



UNIVERSITA
DEGLI STUDI
DI TORINO

Impact of MTD on pileup rejection in the VBF $HH \rightarrow 4b$ channel

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INFN / University of Torino



Outline

- Introduction
- The use of timing to discriminate between signal & PU candidates
- ATLAS analysis (timing not used)



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Introduction

- Aim of this work is to study the impact of the MTD timing information in removing pile-up (PU) candidates from signal jets, considering a 200 PU scenario
- We chose VBF $HH \rightarrow 4b$ as benchmark channel
- Do PU and signal candidates in a jet have different time distributions? Can we use timing to reject PU candidates?



Sample & Setup

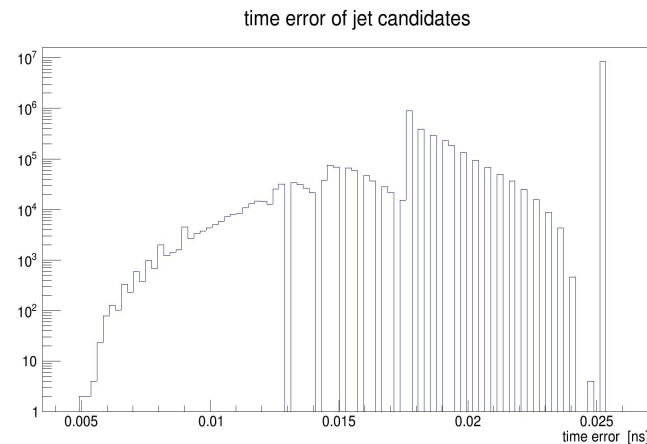
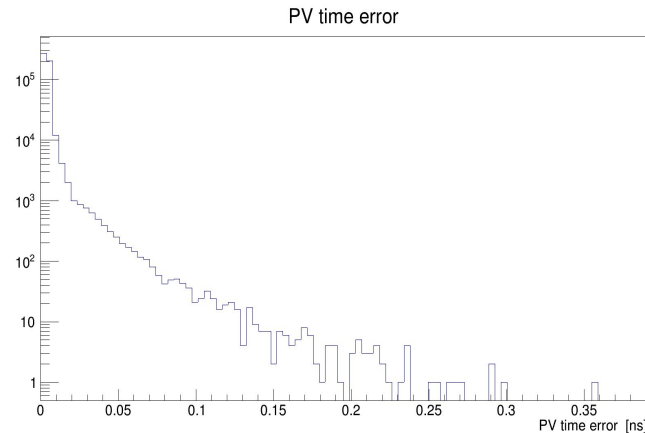


/VBF_HHTo4B_CV_1_C2V_1_C3_1_TuneCP5_PSWeights_14TeV-madgraph-pythia8/
Phase2HLTDRWinter20RECOMiniAOD-PU200_110X_mcRun4_realistic_v3-v2/MINIAODSIM
→ ~ 500k events

- CMSSW_11_1_5
- 4D-PV collection: *'offlineSlimmedPrimaryVertices4D'*
- We used 2 different PAT collections:
 - *'slimmedJetsPuppi'* → following plots produced with this collection if not indicated otherwise
 - *'slimmedJets'* → used only for comparison (PUPPI not used here)
- GenJet: *'slimmedGenJets'* → used for ΔR matching to distinguish signal and PU jets

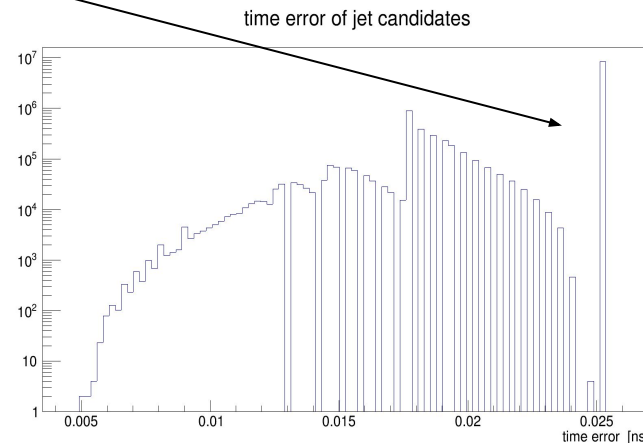
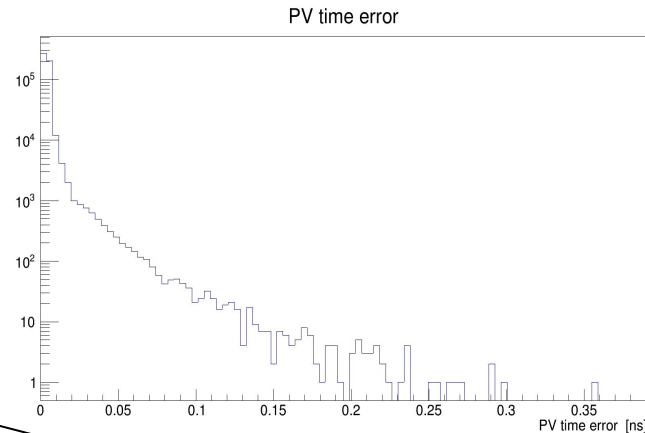
Signal vs PU: cuts

- On all events, primary vertex (PV) time error required to be > 0 (= valid timing info)
- time error > 0 && < 0.025 ns required for all jet candidates



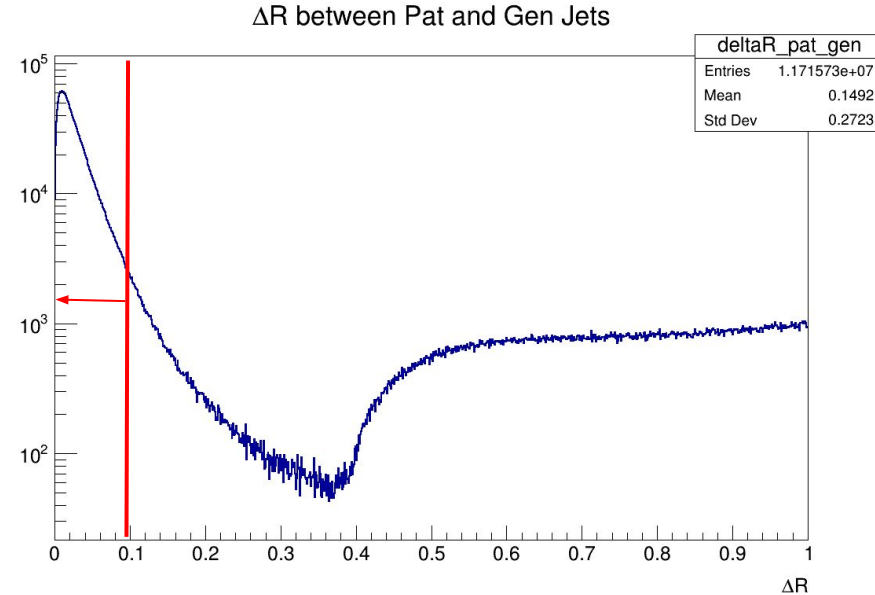
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Signal vs PU: cuts

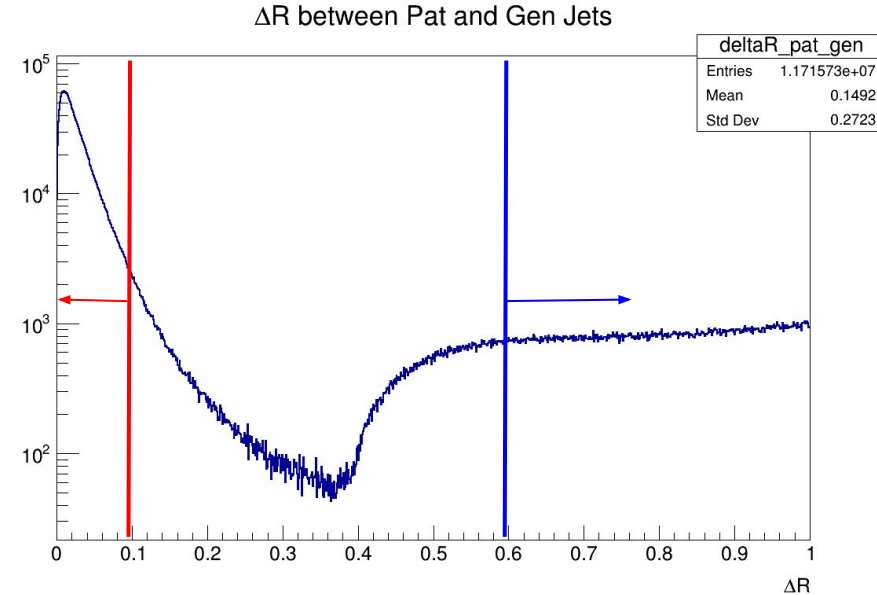
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- Distinction between signal and PU jets based on a ΔR matching between Pat and Gen :
 - Pat jet can be **signal** if $\Delta R(\text{Pat}, \text{Gen}) < 0.1$ for at least one Gen jet \rightarrow not sufficient to be considered signal (see next slide)



**Entries = all possible combinations of Pat and Gen in all events*

Signal vs PU: cuts

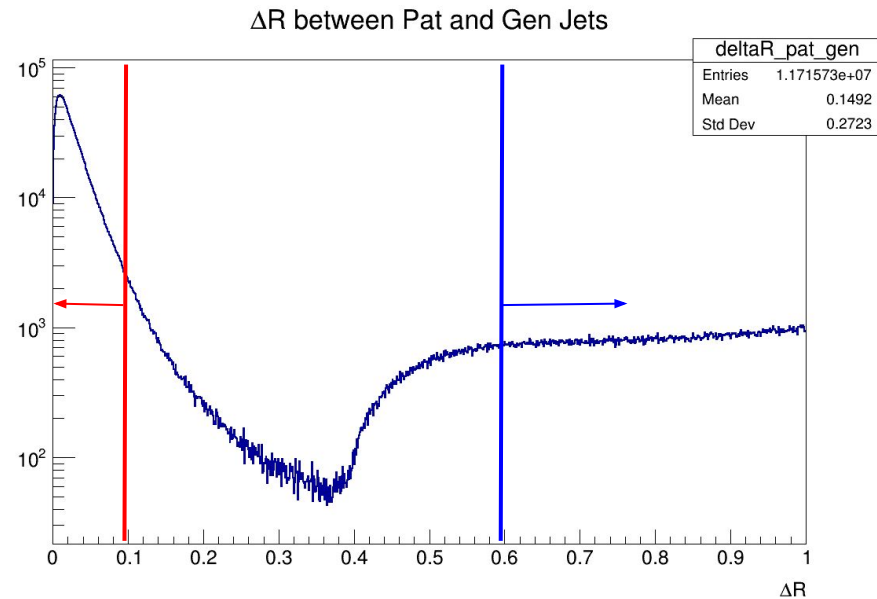
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 - If none of the above conditions are met the jet is excluded

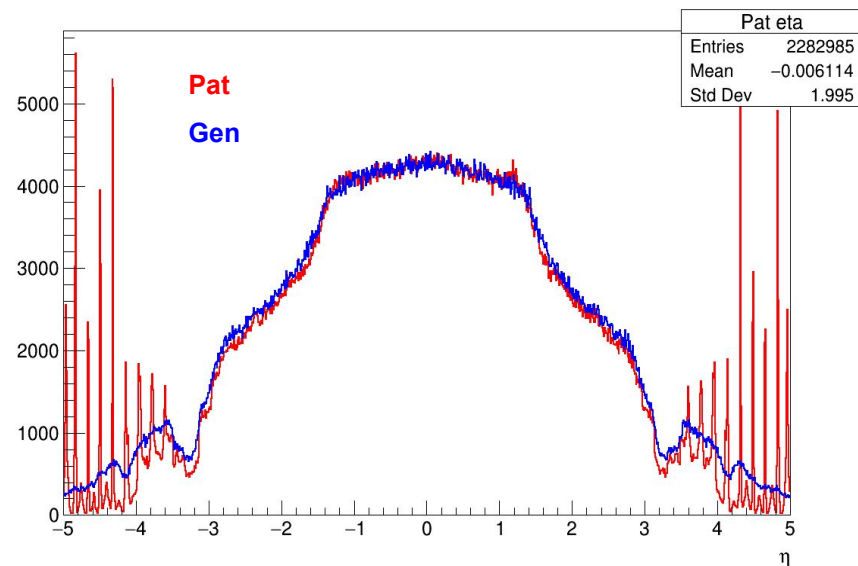
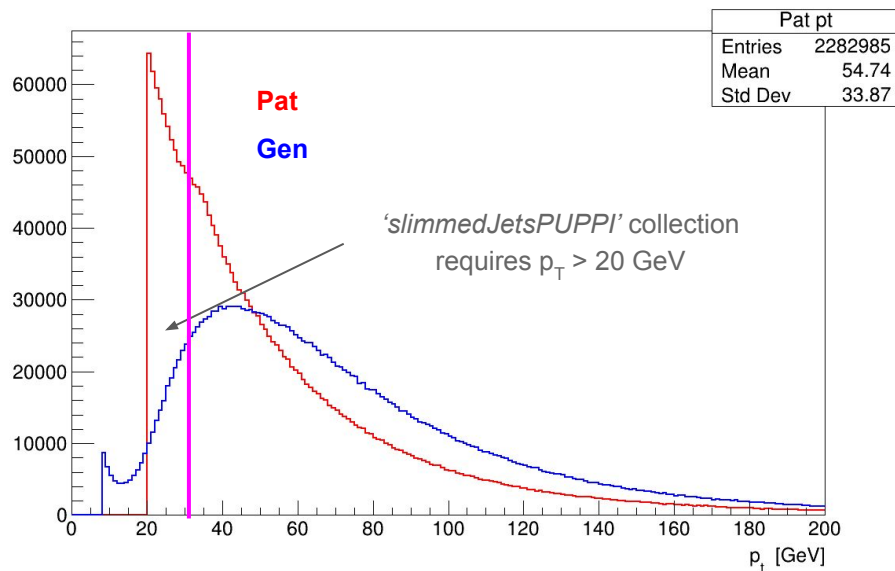


