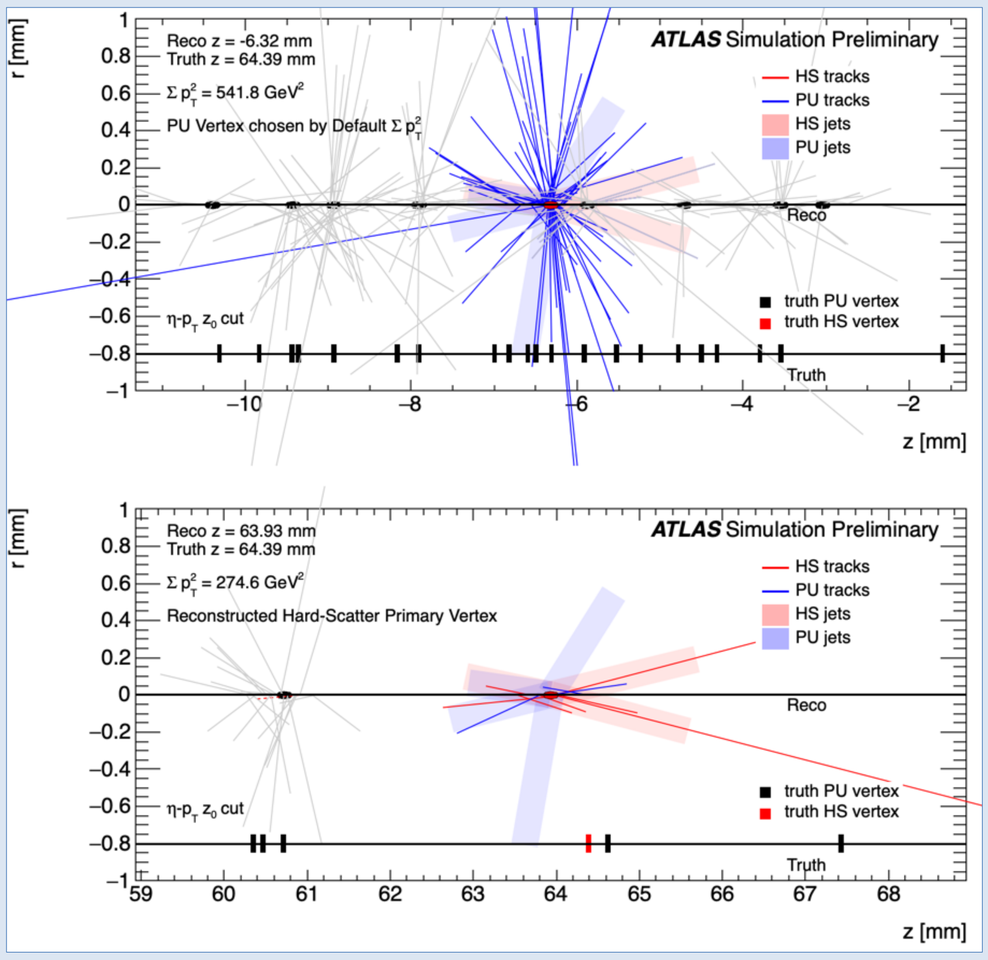
Primary Vertex Selection in VBF Higgs to Invisibles at the HL-LHC with the ATLAS Experiment

Introduction

- The Pile-up (PU) vertex density at the HL-LHC [1] ($\langle\mu\rangle$ = 200) of ~2vtx/mm will lead to increased merging of nearby PU vertices.
- PU vertices incorrectly identified as Hard Scatter (HS) Primary Vertex (PV) by the standard algorithm [**sumPT** = $\Sigma_{\text{tracks}} p_T^2$].
- Vector boson fusion (VBF) to invisible (inv) final state process does not have very high visible p_T activity, resulting in a low vertex selection efficiency (VSE) as a function of PU density.
- Need angular correlations in the selection algorithm; Weight tracks if they belong to jets as a means to counter merged PU vertices.

