Searching for new particles at the HL-LHC

Master 2 internship

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Motivations - event generation

- Become familiar with the theory behind long-lived particles (LLPs) as extension to the Standard Model
- Use event generation to simulate collisions and predict experimental results
- Search for exotic signals like LLPs, that could hide new physics
- Test future detector designs using planned experimental upgrades

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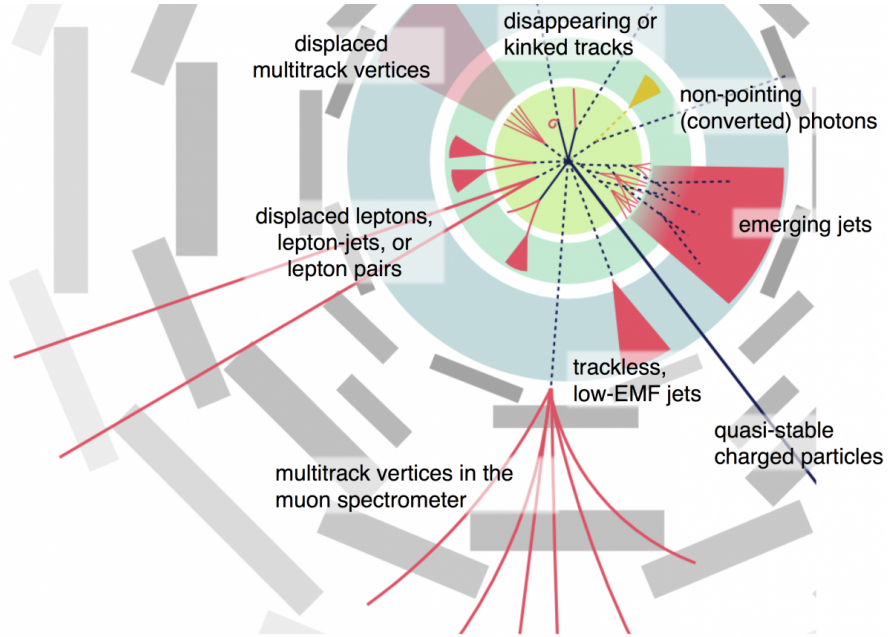
Motivations - LLPs study

- Several types of tracks available to study LLPs :



Schematic of atypical LLPs signatures in LHC detectors. [2]

- LLPs vs Standard Model particles :

  $\Rightarrow$ Microscopic decay lengths for SM particles

  $\Rightarrow$ Macroscopic ones for LLPs

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The Hidden Abelian Higgs Model

The HAHM

- Extension of the Standard Model featuring a hidden sector
- Introduces a new scalar hidden Higgs that mixes with the SM Higgs, which can decay into LLPs

Why Long-Lived Particles ?

- Particle's lifetime linked to its decay width
- Two main mechanisms extend lifetimes:

  $\Rightarrow$ Weak Coupling

  $\Rightarrow$ Restricted Phase Space

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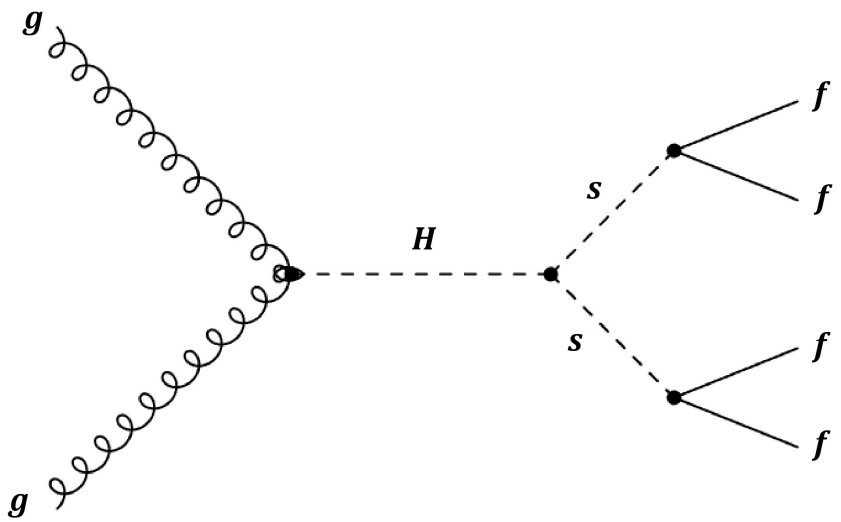
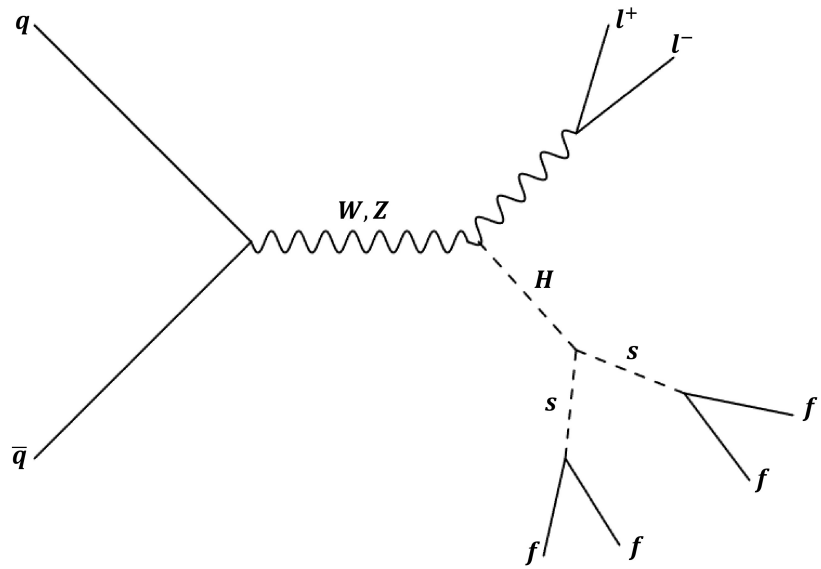
Production modes studied

- Two LLP production modes studied :



(a) Feynman diagram for ggH.

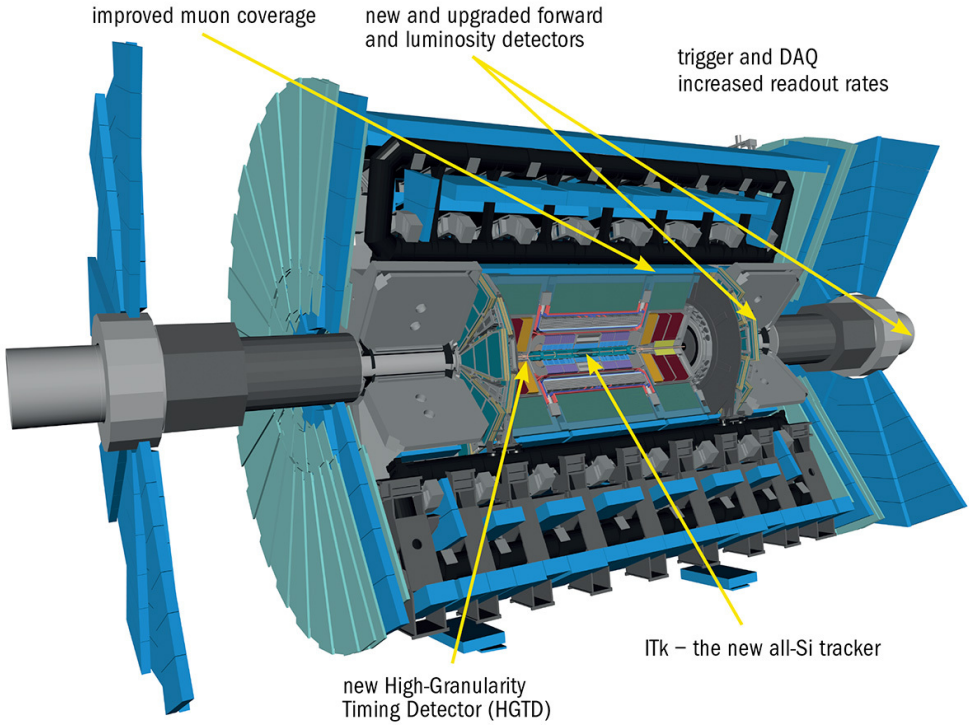


(b) Feynman diagram for VH.