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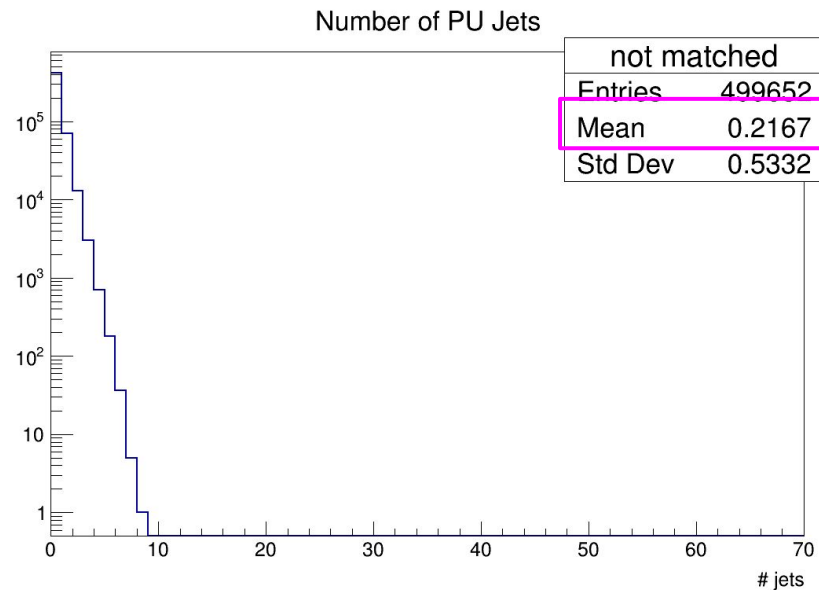
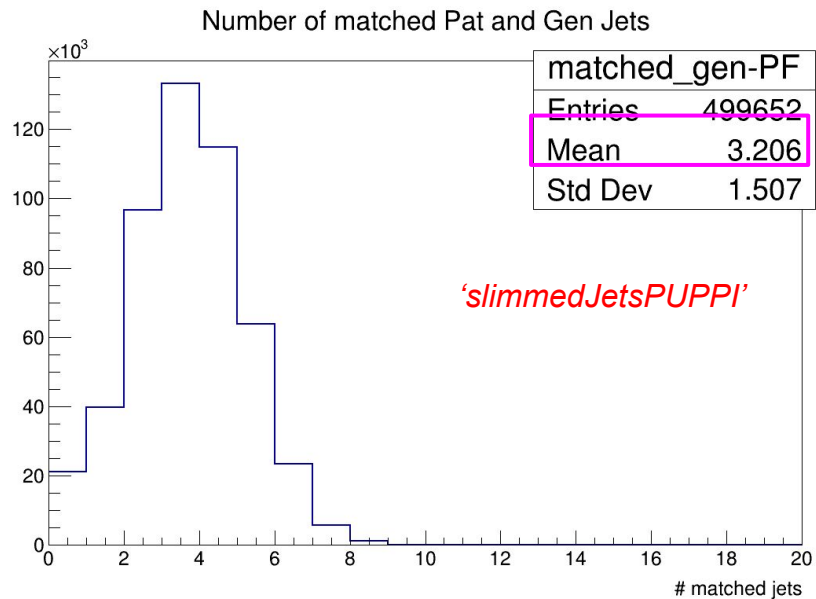
Signal vs PU: cuts - 2

- Additional requirements for signal jets:
 - Pat & Gen $p_T > 30$ GeV
 - Pat & Gen $|\eta| < 5 \rightarrow$ large rapidity gap to include VBF jets

Same cuts used in ATLAS analysis

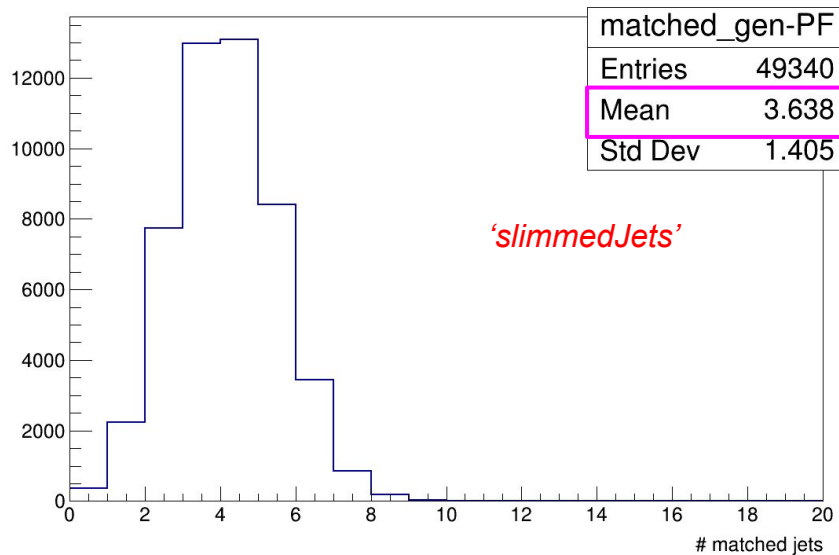


Jets per event

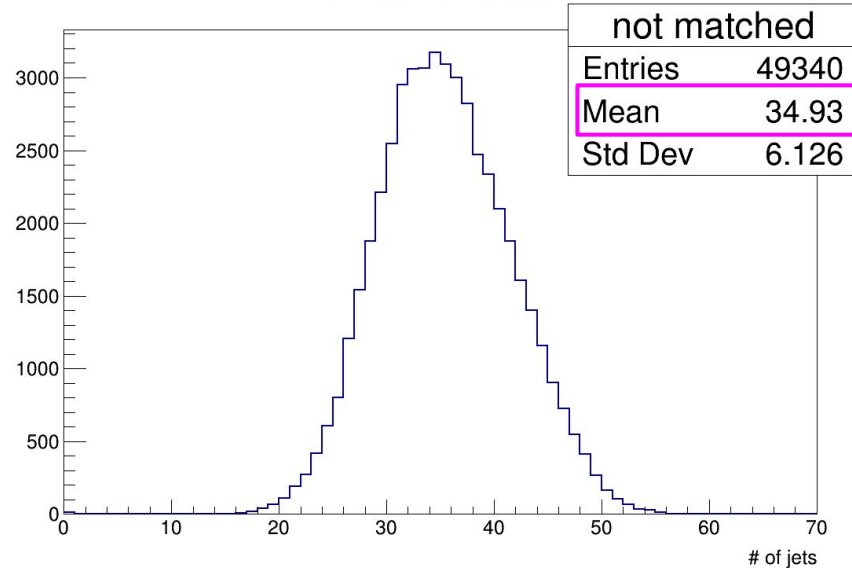


Jets per event - no PUPPI

Number of matched Pat and Gen Jets



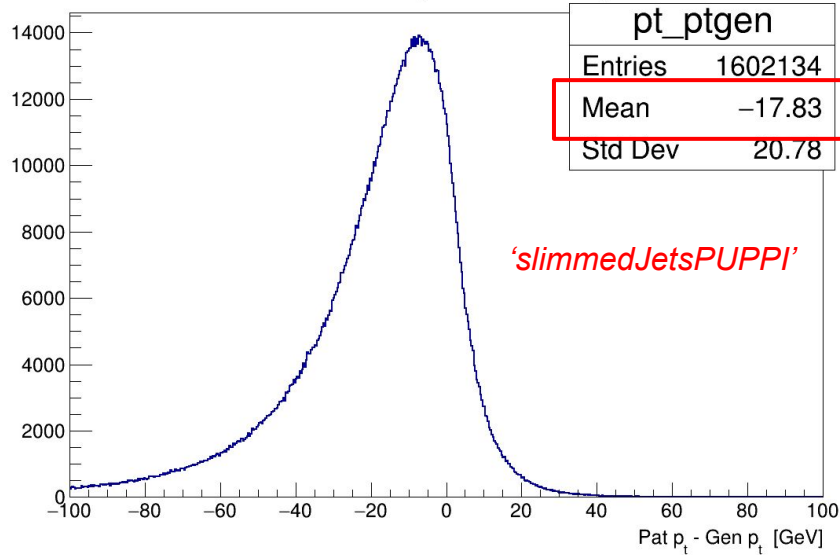
Number of PU Jets



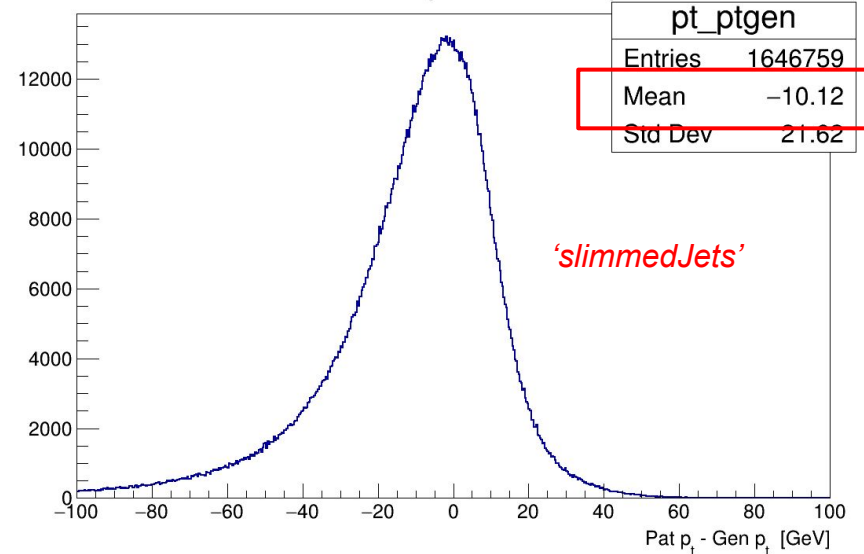
- the number of matched jets per event is unchanged, but the PU jets increases drastically

Pat - Gen p_T distributions

PatJets p_t - GenJets p_t

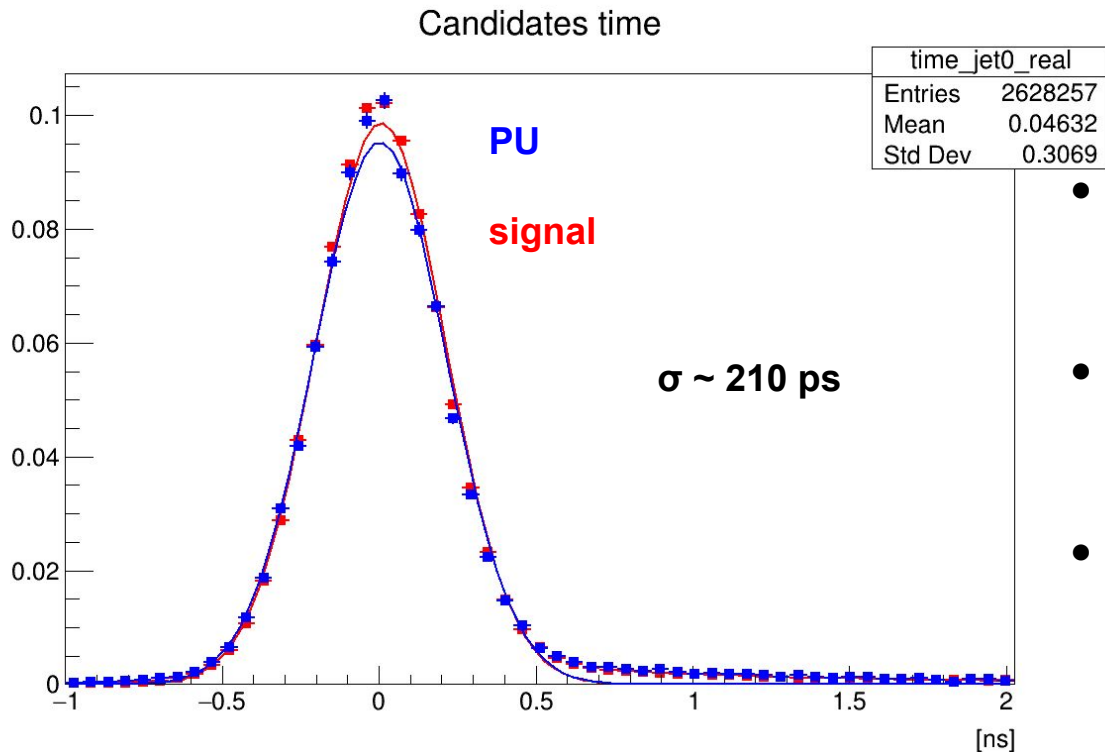


PatJets p_t - GenJets p_t



- Distributions of matched Pat/Gen Jets: **Pat jets have on average a smaller p_T**
- Smaller difference in *'slimmedJets'* collection: hint that **PUPPI is too aggressive in removing candidates from signal jets** (it ends up removing also signal candidates)

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- ATLAS analysis (timing not used)

