Triggering long-lived particles in HL-LHC and the challenges in the first stage of the trigger system

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LHCP 2021

Triggering long-lived particles (LLPs) at the first stage of the trigger system is very crucial in LLP searches to ensure that we do not miss them at the very beginning. The future High Luminosity runs of the Large Hadron Collider will have increased number of pile-up events per bunch crossing. There will be major upgrades in hardware, firmware and software sides, like tracking at level-1 (L1). The L1 trigger menu will also be modified to cope with pile-up and maintain the sensitivity to physics processes. In our study we found that the usual level-1 triggers, mostly meant for triggering prompt particles, will not be very efficient for LLP searches in the 140 pile-up (PU) environment of HL-LHC, thus pointing to the need to include dedicated L1 triggers in the menu for LLPs. We consider the decay of the LLP into jets and develop dedicated jet triggers using the track information at L1 to select LLP events. We show in our work that these triggers give promising results in identifying LLP events with moderate trigger rates.

Why do we need dedicated L1 triggers?

- Efficiency of standard jet triggers will be severely affected by high PU at HL-LHC due to uniform amount of energy deposition by PU.
- Standard triggers like single jet and di-jet triggers will not be able to select LLP with large decay length and small mass.
- Quad jet trigger will only select PU jets in high PU scenario.
- Same z-vertex condition imposed for multi-jet triggers to reduce high PU rate in the standard jet triggers will adversely affect LLP decaying to jets.

We need LLP triggers which can capture

- Light LLPs which will not deposit enough energy in the calorimeters after decay.
- LLP with large decay length such that same vertex condition is not satisfied by the jets coming from LLP decay.

In this work, we have focused on triggering moderately massive LLPs with moderate decay length.

Signal

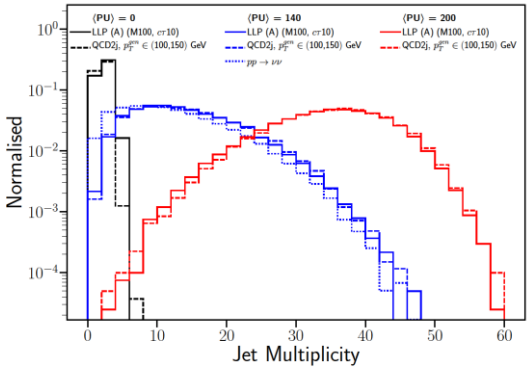
Pair produced LLPs decaying to Jets ($pp \to XX,\ X \to jj$) as the signal with $M_X \in \{50,100,150\}$ GeV and $c\tau \in \{10,100\}$ cm.

Background

QCD dijets ($pp \to jj$) as the background with p_T^{gen} bins - {50,100}, {100,150}, {150,200} and {> 200} GeV.

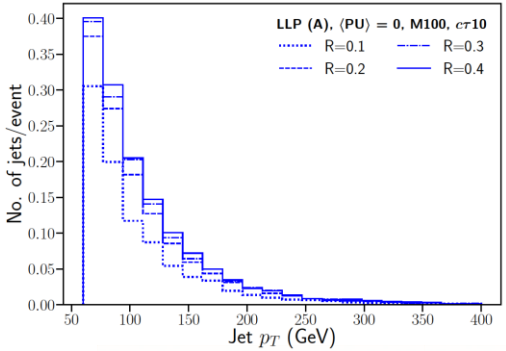
Effect of high PU

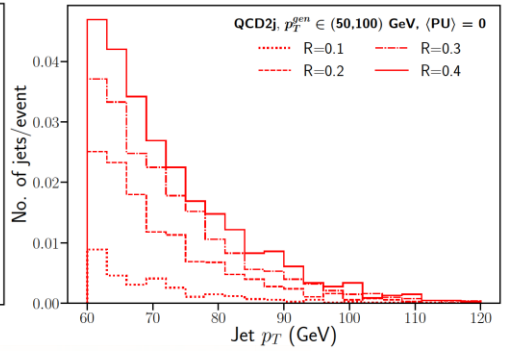
PU jets dominate both QCD and LLP.

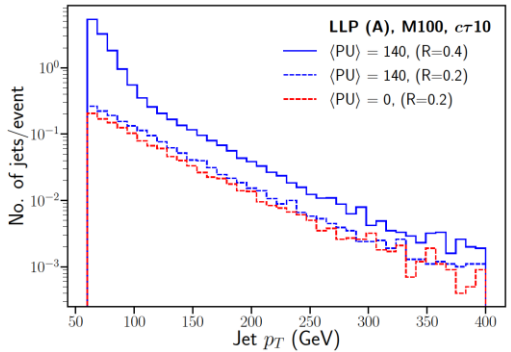


Narrow Jets

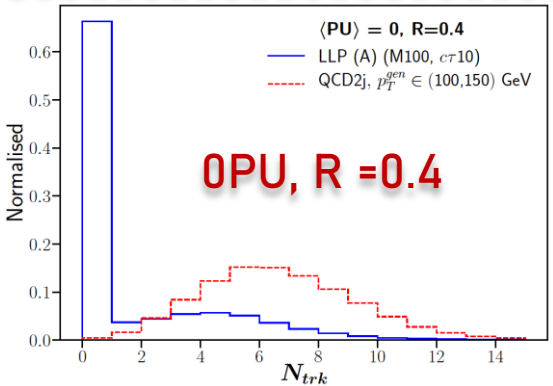
LLP decay products deposit most of the energy in small physical region. Reducing the jet cone size and using narrow jets can decrease the PU contribution without adversely affecting signal efficiency.

