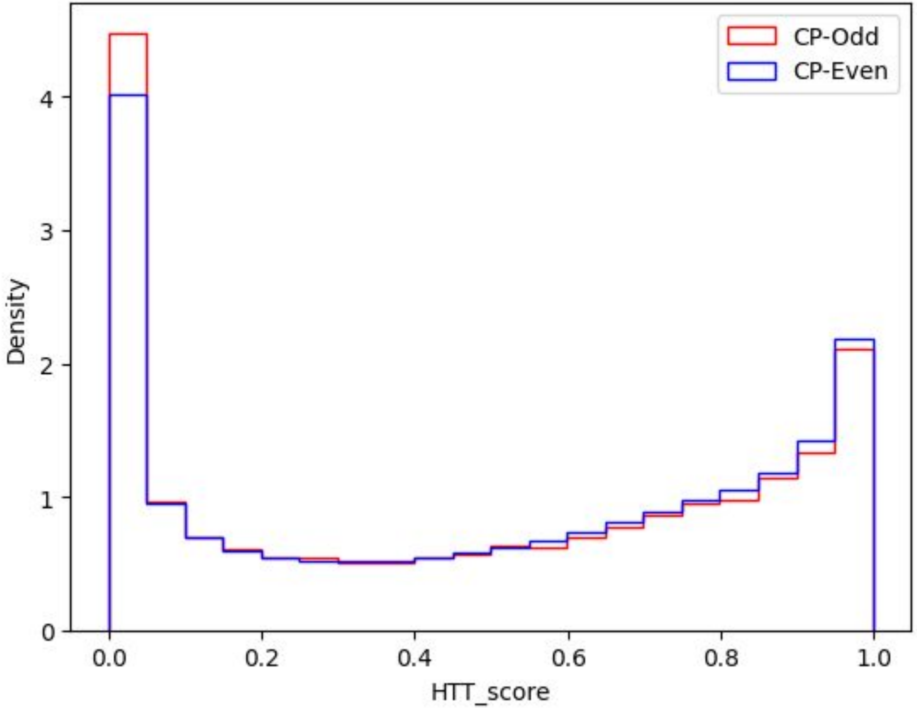

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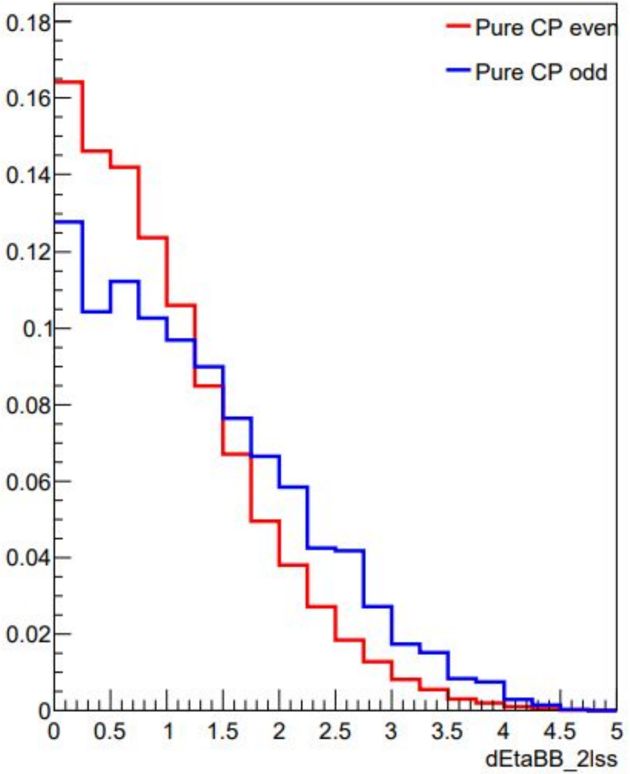

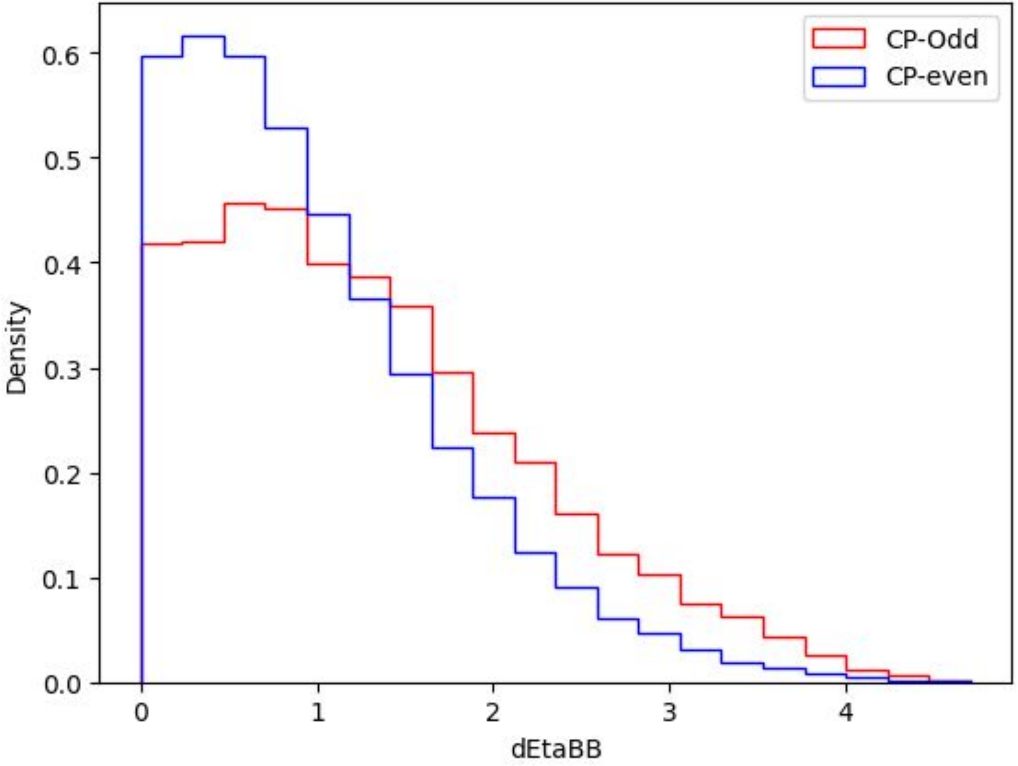

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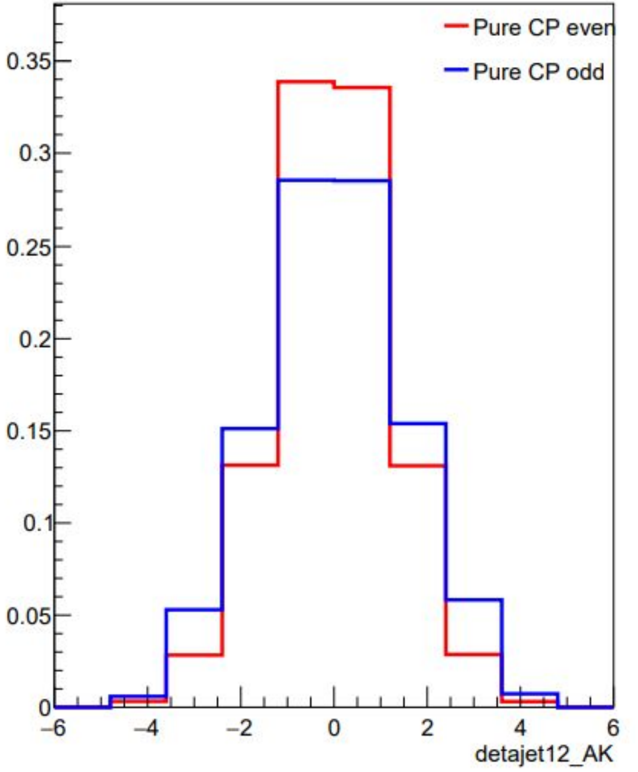