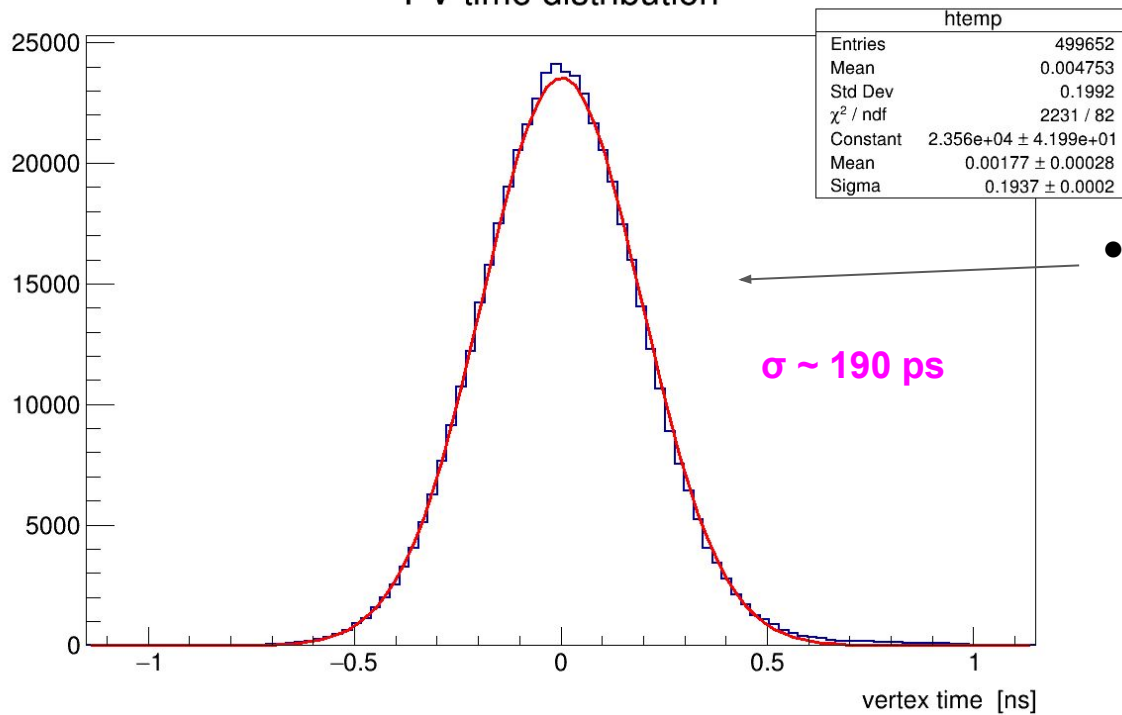


candidates time & time error available
from *PackedCandidate* collection

- All jet constituents are computed wrt the same reference point (t_0 = time of hard-scatter interaction)
- Candidates times are smeared according to the beamspot spread (180 ps in the Phase 2 setup)
- Distributions are centered in 0 with σ given by vertex smearing + detector resolution + any mismeasurement → **no difference between PU and signal observed, as expected**

Primary vertex time distribution

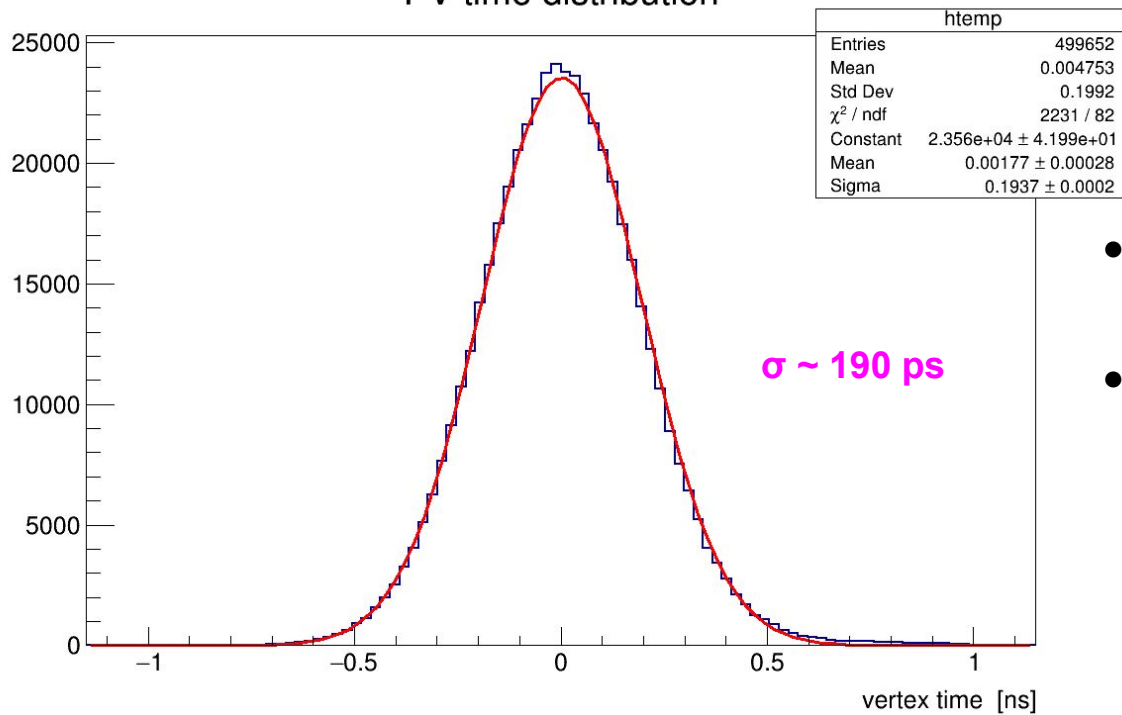
PV time distribution



- Time distribution of jet constituents reflect the PV distribution

Primary vertex time distribution

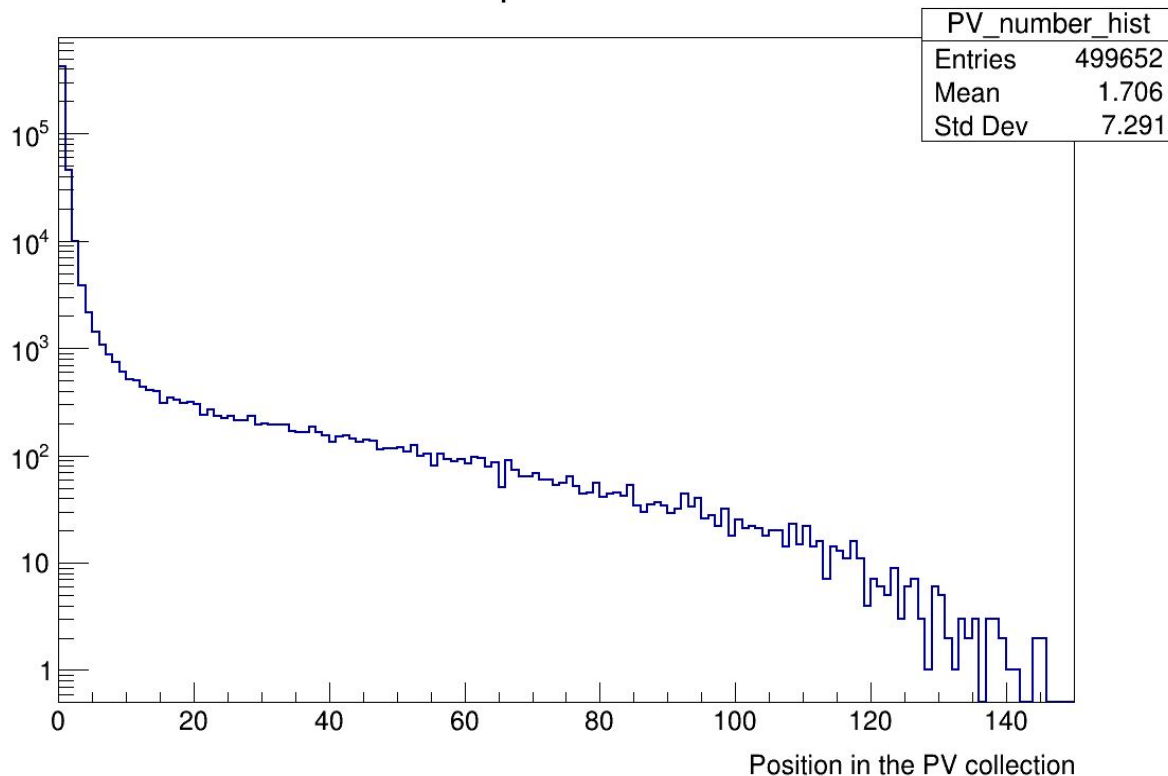
PV time distribution



- Time distribution of jet constituents reflect the PV distribution
- In this study, the 0th element of the PV collection is always assumed to be the hard interaction vertex (not 100% true at 200 PU, see next slide)

PV = 0th element of collection?

Hard-scatter vertex position in the PV collection

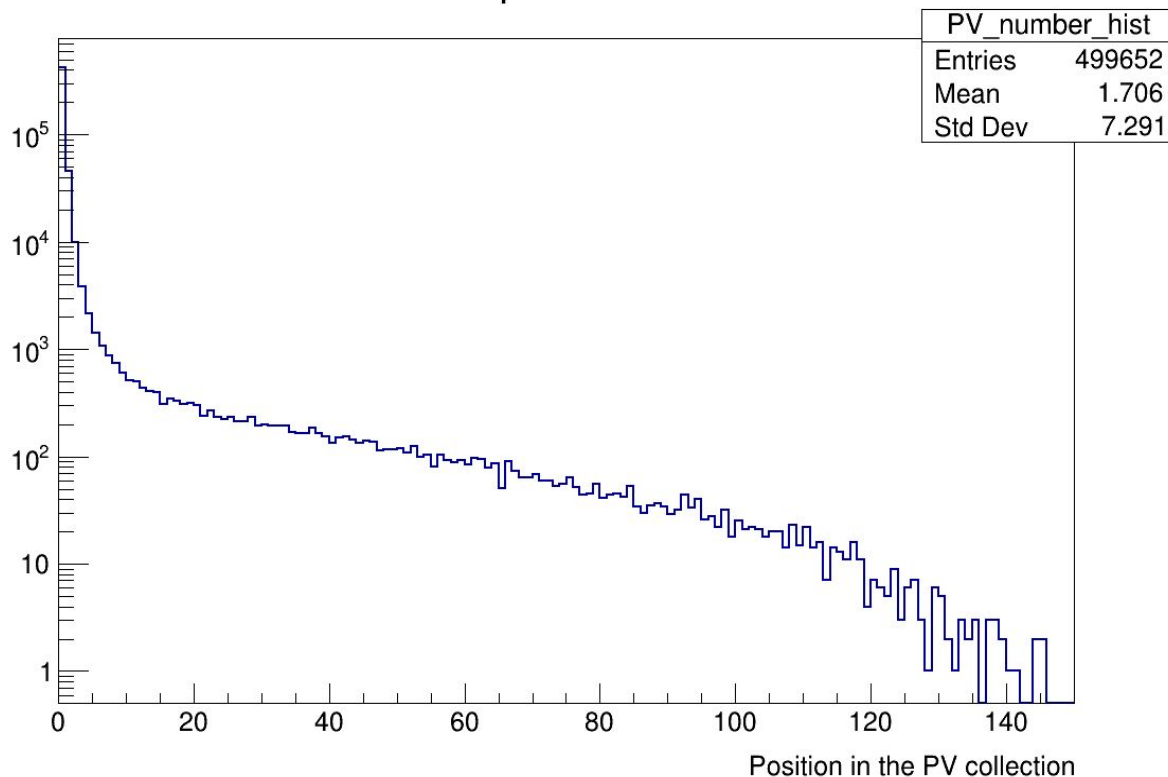


Real hard-scatter vertex determined
by comparing the vertices positions
with the MC truth of the
'genParticles:xyz0' collection

- ~ 16% of the PVs do not correspond to the 0th element of the PV collection

PV = 0th element of collection?