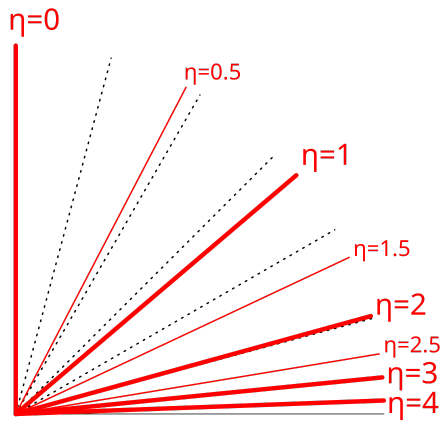
Feynman diagrams for LLP production via ggH and VH processes.

Technical details

- The current detector covers the central region up to $|\eta| < 2.5$
- HGTD and ITk will extend the sensitivity to the forward region, so up to $|\eta| = 4.0$



Schematic of the major upgrades to the ATLAS detector for the HL-LHC phase. [1]



Pseudorapidity values shown on a polar plot. [3]

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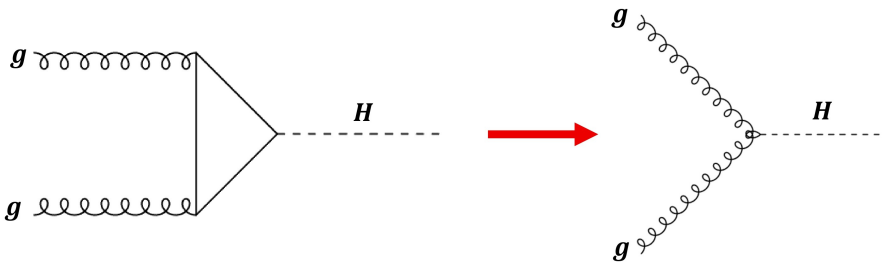
Objectives

- Main question : *What fraction of LLPs will be accessible by the upgraded ATLAS detector?*

- Approach :
  1. Implement a simplified BSM model (HAHM)
  2. Generate events at parton-level with MG5
  3. Simulate the final states with PYTHIA
  4. Use RIVET to process the data

- Apply some simplifications :



Example of Feynman diagram simplification for the ggH mode.

Script used for event generation

```
import model sm
import model HAHM_variableMW_v3_UFO
define f = u c d s u~ c~ d~ s~ b b~ e+ e- mu+ mu- ta+ ta- t t~
define p = g u c d s u~ c~ d~ s~
define j = u c d s b u~ c~ d~ s~ b~
define vl = ve vm vt
define vl~ = ve~ vm~ vt~
define j = g u c d s u~ c~ d~ s~
define l+ = e+ mu+ ta+
define l- = e- mu- ta-
generate p p > w+ h, (w+ > l+ vl), (h > h2 h2, h2 > f f, h2 > f f)
add process p p > w- h, (w- > l- vl~), (h > h2 h2, h2 > f f, h2 > f f)
output script_ppWpmH_LLPs_lepton_55
launch script_ppWpmH_LLPs_lepton_55
shower=Pythia8
0
set nevents = 50000
set mhsinput 30
set mhinput 125
set epsilon 1e-10
set kap 1e-4
set time_of_flight 0
set event_norm = sum
set ebeam1 6800
set ebeam2 6800
```