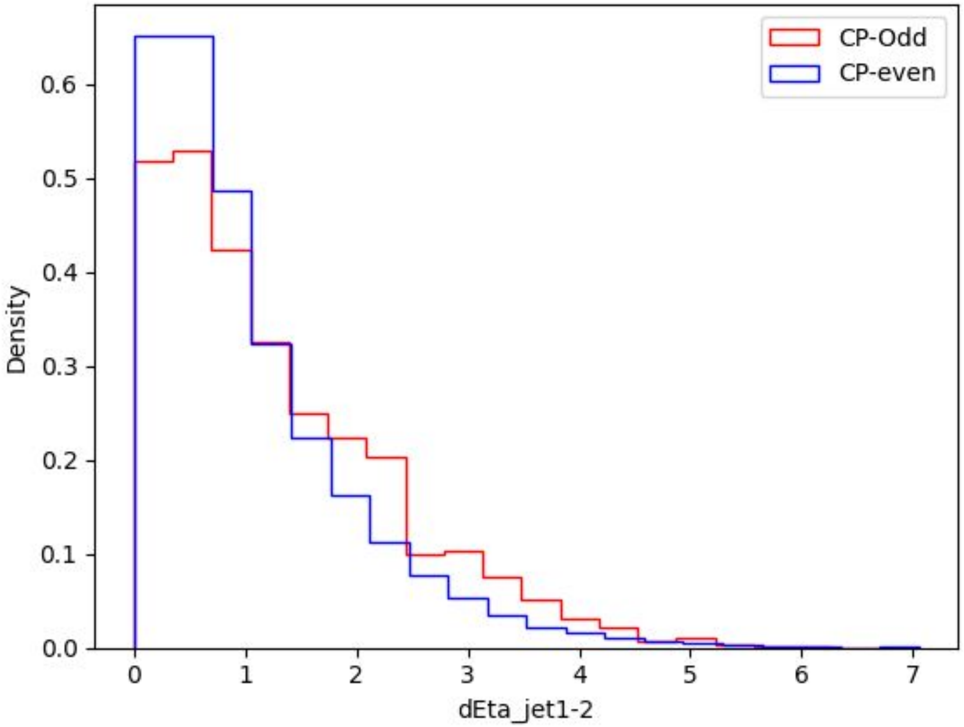

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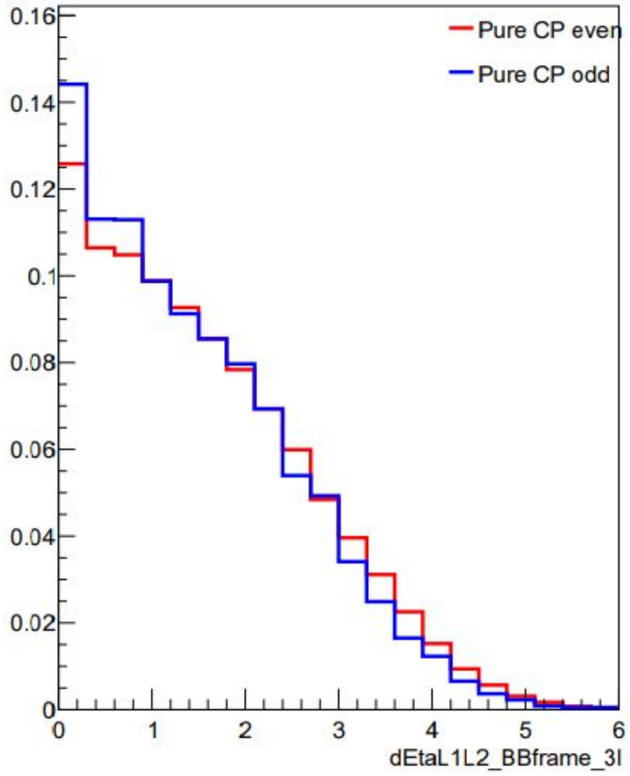