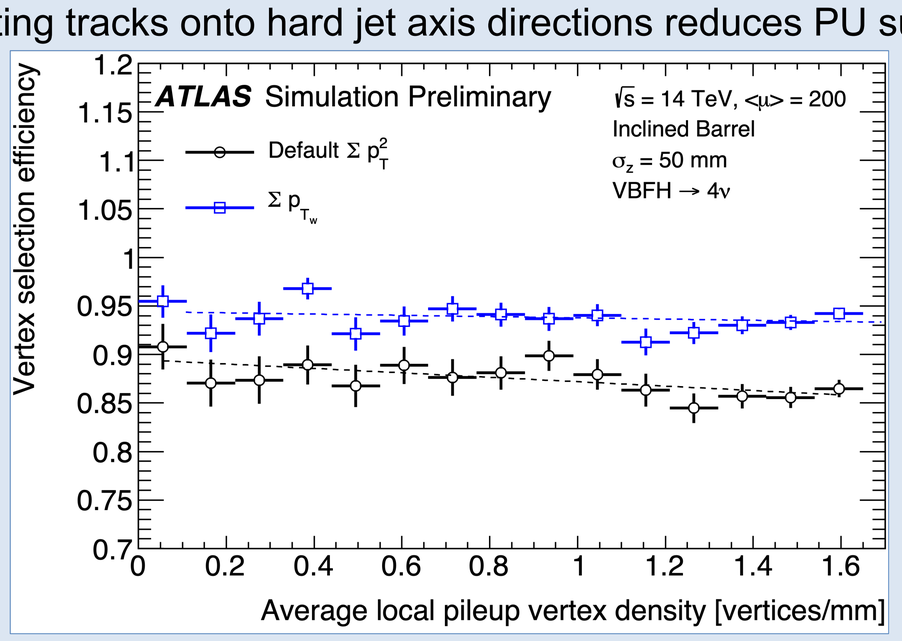


Proposed Improvement

$$\textbf{sumPTw} = \sum_{tracks} p_{T_w}$$

$$= \sum_{tracks} \frac{p_{T-track}^{\alpha} \times p_{T-closest\ jet}^{\beta}}{\Delta R^{\gamma}} \mathbb{1}(\Delta R < 0.8\,).\mathbb{1}\left(p_{T-jet} > p_T^{thr}\right)$$

- $\alpha = \beta = 2,\ \gamma = 1,\ p_T^{thr} = 30$ GeV is used
- *sumPTw* is a measure of the total vertex *sumPT* in jets.
- PU - tracks are not correlated in η-ϕ space with the HS interaction
- Projecting tracks onto hard jet axis directions reduces PU sumPT.



Unbiased event selection is used, looks for vertices with associated jets which satisfy VBF criteria; jets associated to vertices that maximized Rpt, [Rpt = $\sum_{tracks}^{in\ vertex} \frac{p_T}{p_T^{jet}} \mathbb{1}(\Delta R < 0.4\,)$].

Run 4 simulation data is used (<μ> = 200, √s = 14 TeV) for [VBF 125 → ZZ → 4ν] events, with the new Inner Tracker (ITk) geometry layout and reconstruction performance as described in [1]

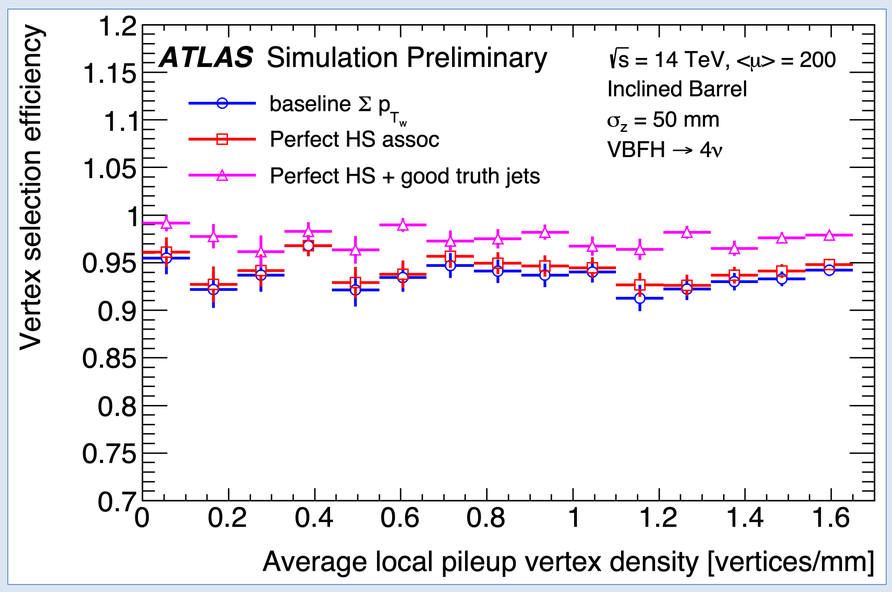
Limitations

sumPTw handles PU vertex merging for VSE performance in VBF invisible events. However *sumPTw* does not achieve perfect VSE. Three primary cases in which *sumPTw* fails:

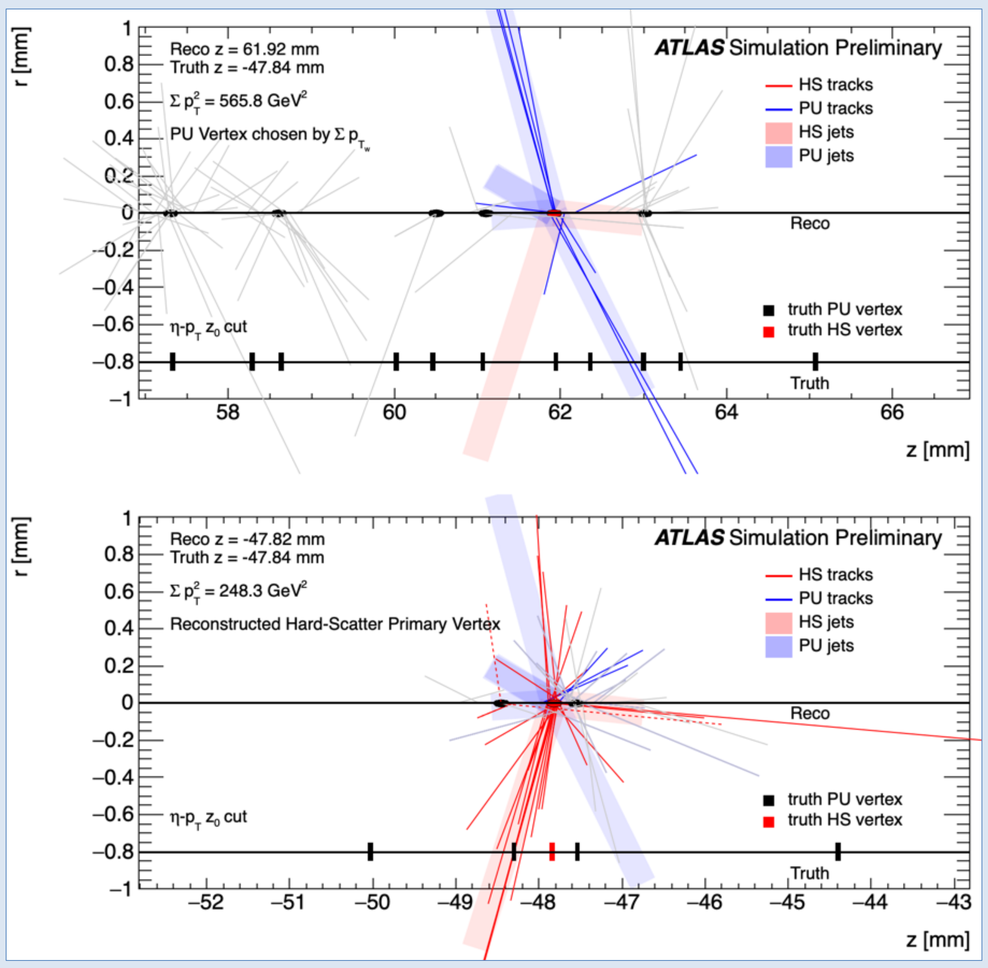
- *Vertex Splitting*. HS tracks mis-associated to nearby PU vertices. HS PV loses out to hard PU vertices. (< 1% effect)
- *Truth jets outside the detector acceptance.* No reconstructed tracks going into these jets. (~ 3% effect)
- *Hard QCD PU interactions*. PU vertices have very hard tracks pointing along very hard jets. (~ 2% effect)

Quantify the effect of first two cases;

- Mitigate *vertex splitting* by reattaching all the HS tracks to PV
- Limiting to events with >2 *truth jets within detector acceptance*.



- Taking these into account, sumPTw performs almost perfectly.
- sumPTw truly runs short with *Hard QCD PU interactions*.
- Can't distinguish topologies, *Hard QCD PU* can win over VBF inv



Conclusions

- **sumPTw** exploits new forward tracking capabilities of ATLAS at HL-LHC [1], integrates calorimeter and tracking information to mitigate impact of PU vertex merging; **insensitive to PU density**.
- **sumPTw improves the average VSE from 86% to 95%.**
- Possible avenue for improvement upon the *sumPTw* proposed here involves developing a *topology exploiting selection algorithm* which can handle *Hard QCD PU interactions* in the event.

[1]: ATLAS PIXEL TDR: [CERN-LHCC-2017-005 ; ATLAS-TDR-025]
[CERN-LHCC-2017-021 ; ATLAS-TDR-030]

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