Hard-scatter vertex position in the PV collection



Real hard-scatter vertex determined by comparing the vertices positions with the MC truth of the 'genParticles:xyz0' collection

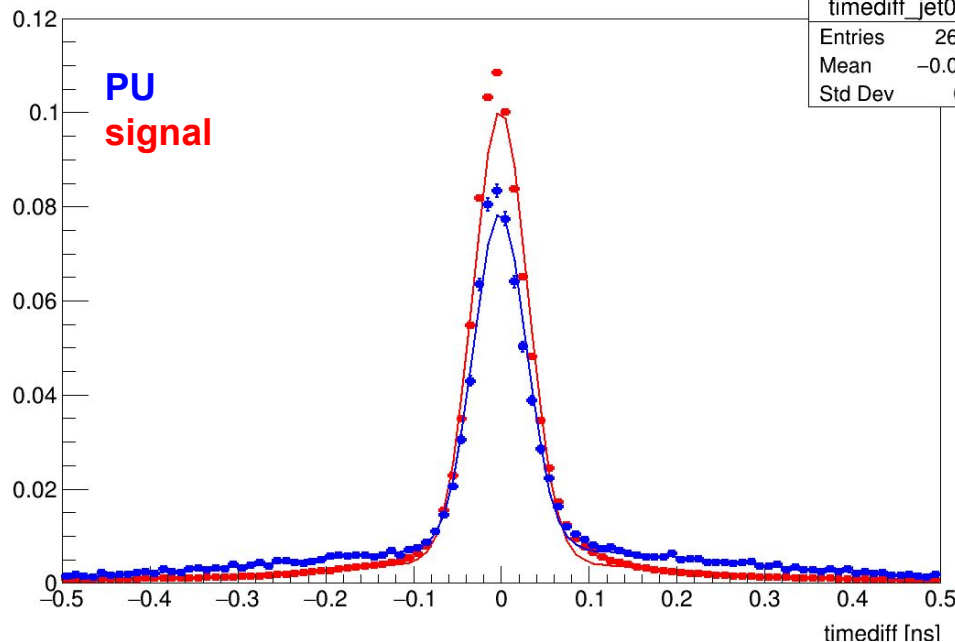
- ~ 16% of the PVs do not correspond to the 0th element of the PV collection
- BUT we always assume that the 0th element is the hard interaction
→ in the 16% of the event a PU vertex is wrongly considered the hard-scatter vertex

Time difference distribution

| PV time - candidate time |

timediff_jet0_real	
Entries	2628257
Mean	-0.001767
Std Dev	0.1038

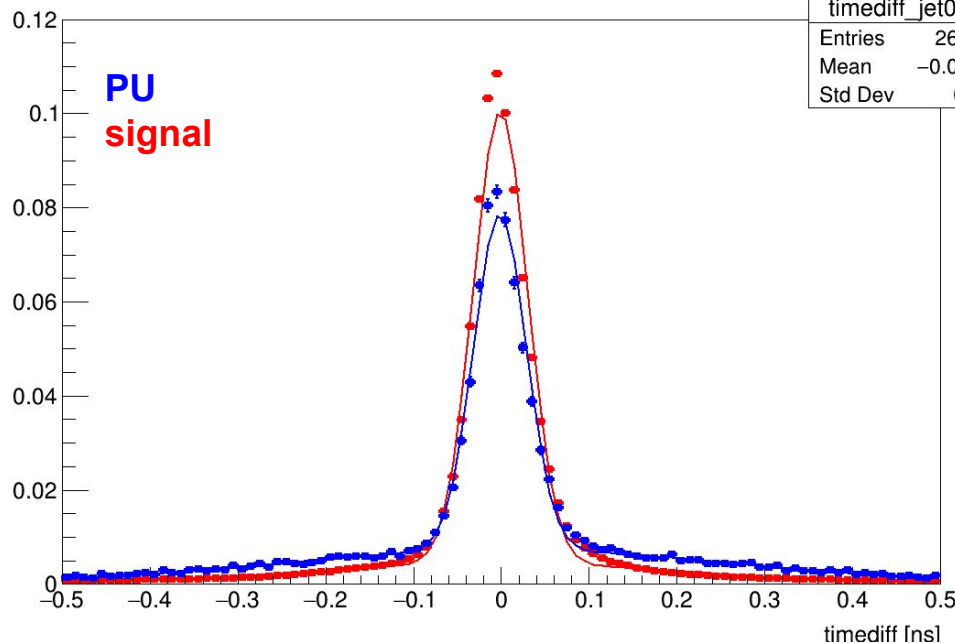
- Constituents time alone is not effective in distinguishing signal from PU candidates



normalized to integral

Time difference distribution

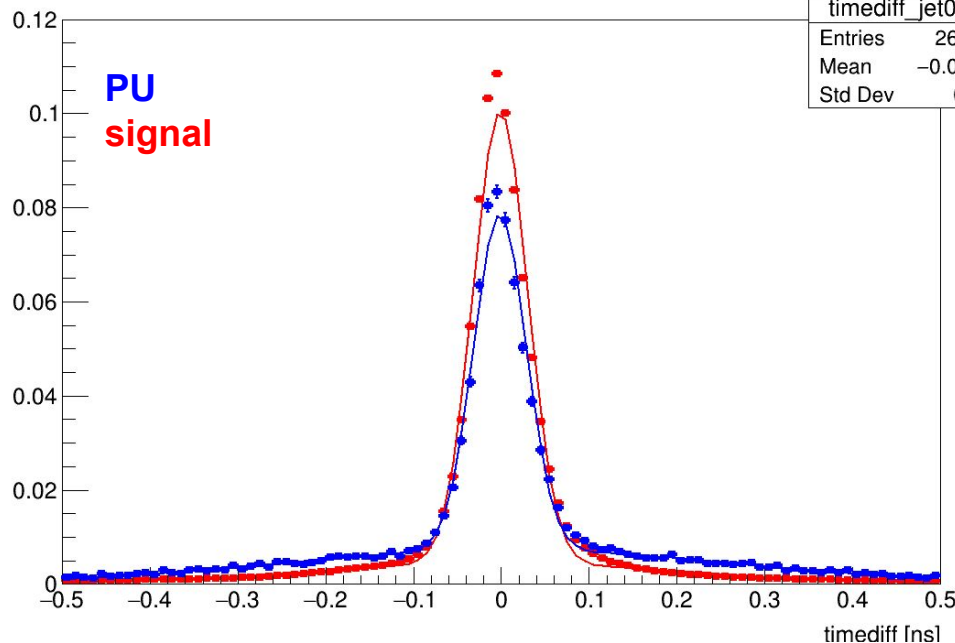
| PV time - candidate time |



- Constituents time alone is not effective in distinguishing signal from PU candidates
- More useful is the **time difference between candidates and PV:**

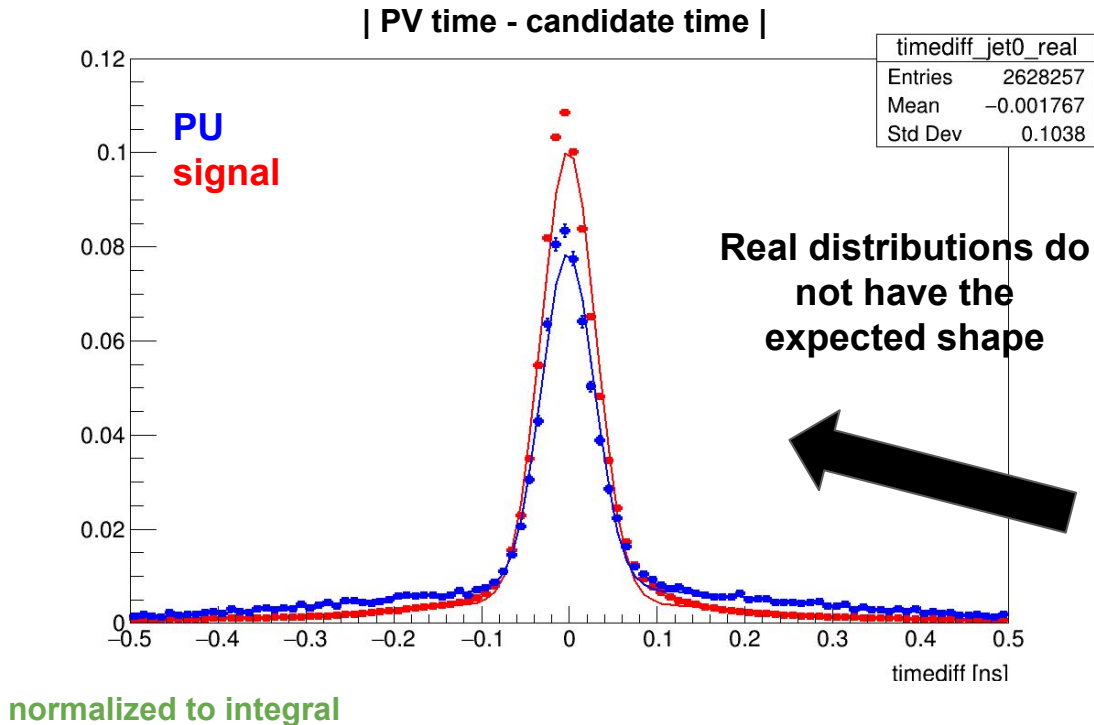
normalized to integral

| PV time - candidate time |



normalized to integral

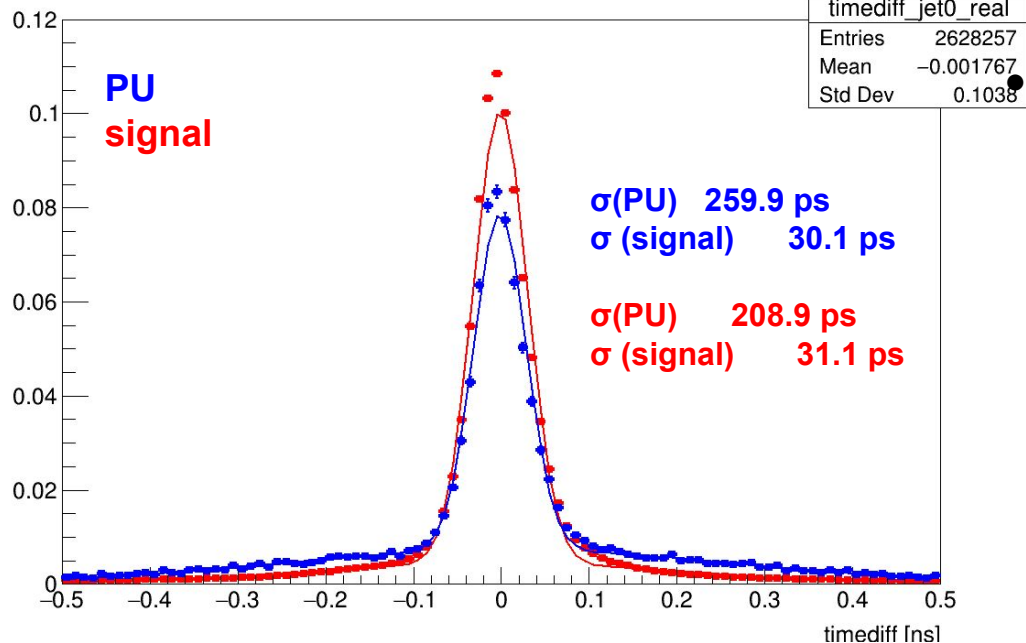
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- More useful is the **time difference between candidates and PV**:
 - PU events should result in a gaussian centered in 0 with $\sigma = \sqrt{2} \cdot 180 \text{ ps} = 250 \text{ ps}$ → squared sum of candidates and PV resolution
 - Signal should be centered in 0 with $\sigma = 40 \text{ ps}$ (detector resolution) → in this case, candidates and PV times are correlated



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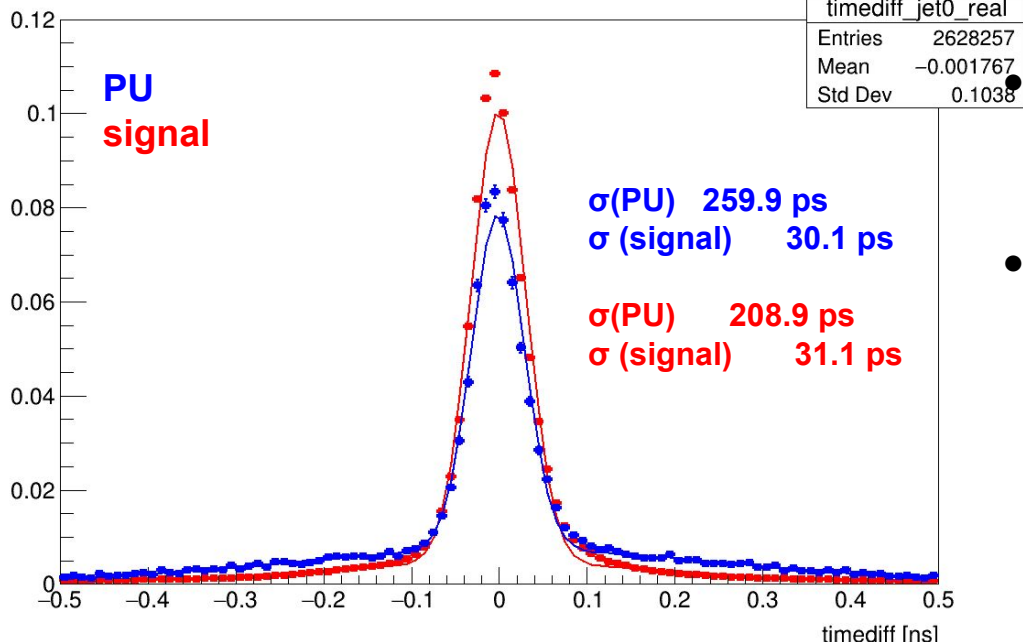


Since PUPPI is not 100% efficient, the real distributions are the sum of signal and PU (=2 gaussian summed)

normalized to integral

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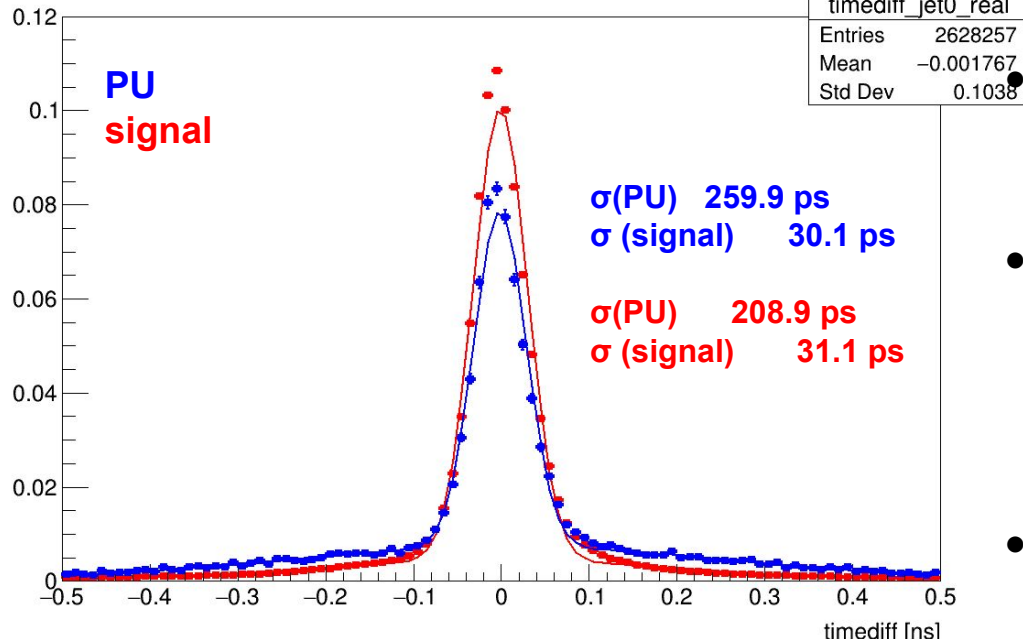
normalized to integral