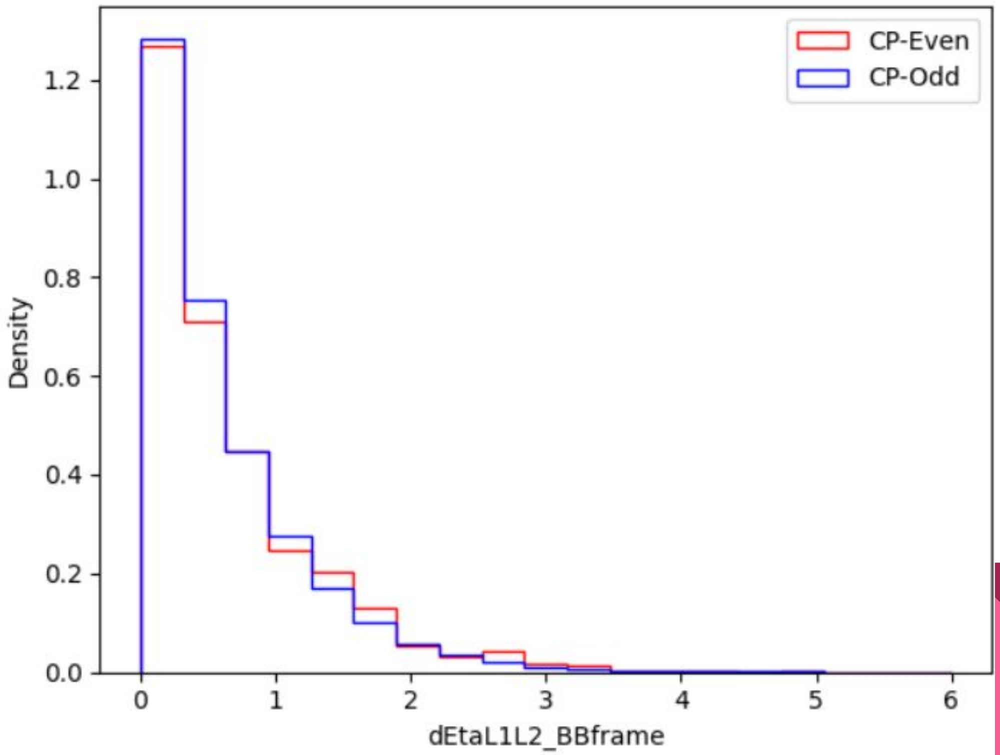

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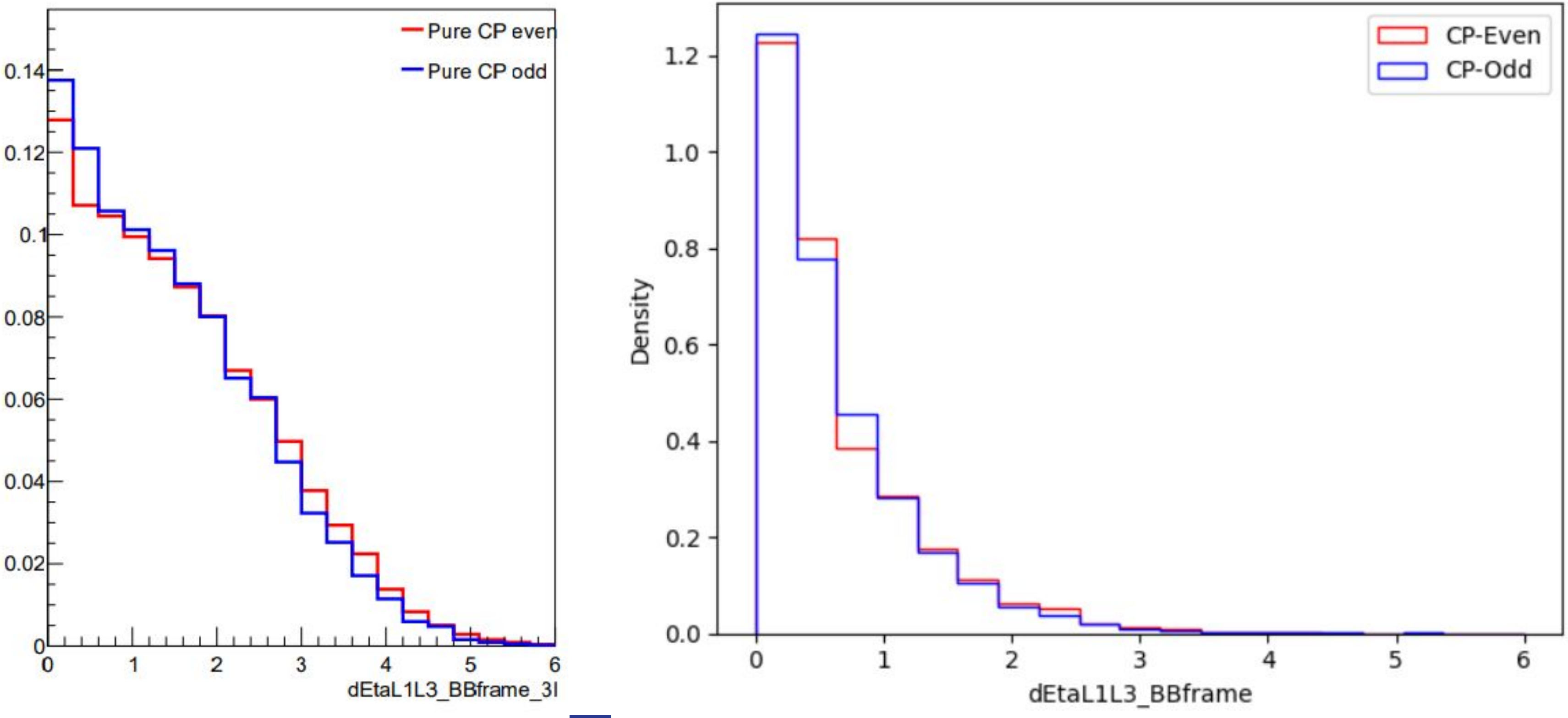