Model import

Particle definitions

Defining the Production Processes

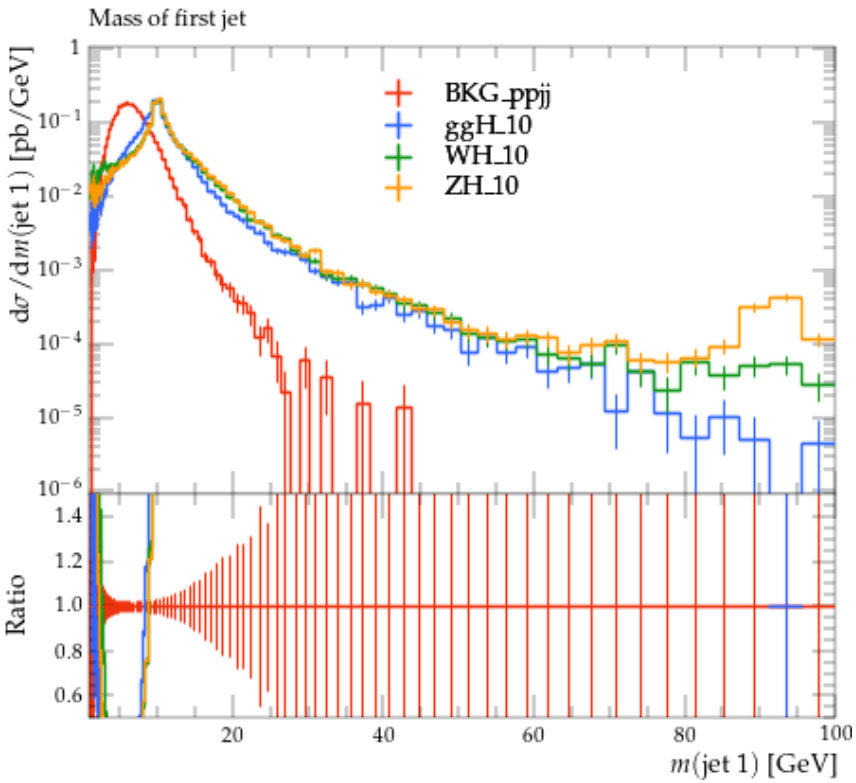
Start the parton showering and hadronization process

Simulation Parameters

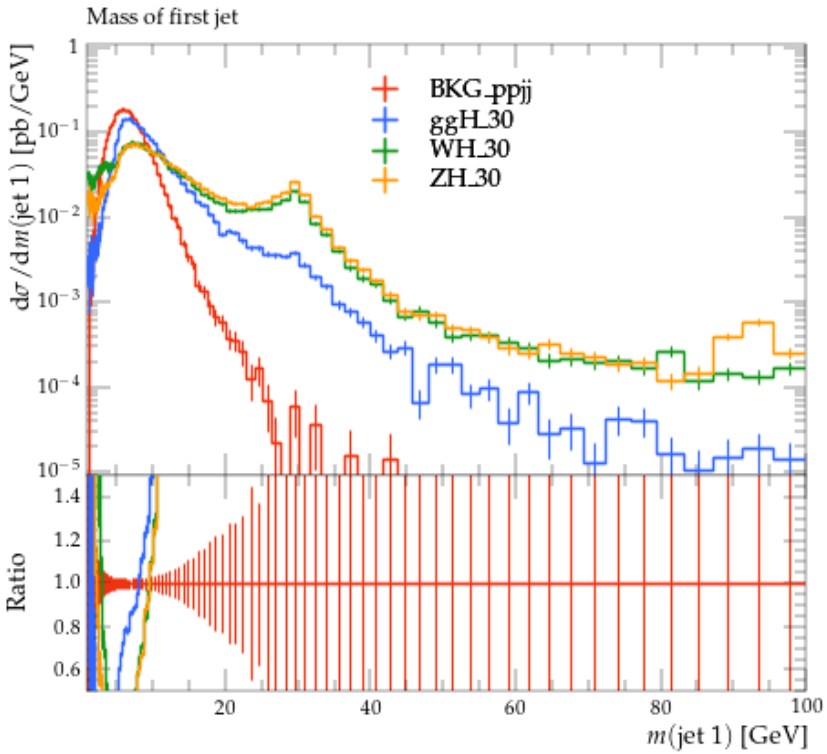
Extract from a MG5 script used to generate events in the VH channel.

Mass of the leading jet

- Peak around the expected LLP masses
- For VH, the high-mass distribution tail is caused by the presence of the bosons



(a) $m_{\text{LLP}} = 10$ GeV.