Since PUPPI is not 100% efficient, **the real distributions are the sum of signal and PU (=2 gaussian summed)**

- Despite that, **we would expect the distributions to be different**, dominated by signal or PU candidates respectively → **very similar instead**, both dominated by signal-like candidates

Time difference distribution

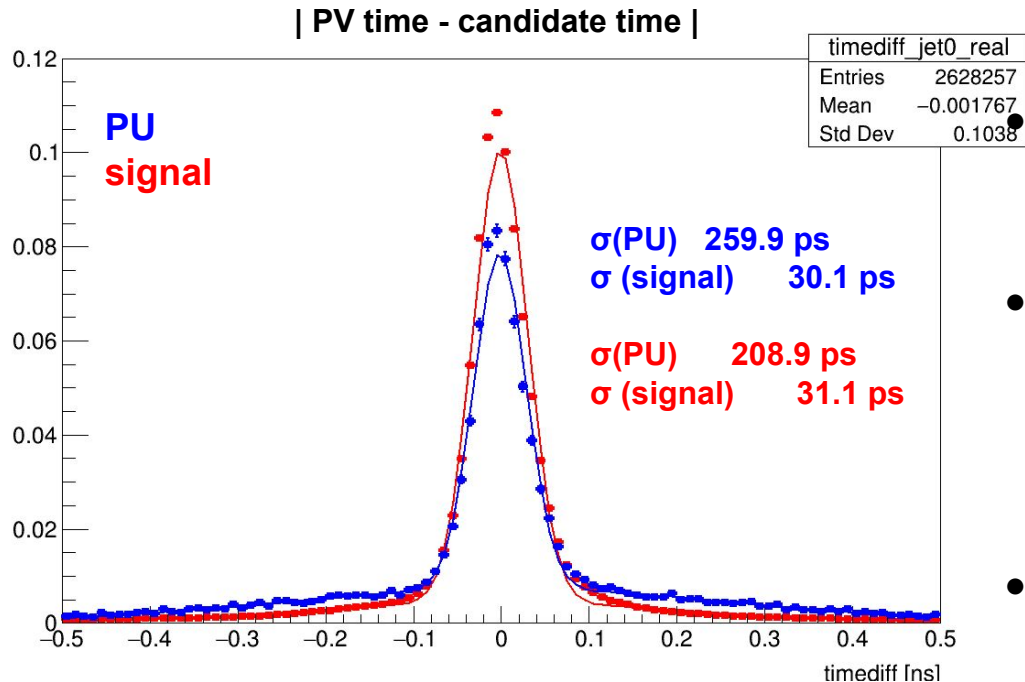
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- Despite that, **we would expect the distributions to be different**, dominated by signal or PU candidates respectively → **very similar instead**, both dominated by signal-like candidates
- MTD timing information used after PUPPI not really useful in distinguishing signal and PU → Issue already pointed out by [D.Roy](#) in December using a different sample



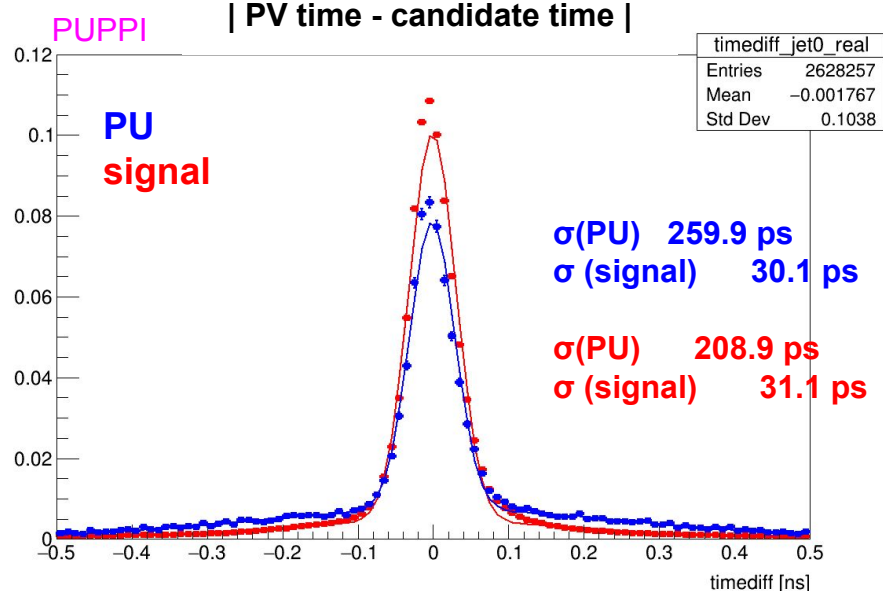
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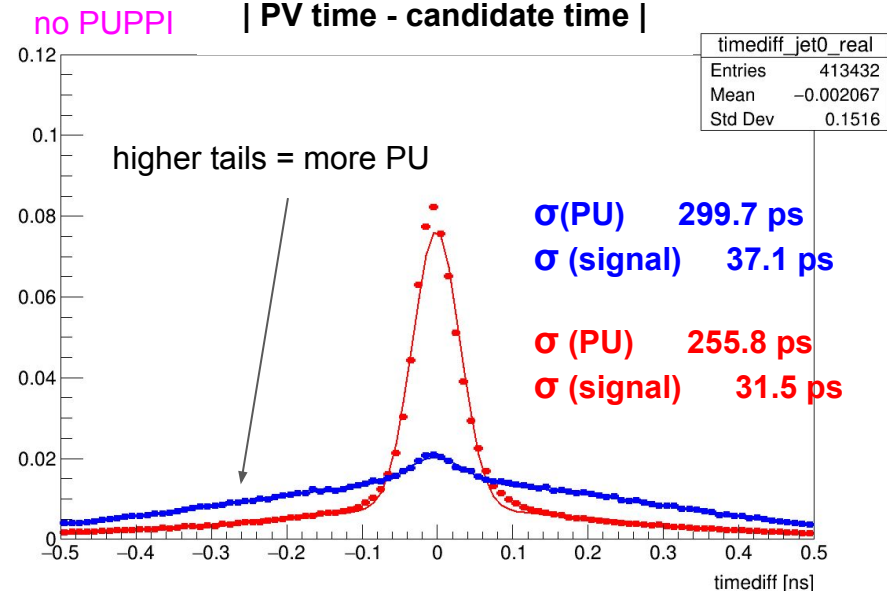
Why many signal-like candidates in PU jets ?

PUPPI vs no-PUPPI

| PV time - candidate time |



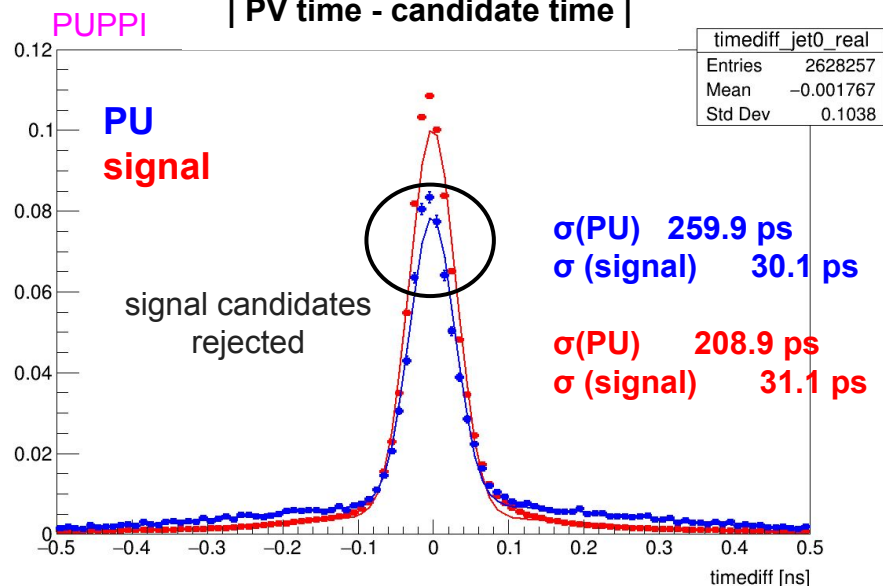
| PV time - candidate time |



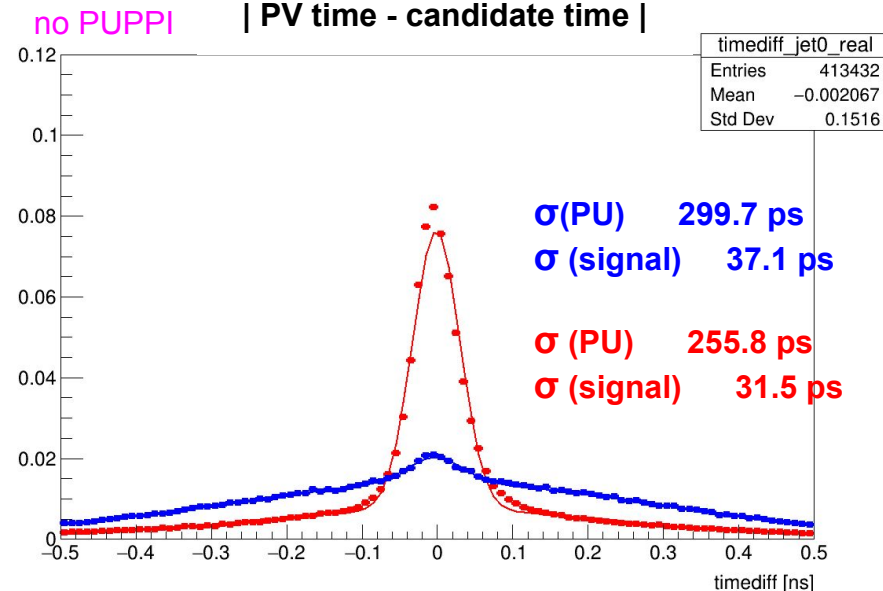
- PUPPI is good at rejecting PU: difference in the number of PU candidates in the two collections is evident

PUPPI vs no-PUPPI

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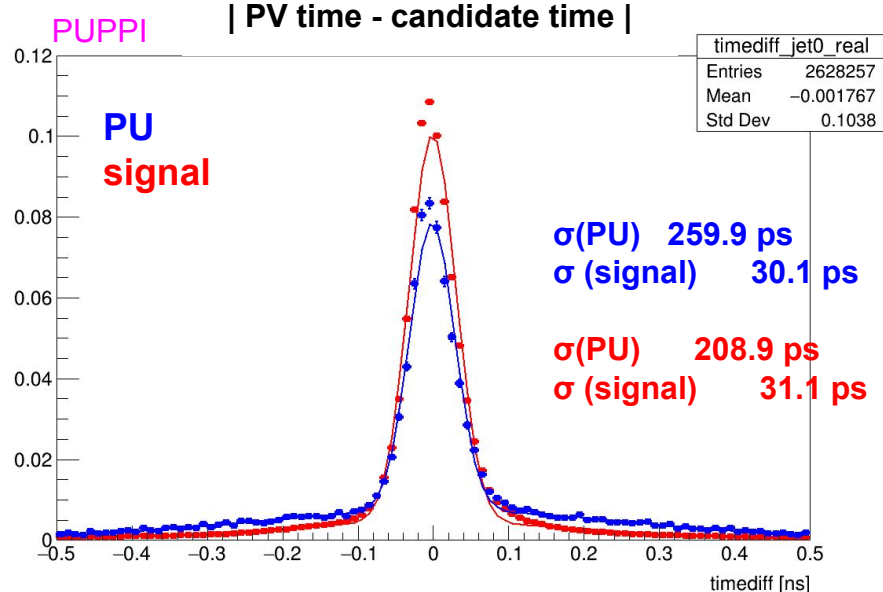
| PV time - candidate time |



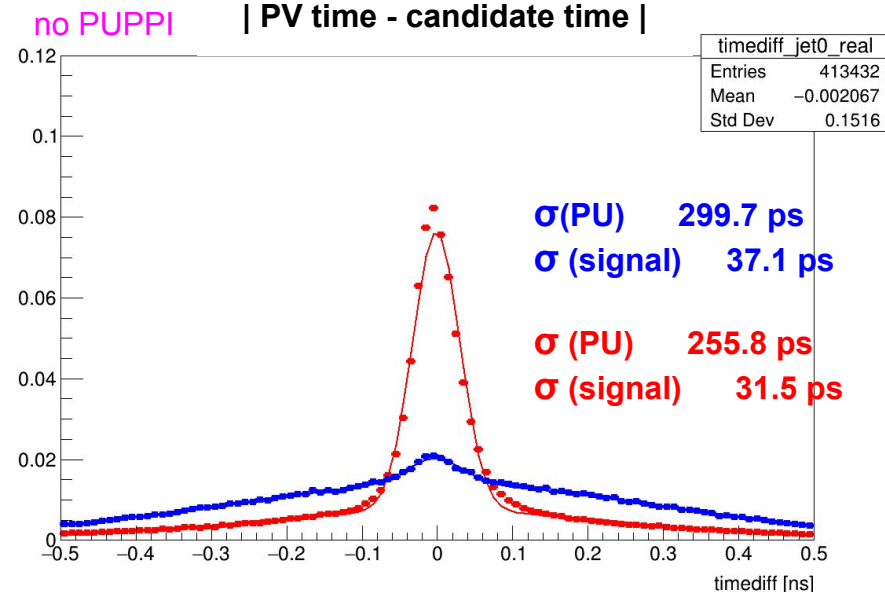
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PUPPI vs no-PUPPI