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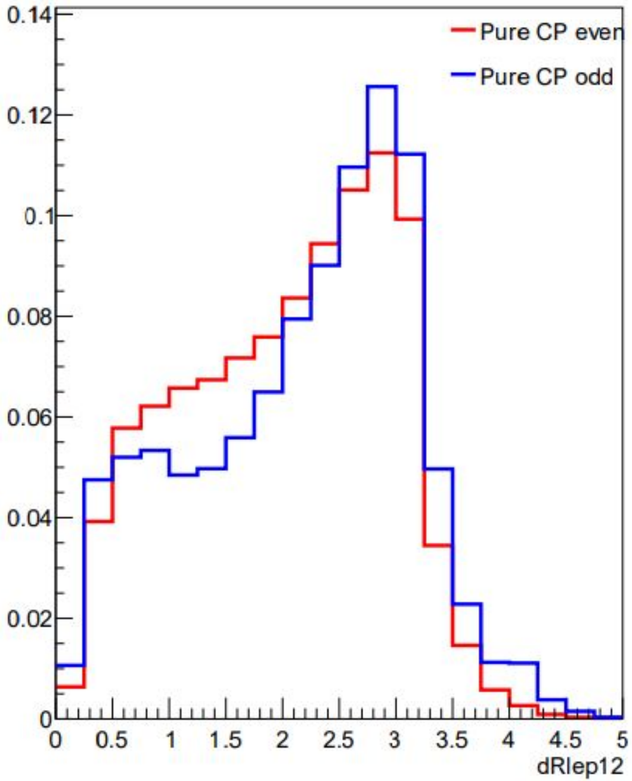
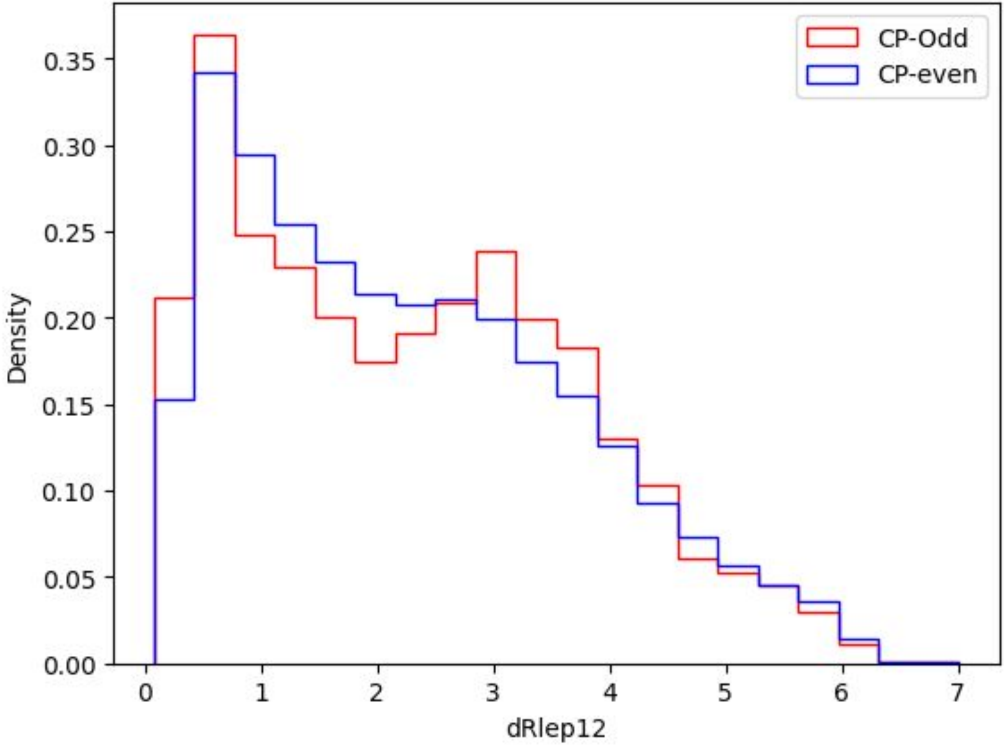
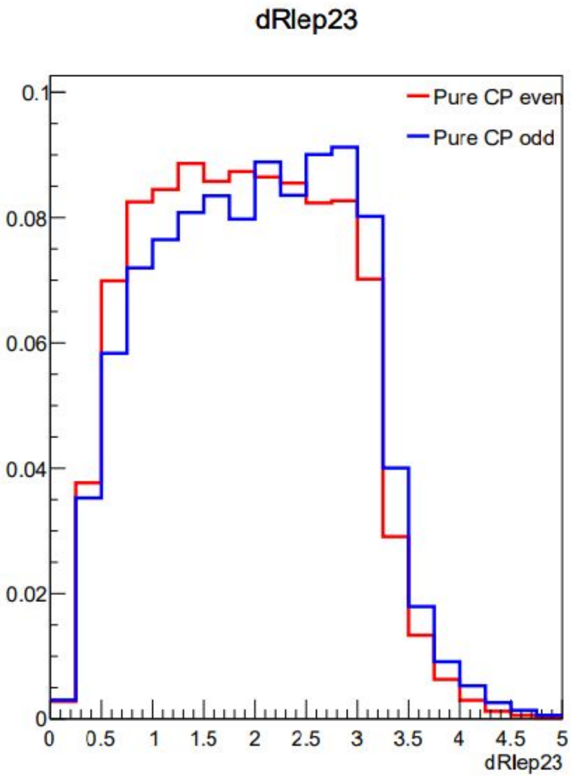
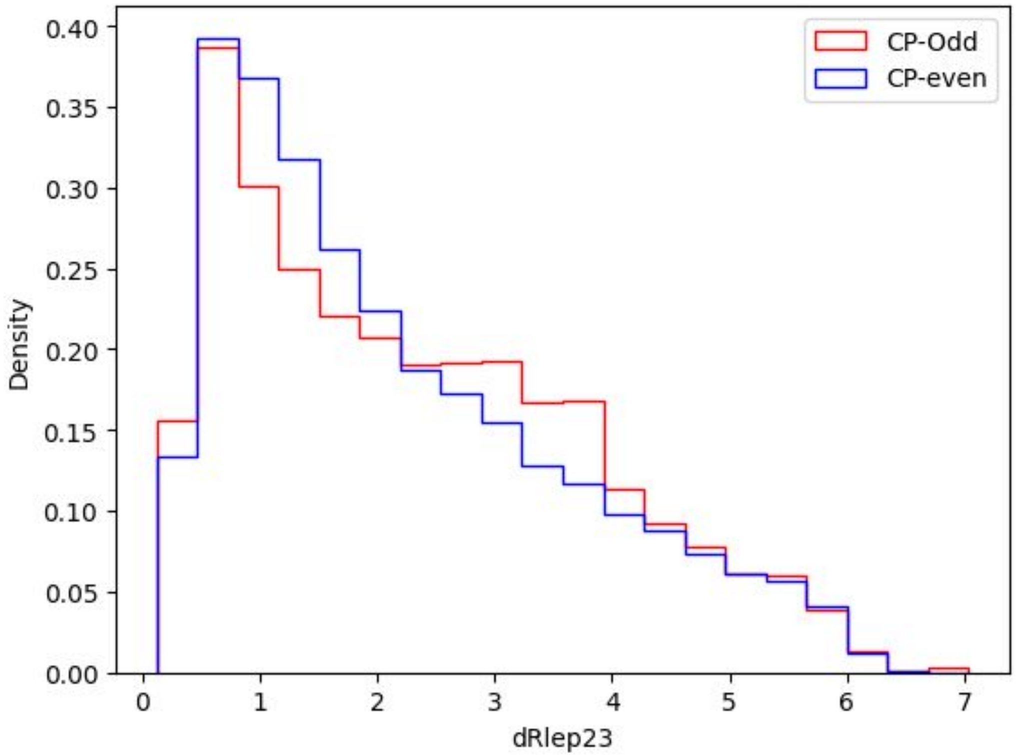




3l0tau Input variables comparison: Run2 vs Run3





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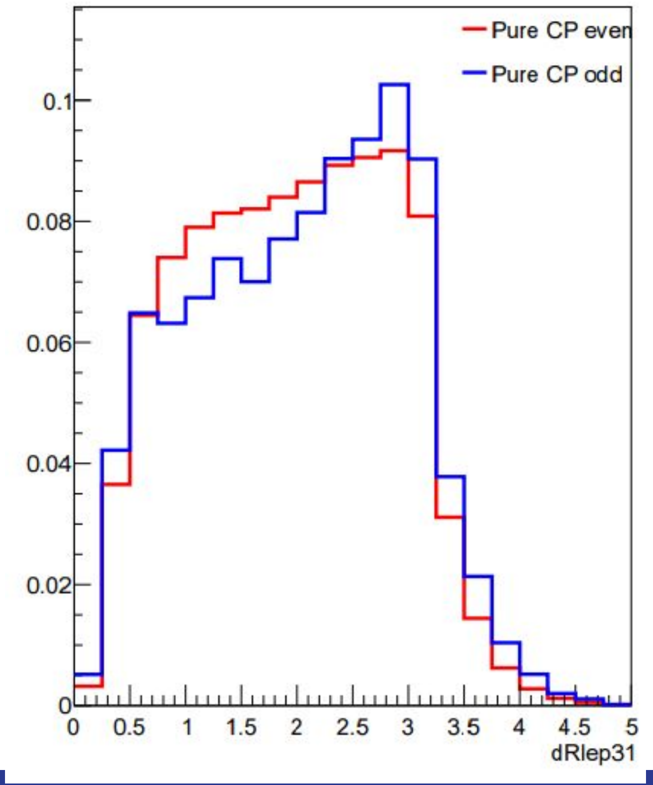