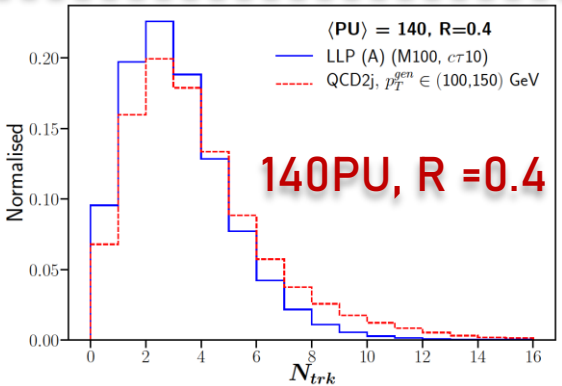




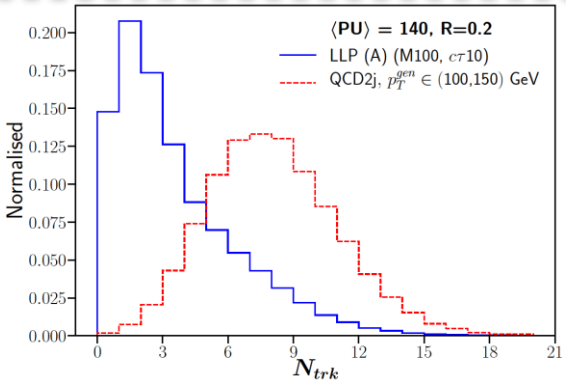


L1 Tracking



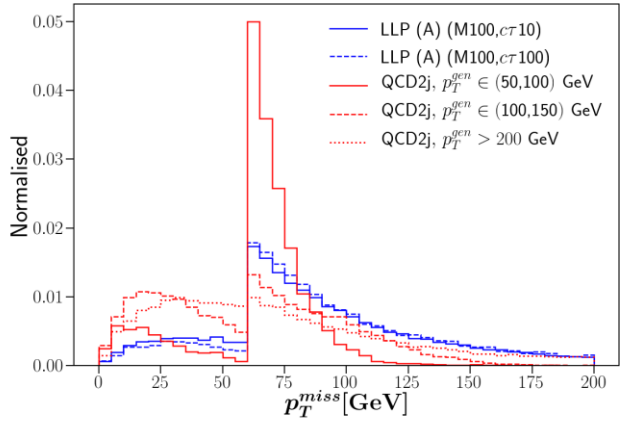


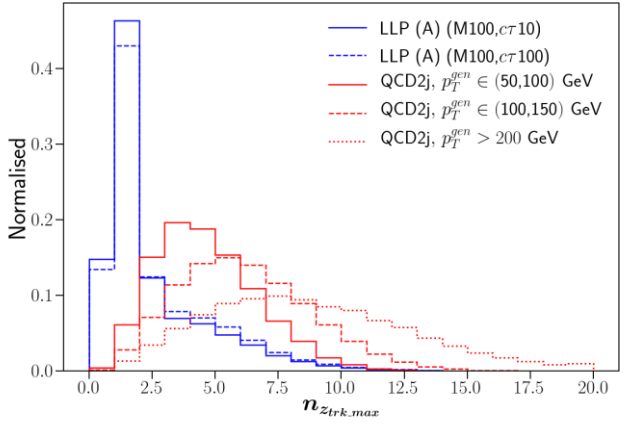
R=0.2 →

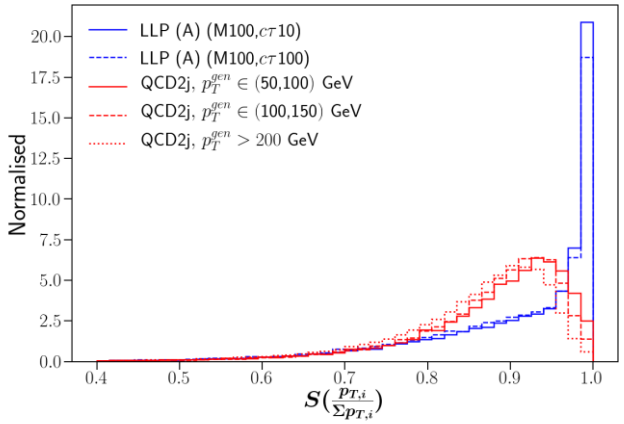


L1 tracking variables

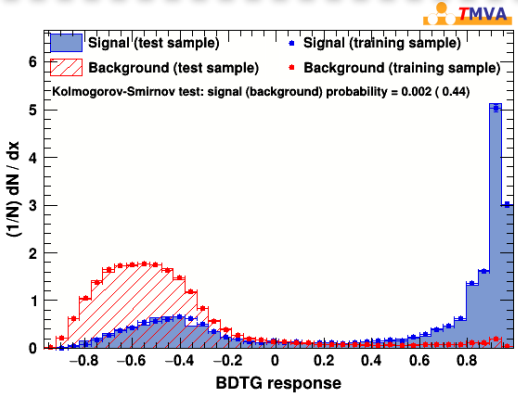
$\sum p_T$, z_{j_vtx} , Δz_{j_vtx} , $p_{T(vtx)}^{miss}$, $n_{z_{trk\_max}}$, Δz_{trk_vtx} , $\sum p_T^{z_{trk\_max}}$, $\sum p_T^{z_a \neq z_{trk\_max}}$, $\frac{\sum p_T^{z_{trk\_max}}}{\sum p_T}$, $S(z_i)$, $S(p_{T_i})$, All Variables within R = 0.2 , $\frac{N_{trk}}{N_{trk}^{(0.2)}}$, $\frac{\sum p_T}{\sum p_T^{(0.2)}}$







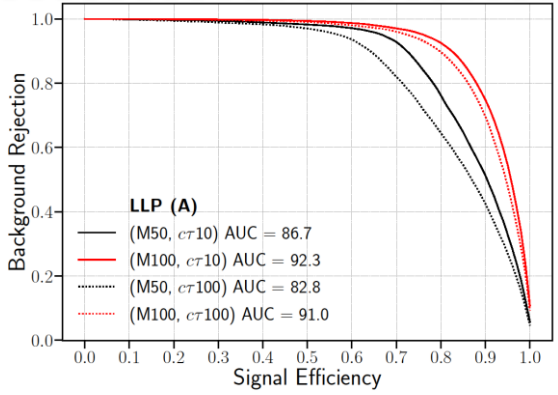
Performance



BDT classifier trained using 32 tracking variables

BDT Response for LLP (50 GeV, 10 cm)

Classification performance

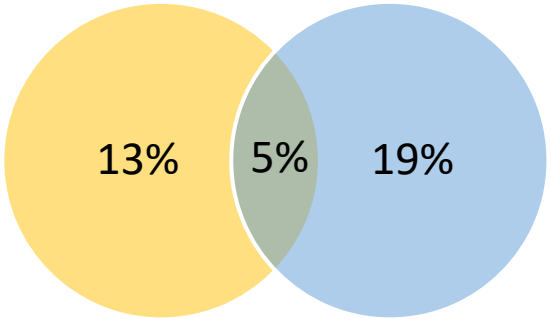


Triggers based on the BDT training using tracking variables

- $\mathbf{T_1}$: At least one R=0.2 jet with p_T > 60 GeV;
- $\mathbf{T_2^a}$: T_1 + that jet passes the BDT threshold corresponding to a background rejection of 98% (a=0), 90% (a=1) and 70% (a=2);
- $\mathbf{T_3^a}$: T_2^a + no other jet from the same z-vertex (i.e., Δz with all other jets is greater than 1 cm) ;