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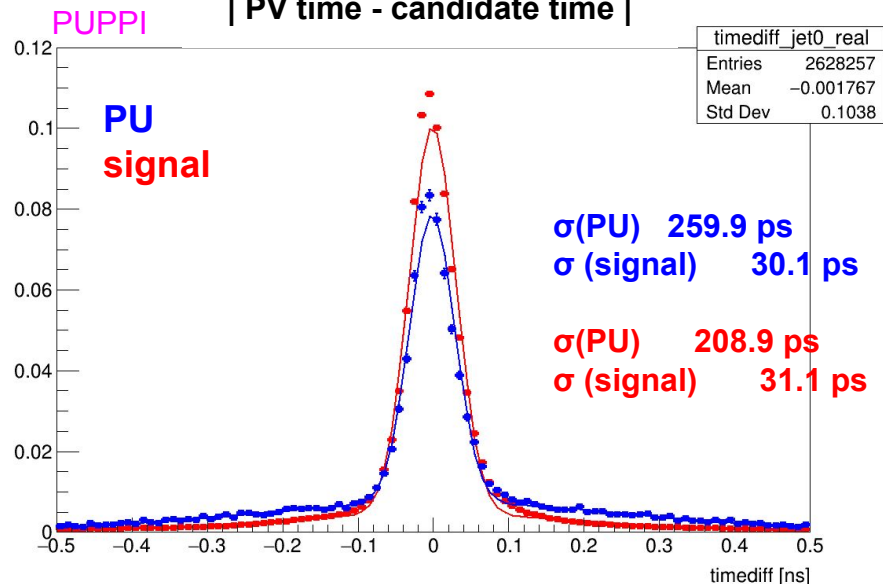
| PV time - candidate time |



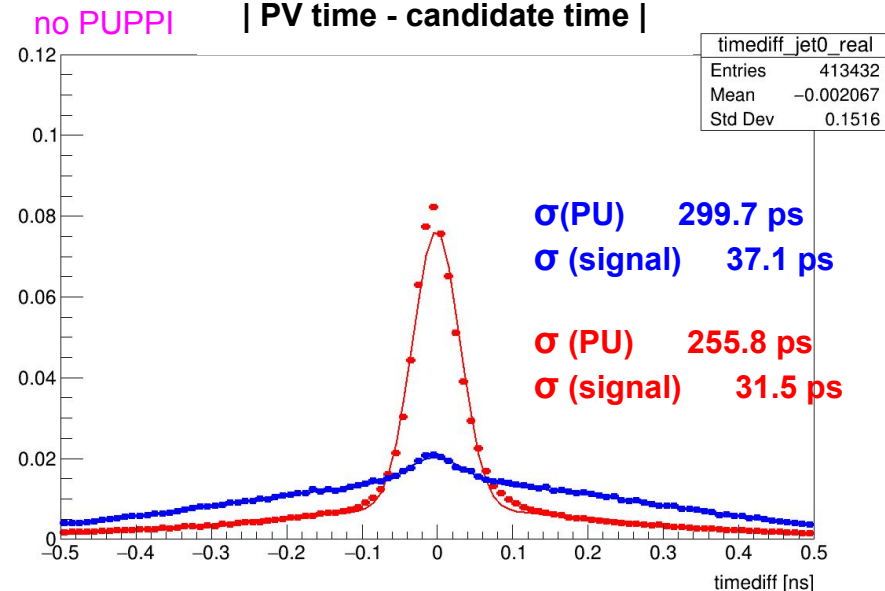
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PUPPI vs no-PUPPI

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- It is even TOO good → **at 200 PU, it ends up removing also signal candidates**
- **Hence, MTD timing to remove PU candidates not useful:** PUPPI already did the job
- **Better solution: implement timing in PUPPI to keep the signal candidates which are currently removed**



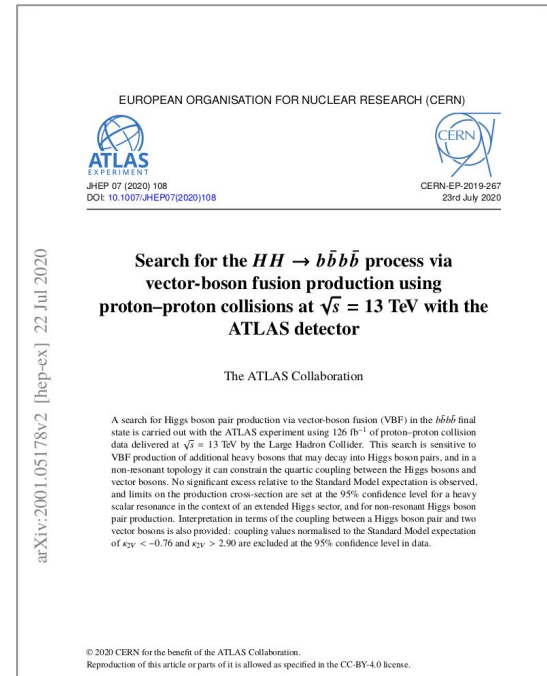
Outline



- Introduction
- The use of timing to discriminate between signal & PU candidates
- **ATLAS analysis (timing not used)**

ATLAS analysis (no timing)

- ATLAS analysis performed with Run 2 data
 - PV with highest p_T is chosen as hard-scatter PV
 - VBF selection:
 - 2 or more jets with $p_T > 30$ GeV && $|\eta| > 2$
 - take the 2 selected jets with highest p_T and opposite η
 - Additional requirement on the 2 VBF candidates: $|\Delta\eta| < 5$ && $m_{jj} > 1000$ GeV
 - b-jet selection:
 - b-tag threshold = 0.4184
 - b-tagger = "pfDeepCSVJetTags:probb"
 - exactly 4 b-tagged jets with $p_T > 40$ GeV && $|\eta| < 2$
- 110667 events with 6 jets out of: 499517
- 1042 events passes cuts out of: 499517

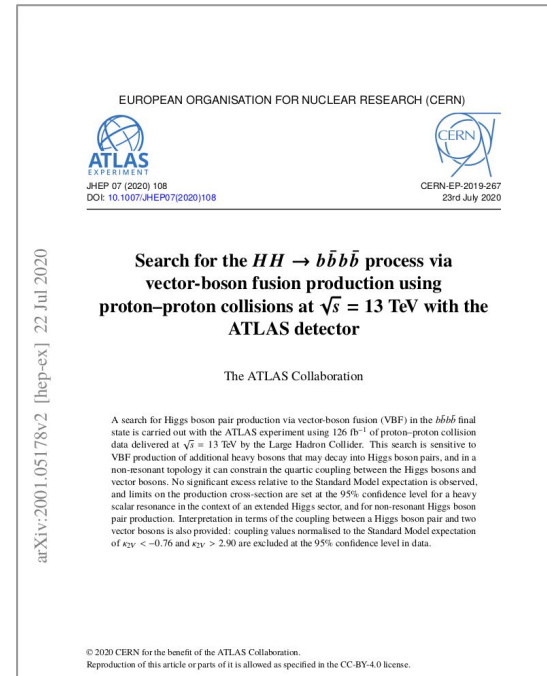


- ΔR_{bb} requirements on both leading and sub-leading bb pairs to account for the correlation of m_{4b} with the Lorentz boost of the Higgs candidates and the angle between their decay products

→ 829 events pass this cut

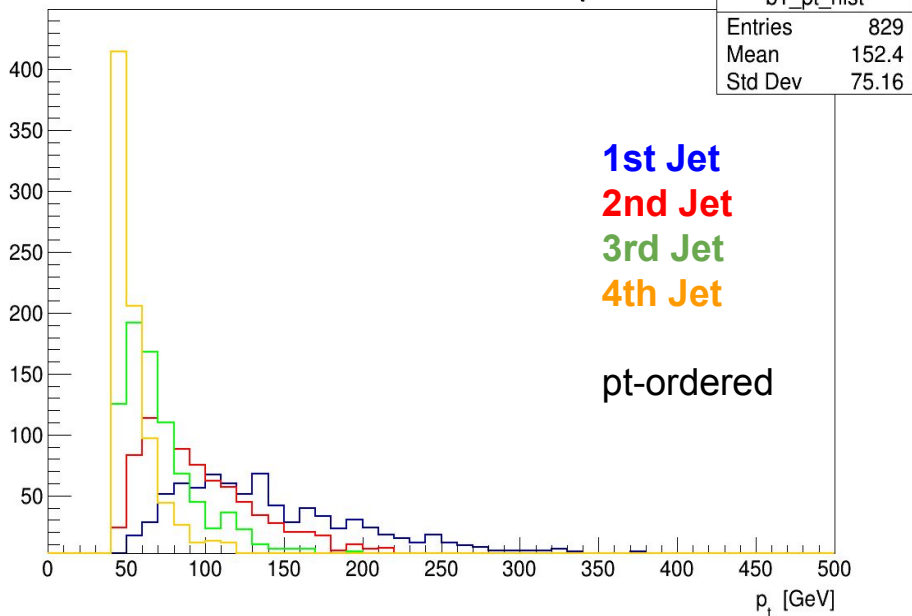
- Among all the possible pairs fulfilling the former requirements, the one with the smallest D_{HH} is chosen
 - D_{HH} : distance of lead and sub-lead H candidates masses in the $(m_{2b}^{\text{lead}}, m_{2b}^{\text{sublead}})$ plane
- Explicit definition of the signal topology in the backup

- ΔR_{bb} = distance in the Φ - η plane between the two b-jets coming from the H decay
- m_{4b} = invariant mass of the 4 b-jets