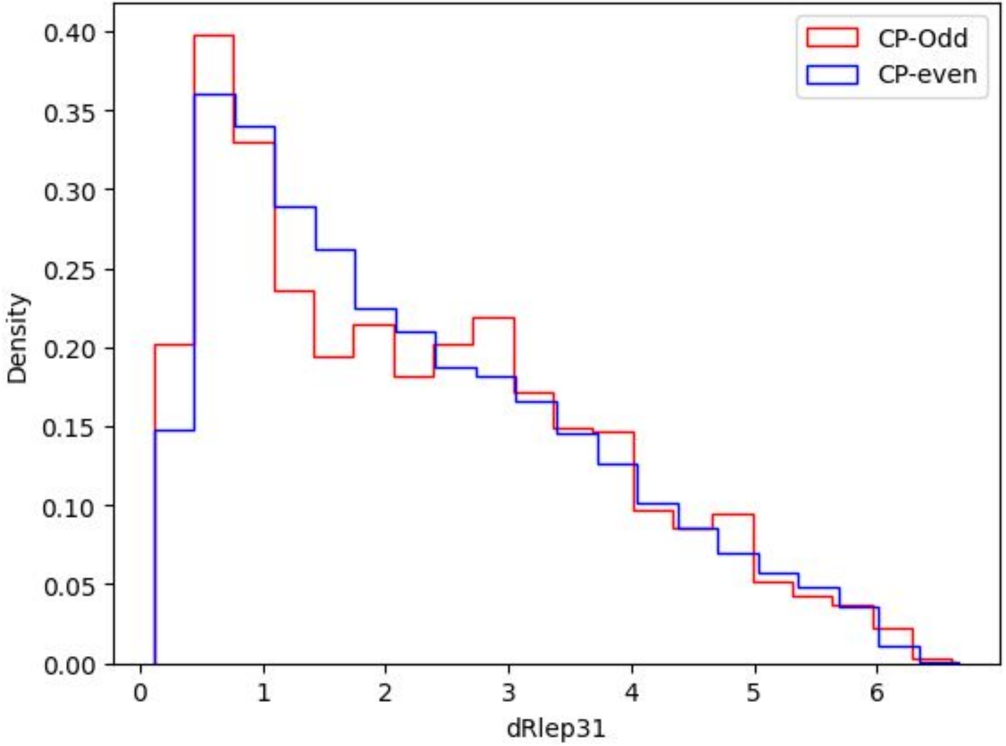

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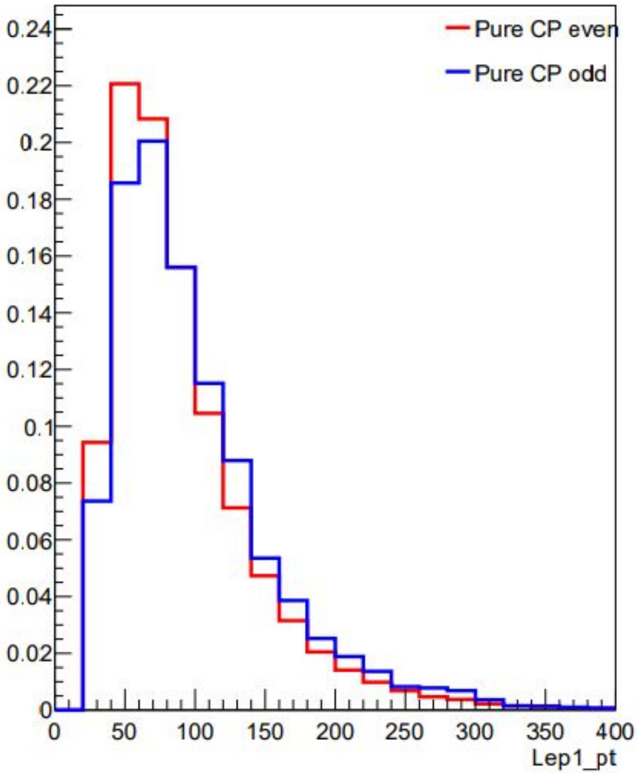

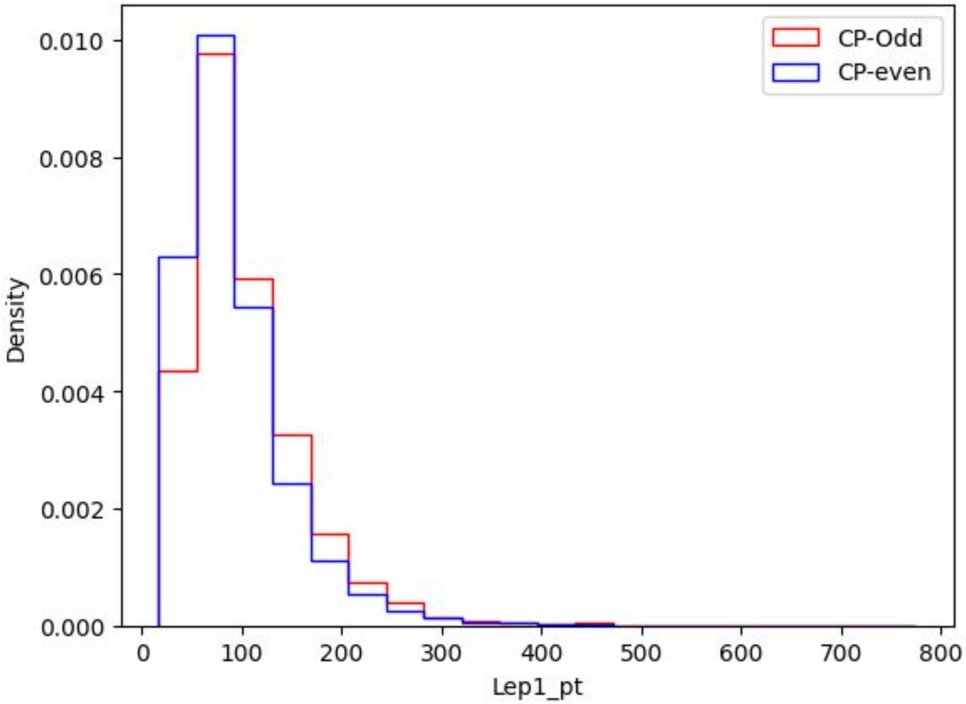

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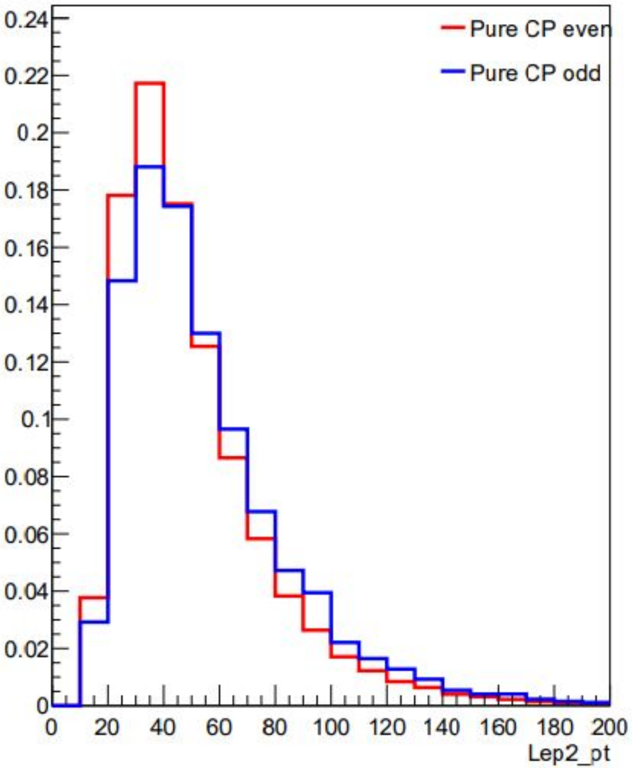