- $\mathbf{T_{4b}^a}$: T_3^a + At least one jet with $p_T \in$(60,100) (b=1)/ $p_T \in$(60,120) (b=2);

Results

$\mathbf{T_3}$ ⟶ Background Rejection ↓	Rate (KHz) QCD2j $p_T^{gen} \in \{50, 100\}$GeV	Efficiency (%) LLP (M50, $c\tau 10$)	Efficiency (%) LLP (M100, $c\tau 10$)
98%	1046 ⟶ 14	13	60
70%	1046 ⟶ 190	19	73



For 70% background rejection, we will get signal efficiency of 13% for LLP of mass 50 GeV and decay length 10 cm from standard jet triggers with an overlap of 5% taking total efficiency to 27%.

Conclusion

- Dedicated triggers are needed to capture rare LLP events at L1.
- Standard triggers targeting prompt particles will be inefficient for some LLP searches in high PU conditions.
- High PU being an issue at L1 can be managed by reducing the cone size of jets and using narrow jets in the trigger.
- BDT based triggers constructed using tracking variables keeping in mind tracklessness of LLP at L1 improve signal efficiency at moderate rates.
- Triggers based on timing capabilities of MTD were also studied.
- Classifier trained using timing variables (and applied on jets with track based BDT cut) can further reduce the background rates.

For further details please have a look at
B. Bhattacherjee, S. Mukherjee, R. Sengupta, and P. Solanki, JHEP 08 (2020) 141,
e-Print: 2003.03943 [hep-ph]

Thank You.