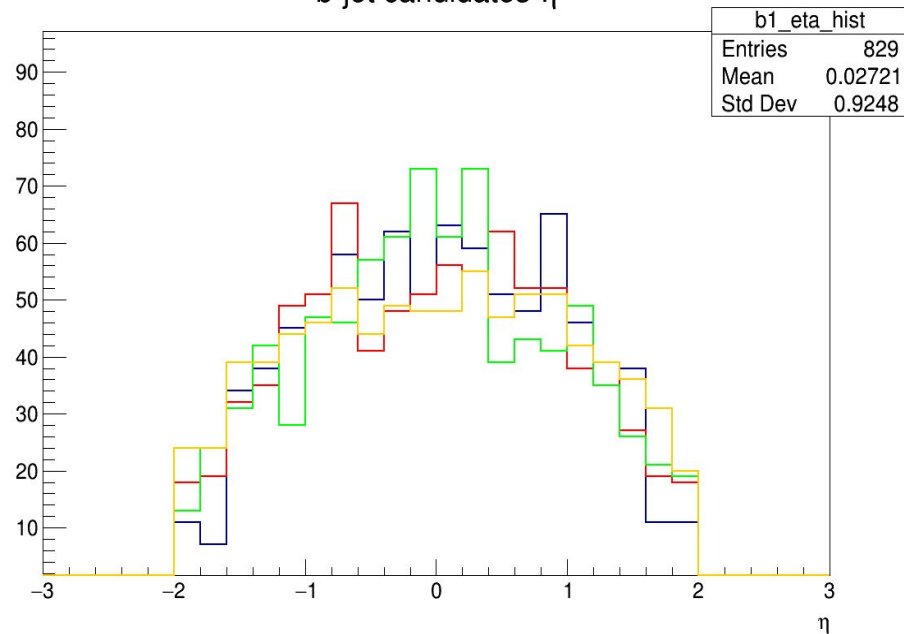


b-jet candidates

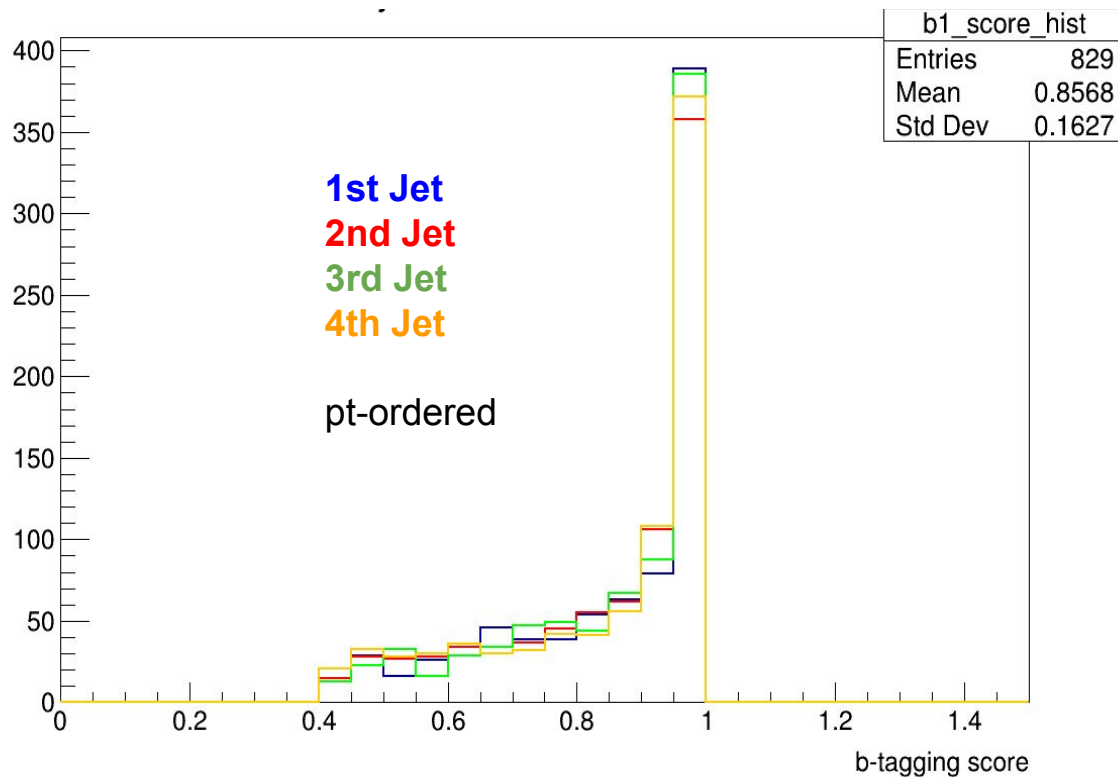
b-jet candidates p_t



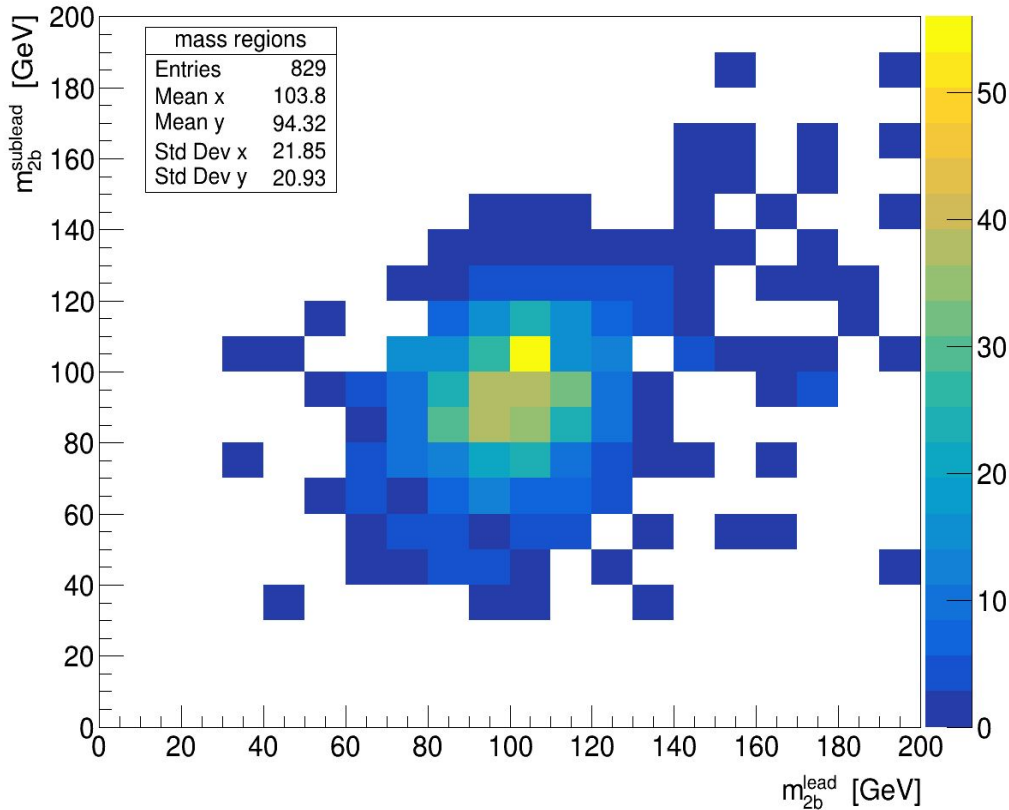
b-jet candidates η



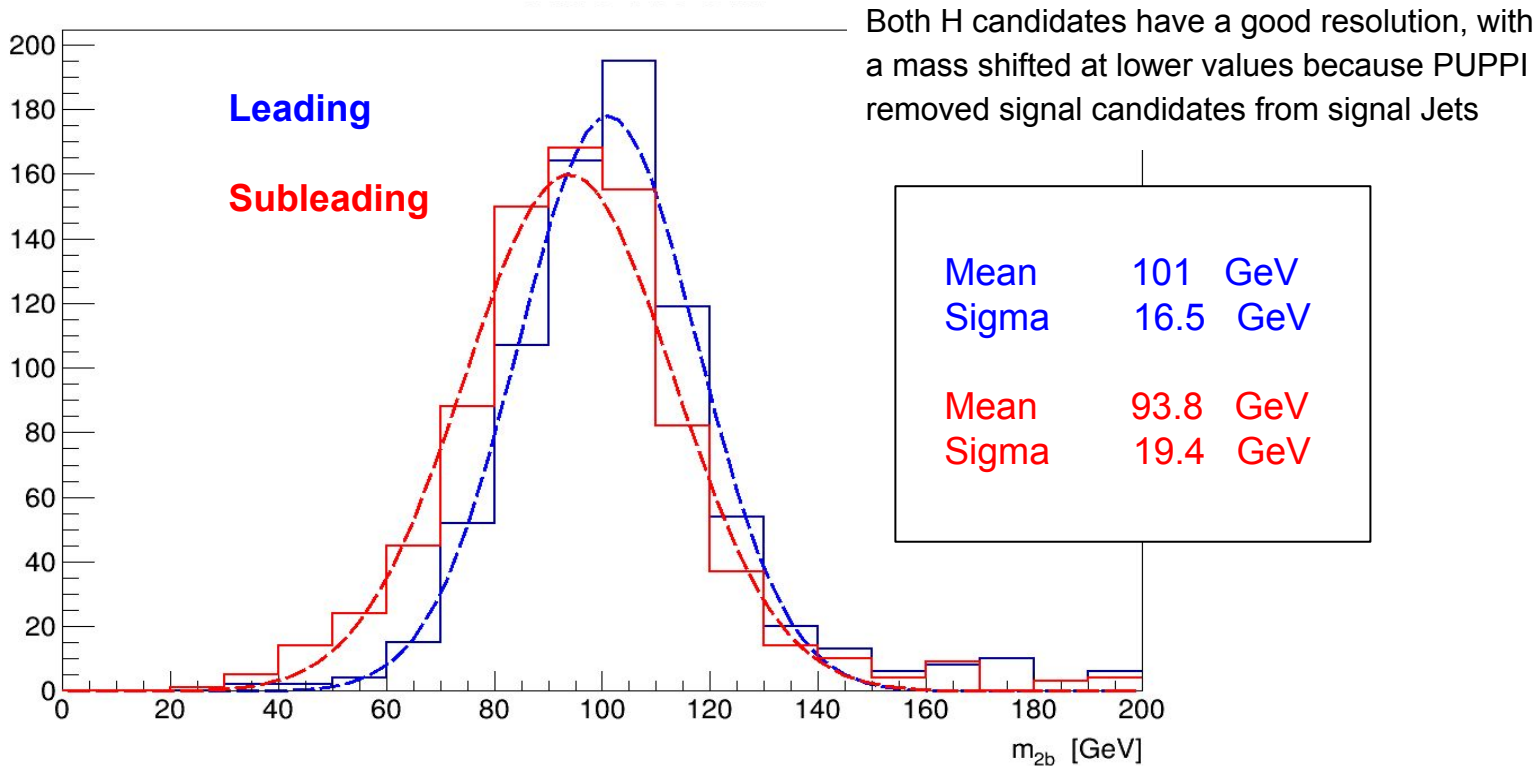
b-jet candidates: b tagging score



Mass distributions of leading and sub-leading Higgs candidates



Mass distributions of leading and sub-leading Higgs candidates



- We studied the **impact of the MTD timing in removing PU candidates from signal jet**
 - We used the VBF $HH \rightarrow 4b$ channel as benchmark
- The time difference between PV e jet candidates is the most useful information:
 - Signal candidates should have a time distribution with $\sigma = 40$ ps (detector resolution)
 - PU candidates: $\sigma = \sqrt{2} \cdot 180$ ps (squared sum of vertex + candidate resolution)
- However, **MTD timing not very useful** : PUPPI is already good at removing PU candidates
- The **MTD timing** might be **implemented in PUPPI to avoid rejecting signal candidates**
 - any help with this would be much welcome!
- We used the same dataset to perform a simplified version of the ATLAS analysis of this process
 - Good mass resolutions of both Higgs candidates
 - Mass values shifted down by PUPPI, due to the subtraction of constituents from signal jets

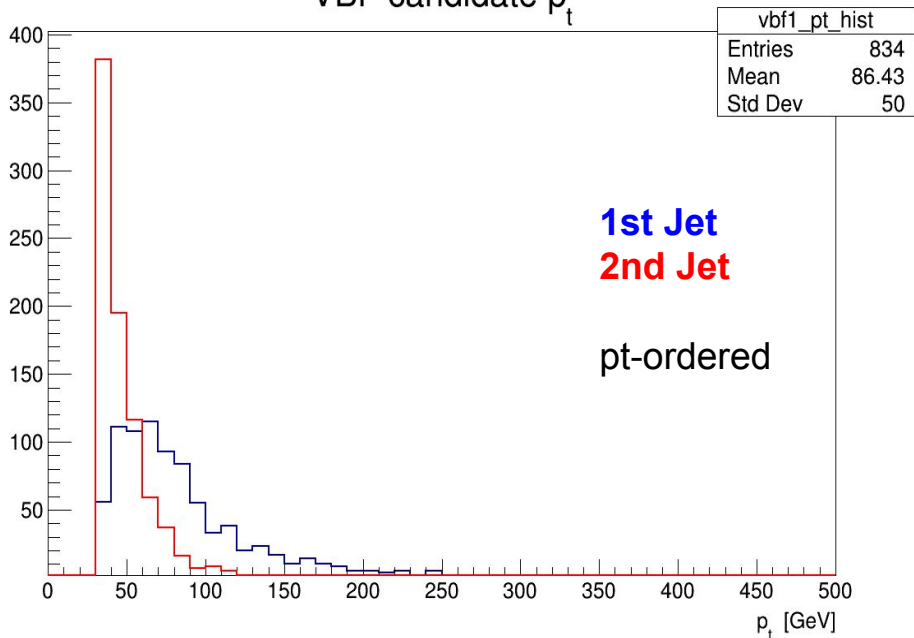
Thank You!

BACKUP

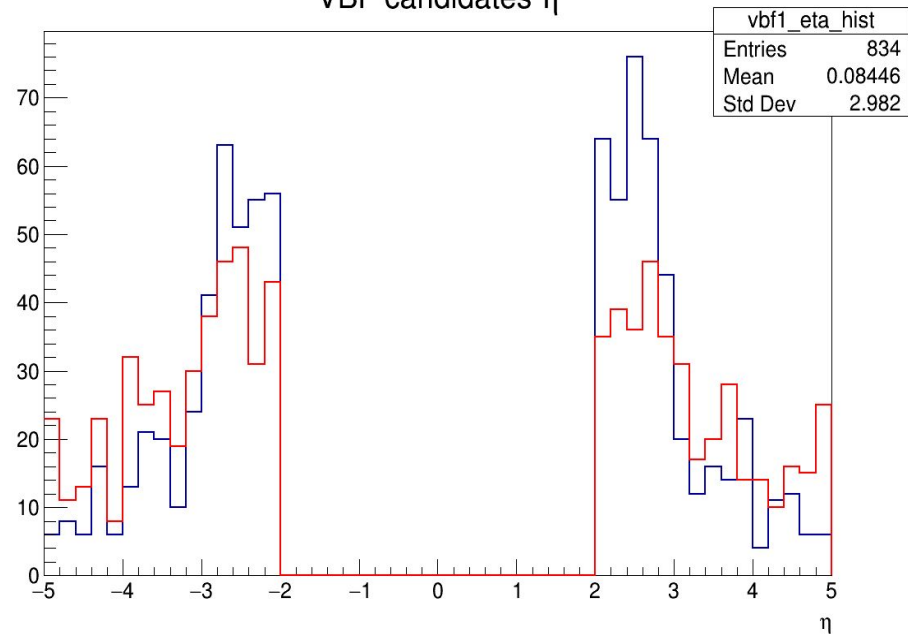
Signal topology	Exactly 4 b -tagged jets with $p_{\text{T}} > 40$, $ \eta < 2.0$	
	If $m_{4b} < 1250$	$\frac{360}{m_{4b}} - 0.5 < \Delta R_{bb}^{\text{lead}} < \frac{653}{m_{4b}} + 0.475$
		$\frac{235}{m_{4b}} < \Delta R_{bb}^{\text{subl}} < \frac{875}{m_{4b}} + 0.35$
	If $m_{4b} \geq 1250$	$\Delta R_{bb}^{\text{lead}} < 1$
		$\Delta R_{bb}^{\text{subl}} < 1$
Pairs with minimum		
$D_{HH} = \sqrt{(m_{2b}^{\text{lead}})^2 + (m_{2b}^{\text{subl}})^2} \left \sin \left(\tan^{-1} \left(\frac{m_{2b}^{\text{subl}}}{m_{2b}^{\text{lead}}} \right) - \tan^{-1} \left(\frac{116.5}{123.7} \right) \right) \right $		