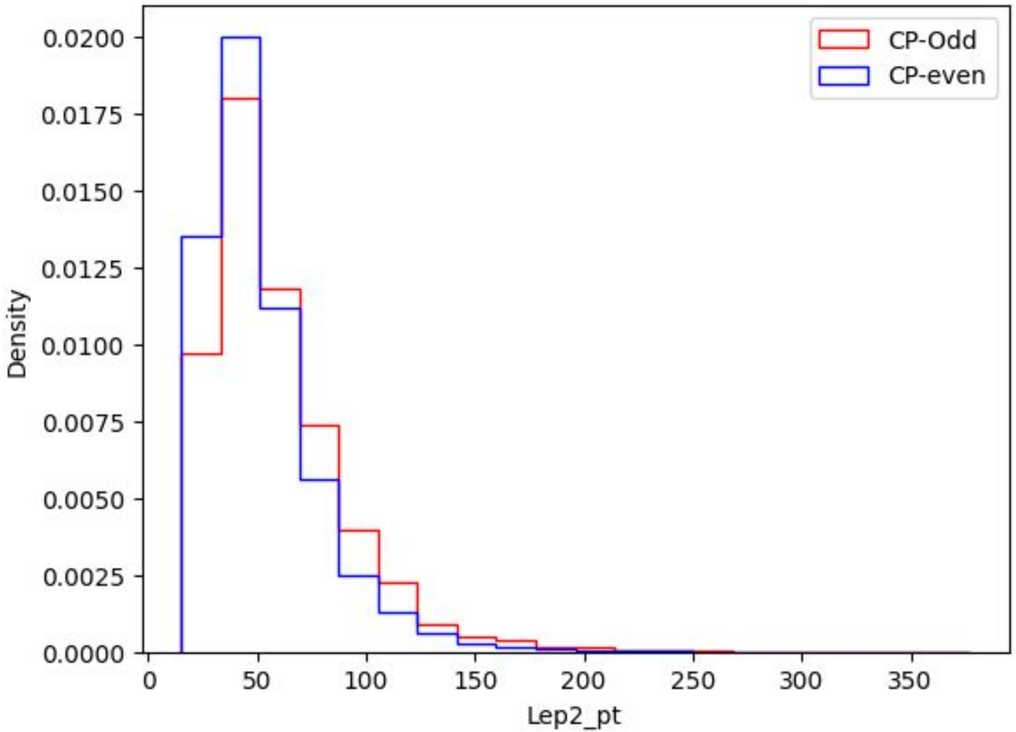

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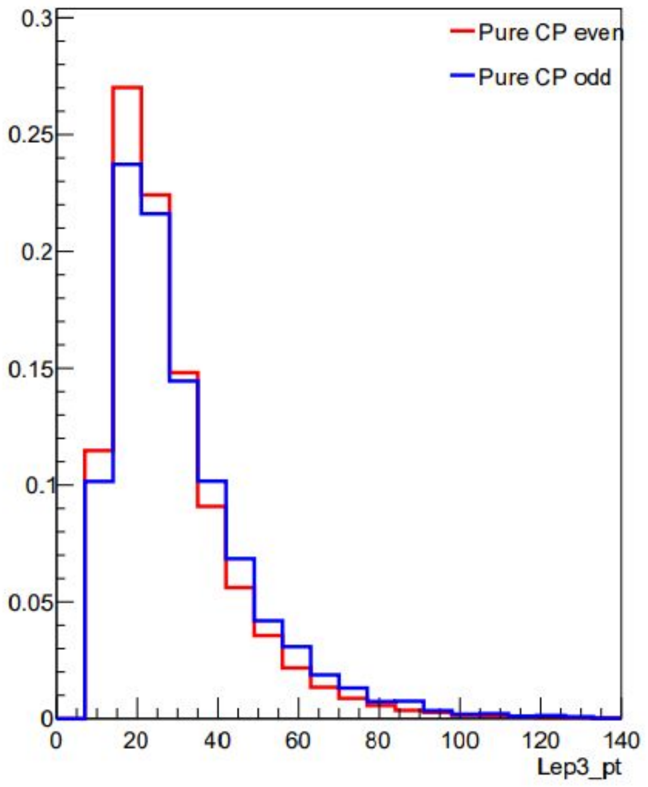

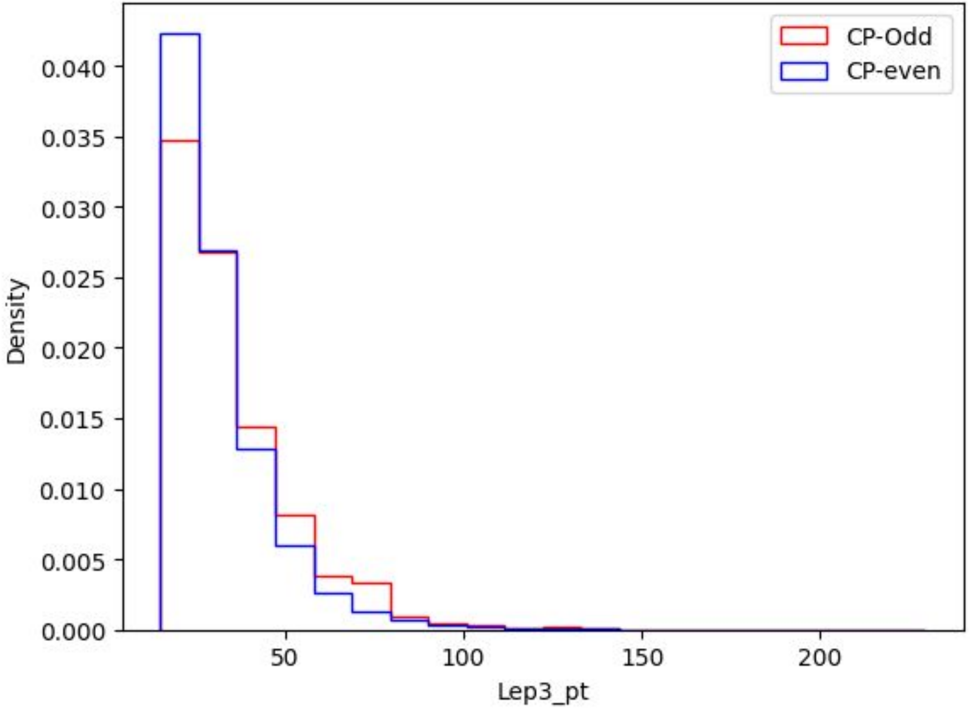

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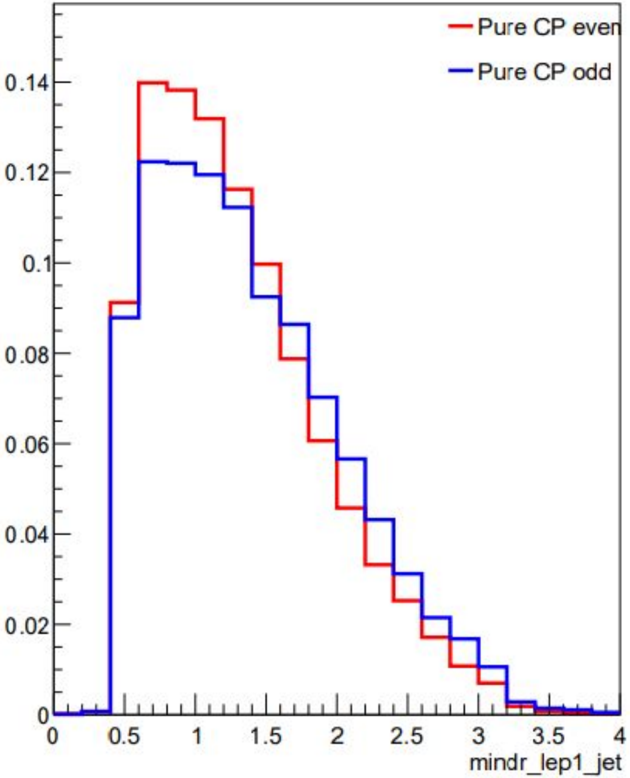