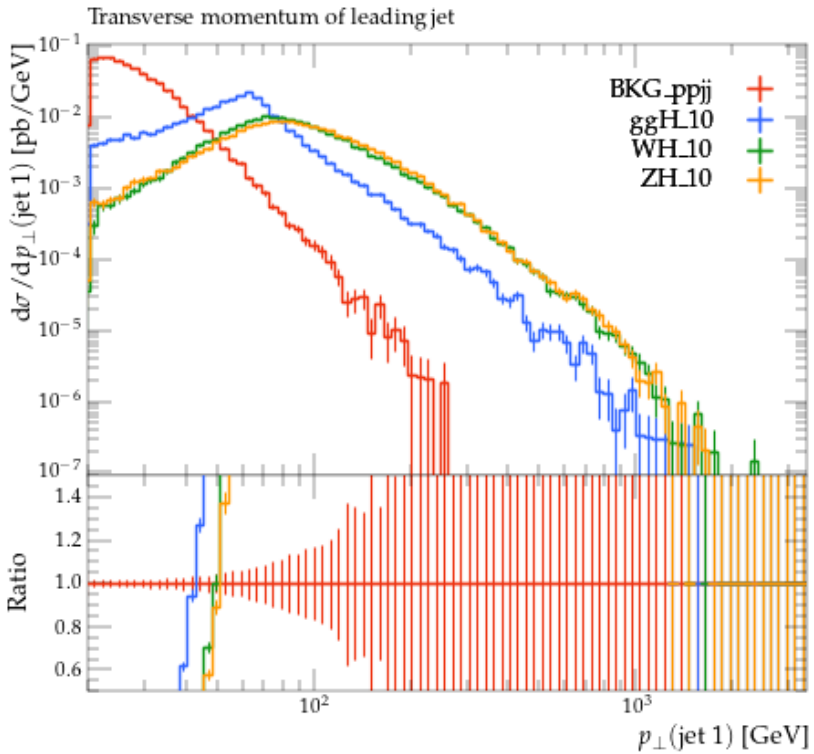


(b) $m_{\text{LLP}} = 30$ GeV.

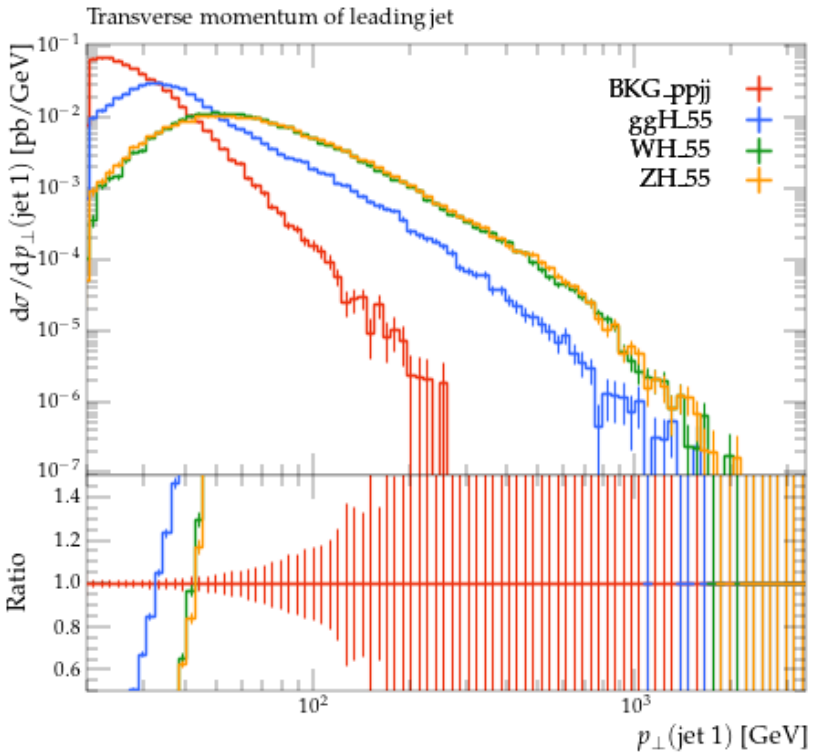
First jet mass distributions for LLP masses 10 and 30 GeV.

Transverse momentum of the leading jet

- Light LLPs typically carry high-energy



(a) $m_{\text{LLP}} = 10$ GeV.