VBF candidates

VBF candidate p_t

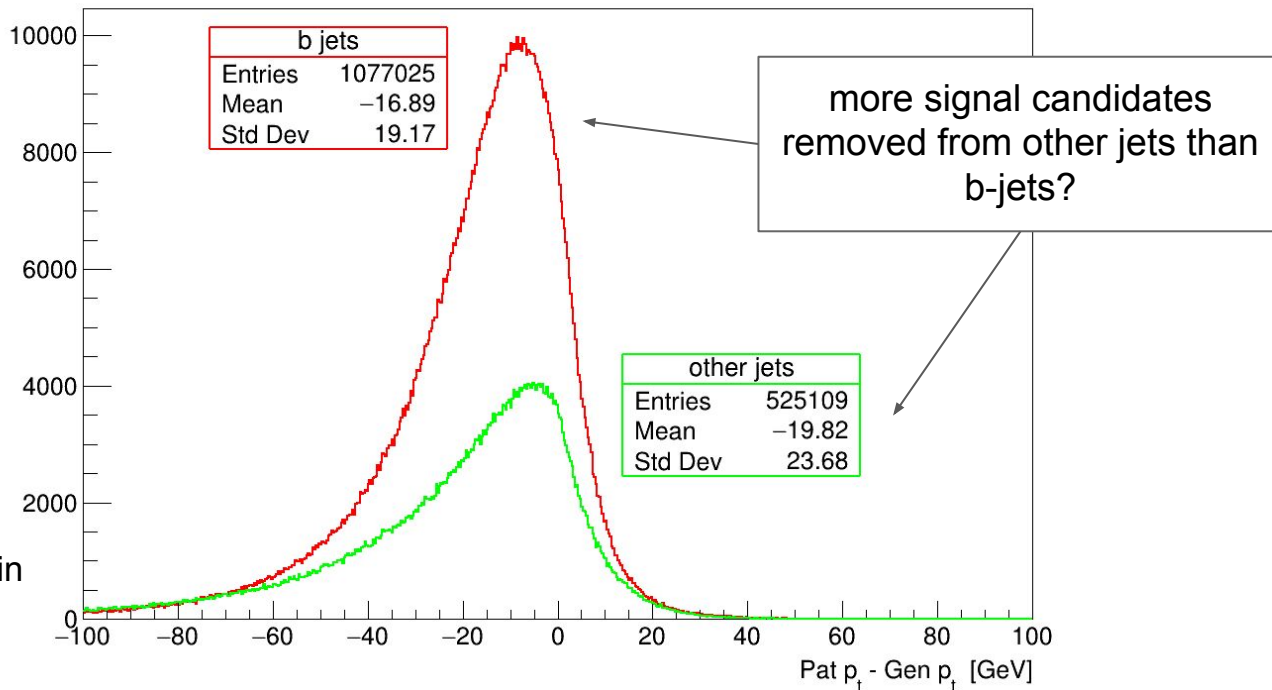


VBF candidates η

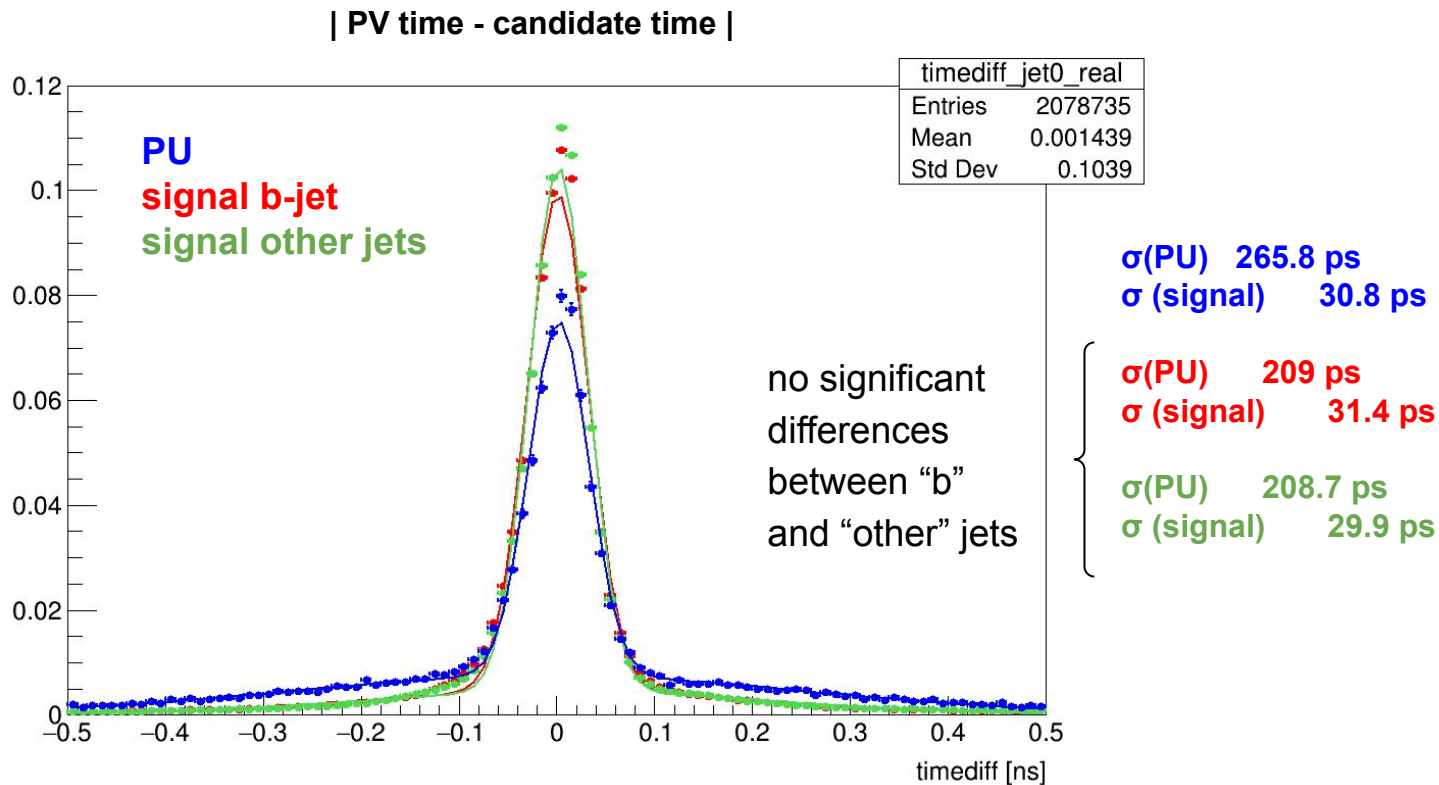


Pat - Gen p_T distributions - 2

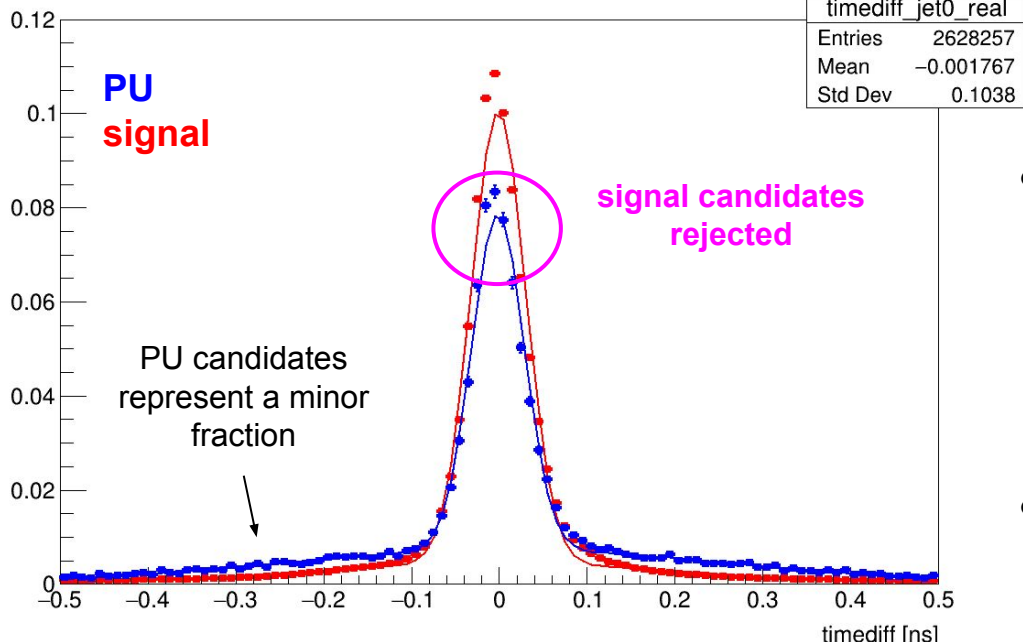
- We also splitted signal jets in “b” and “other” jets



b jet: at least one b quark within
 $\Delta R(\text{Gen}, \text{GenParticle}) = 0.4$



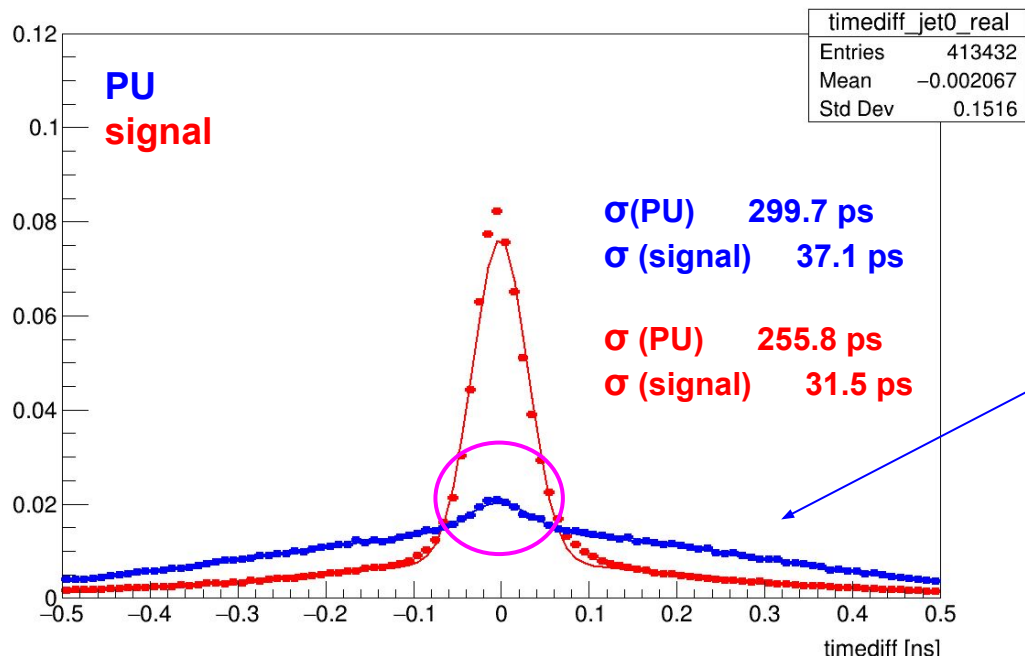
| PV time - candidate time |



- **PUPPI is good in rejecting PU candidates** → PU represents a minor fraction of total candidates
 - PU candidates in the signal distribution might come from the wrong assignment of the PV, as pointed out in slide 15
- **Sometimes it is TOO good** and signal candidates are rejected from signal jets

Time difference distribution - no PUPPI

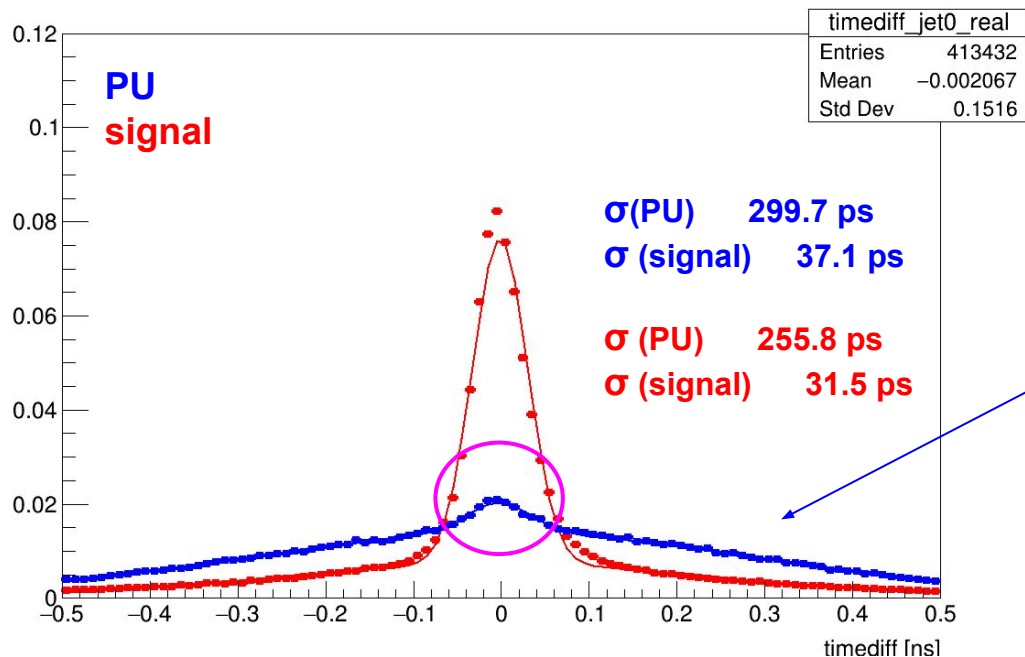
| PV time - candidate time |



normalized to integral

- Collection 'slimmedJets':
 - Cuts to separate signal from PU are the same used for the PUPPI collection (slide 7-8)
- Much larger number of PU jets per event → larger tails

| PV time - candidate time |



normalized to integral

- Collection 'slimmedJets':
 - Cuts to separate signal from PU are the same used for the PUPPI collection (slide 7-8)
- Much larger number of PU jets per event → larger tails
- Signal candidates are less evident in the PU distribution because the number of PU candidates is much higher (distributions are normalized to integral)