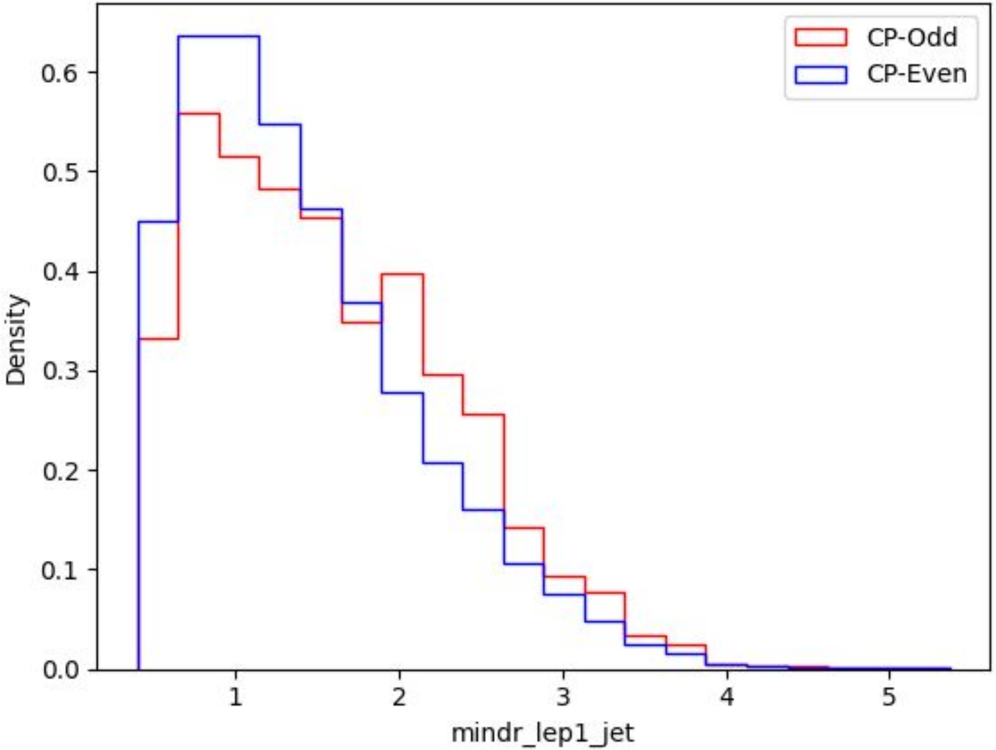

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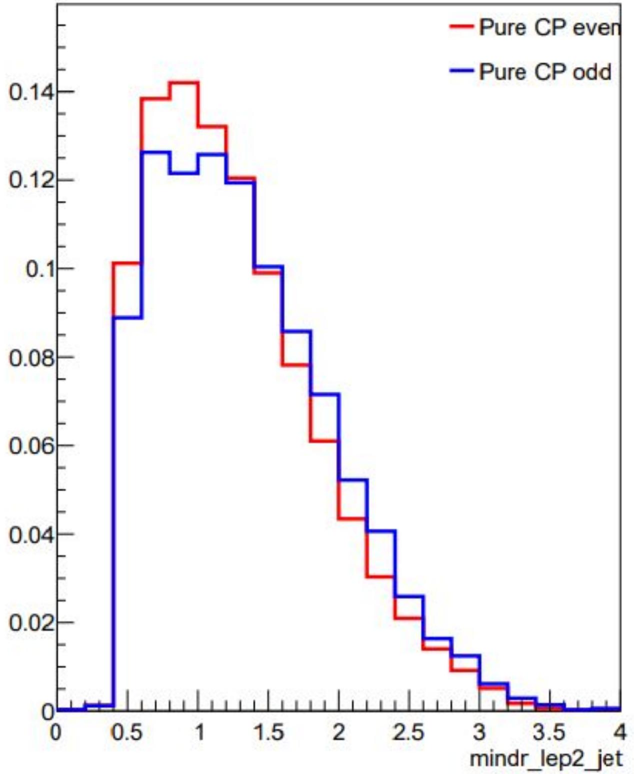