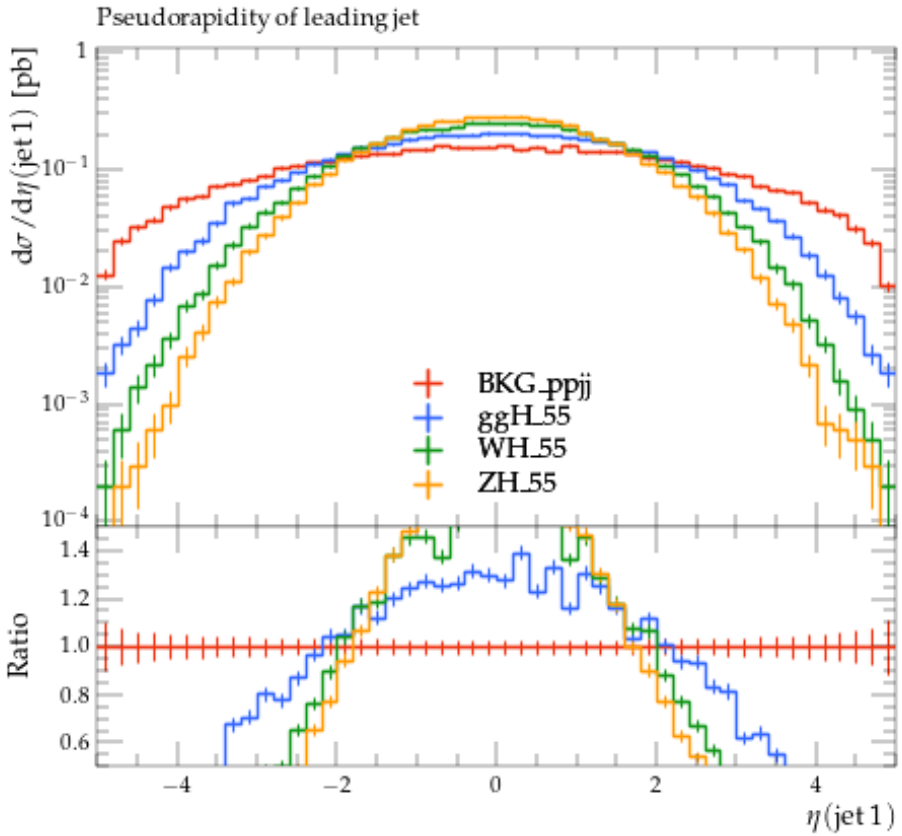


(b) $m_{\text{LLP}} = 55$ GeV.

Leading jet transverse momentum distributions for LLP masses 10 and 55 GeV.

Pseudorapidity of the leading jet

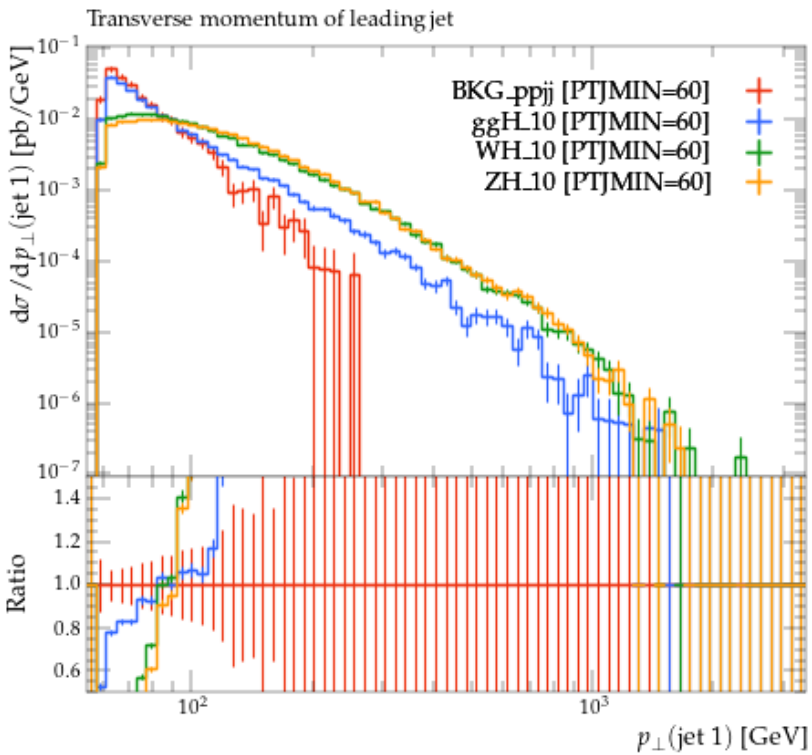
- Maximum in the central region of the detector
- Upgraded ATLAS will improve the statistics in the forward region