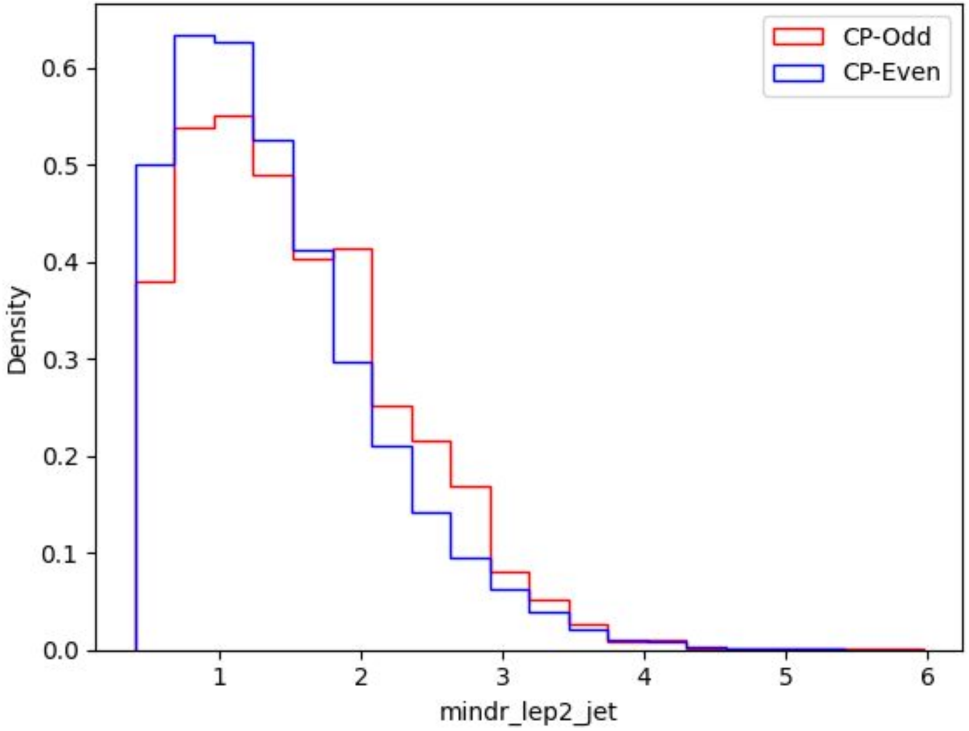

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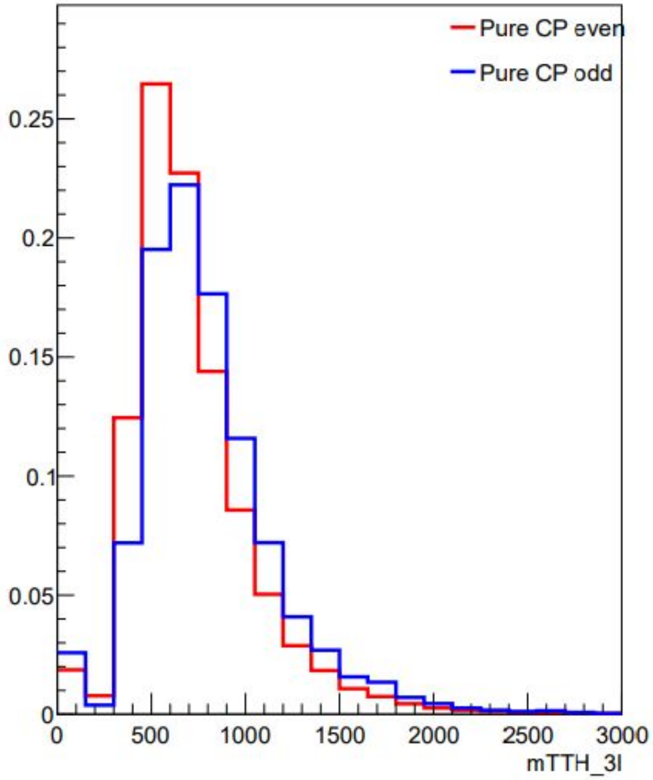

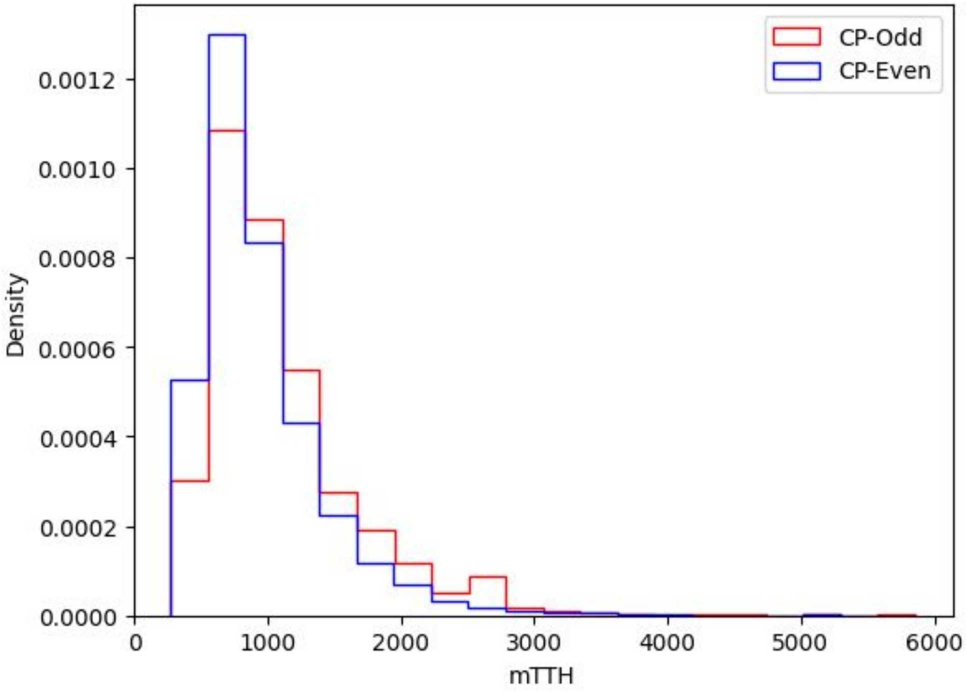

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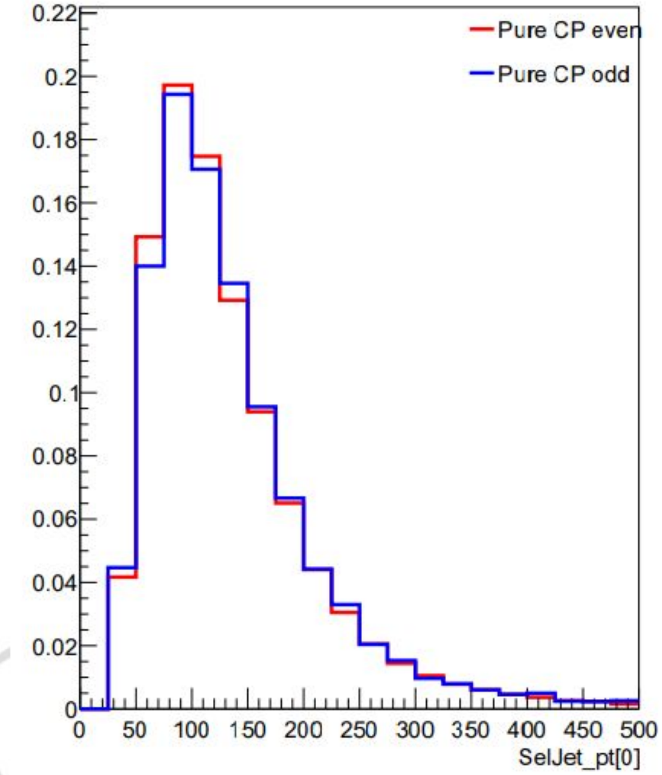

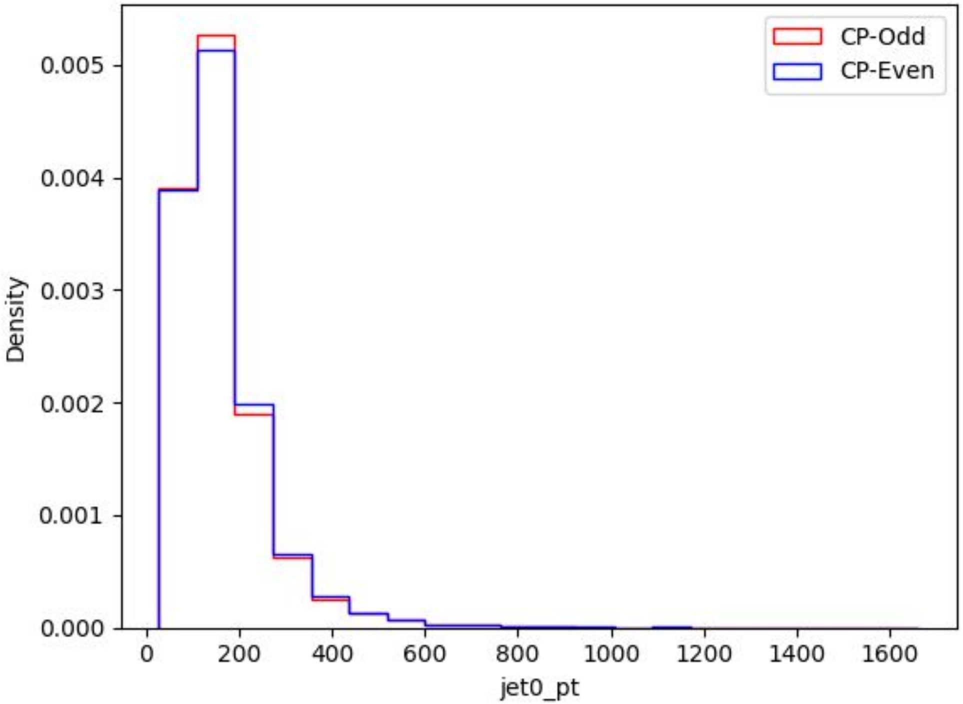

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