Pseudorapidity distribution of the leading jet for $m_{\mathrm{LLP}} = 55$ GeV.

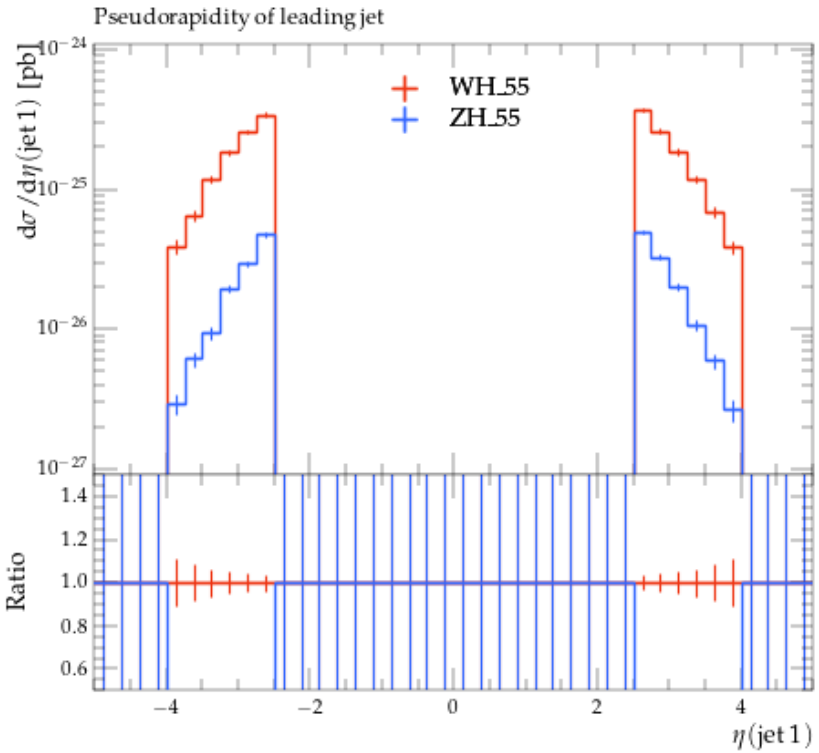
Application of selection cuts

- $p_T < 60$ GeV contains mostly background noise, only 7% remaining



Leading jet p_T distribution for $m_{\text{LLP}} = 10$ GeV after the cut.

- The new region accessible to ATLAS tracking systems adds 16% more data



η distribution of the leading jet for $m_{\text{LLP}} = 55$ GeV after the cut.

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Conclusion

- Use simulated data to study a new set of particles
- Apply basic cuts to reduce background noise
- No precise answer yet for estimating the visiblity of LLPs in the upgraded ATLAS detector

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Future works

- Include other Higgs production modes VBF and ttH
- Add a parameter to scripts to control the decay distance
- Use a more complex analysis, study more observables

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Sources

[1] ATLAS Collaboration. "ATLAS Feature: A new ATLAS for the high-luminosity era". General Photo. 2023. URL: https://cds.cern.ch/record/2846341.

[2] Heather Russell. *An experimental introduction to longlived particle searches at the LHC*. Diapositives. 2017. URL: https://indico.cern.ch/event/607314/contributions/2542309/attachments/1447873/2231444/20170424_LLPs.pdf.

[3] Wikimedia Commons users. *Pseudorapidity plot*. URL: https://en.wikipedia.org/wiki/Pseudorapidity#/media/File:Pseudorapidity_plot.svg.

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