Data-driven approaches to pile-up treatment at the LHC

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Introduction

- Upcoming high luminosity runs at the LHC face the challenge of very large pile-up conditions

- Current techniques allow for inclusive measurements and can correct transverse momenta by utilizing precise vertex and track reconstruction

- This works well within tracking detectors' acceptances. Outside these acceptances one has to rely more strongly on Monte Carlos.

- The purpose of our work is to explore techniques which can be used outside tracker acceptances and do not rely on Monte Carlos.
Pile-up effects: Drell-Yan + jet case study

- With pile-up of e.g. 20 or 50 additional pp collisions

- Large effect on Drell-Yan + jets
- $p_T$ spectrum shifts to lower values (inclusive spectrum)
  - jet $p_T > 30$ GeV requirement no longer sufficient
  - signal process drowns in pile-up

- Two main effects appear:
  - large bias in jet $p_T$ due to added pile-up particles in jet cone
  - probability that high $p_T$ jets come from independent pile-up event
Correcting the jet $p_T$ pedestal

- Can be done with several existing methods for central jets
  PUPPI: Bertolini D. et al. JHEP 1410 (2014) 59

- Apply SoftKiller method: (also works more forward)

**Principle:**
- remove particles below a $p_T$ cutoff
- minimal value that ensures that the event-wide estimate of $p_T$ flow density ($\rho$) = 0
- re-cluster jets (Anti-$k_T$, $R = 0.5$)

Can be used with calorimeter information only

\[
\rho = \text{median}_{i \in \text{patches}} \left\{ \frac{p_{ti}}{A_i} \right\}
\]

- These methods correct transverse momenta of individual objects, but not any misidentifications
Apply SoftKiller to $p_T$ spectra of boson + jet topologies

SoftKiller correction on boson + jet $p_T$ spectra:

- At high $p_T$ values no need for corrections
- At low $p_T$ still significant contribution from misidentified pile-up jets

$\sqrt{s} = 13$ TeV

$30 \text{ GeV} < p_T^{\ell} < 4.5$

$115 < m^{\text{boson}} < 135 \text{ GeV}, |\eta^{\text{boson}}| < 2$

$\text{PU} = 0, 50$

$\text{PU} = 50 \text{ SK}$

$\text{PU}_{50}/\text{PU}_{0}$

$0 \leq \text{PU}_{50}/\text{PU}_{0} \leq 30$

Need to treat this remaining contribution
Data-driven pile-up treatment

➢ Use event mixing technique

➢ Minimum bias sample of real data in high pile-up

➢ Mix this independent sample with signal events without pile-up

➢ Extract unbiased signal without the use of MC
Drell-Yan $p_T$ spectrum with pile-up construction

- Extract signal without relying on Monte Carlos

- From mixed sample can extract true signal perfectly

- Advantages:
  - use data recorded in high pile-up
  - no Monte Carlo needed
Control checks with $p_T$ resolution and $\Delta R = \sqrt{(\Delta \phi^2 + \Delta \eta^2)}$

> true signal reproduced
Conclusions

➢ Many interesting measurements in LHC high-luminosity runs are hampered by high pile up

➢ Especially topologies that exploit the correlation between final state products
  ➢ e.g. Drell-Yan or Higgs + jet production

➢ Two pile-up effects are present in such measurements:
  1. large bias in jet $p_T$ due to added pile-up particles in jet cone
     ➢ several methods exist to correct for this (e.g. CHS, PUPPI, SoftKiller)
  2. mis-tagging of high $p_T$ jets from independent pile-up events
     ➢ not properly treated yet

➢ Proposed new method of event mixing to treat pile-up:
  ➢ use data recorded at high pile-up
  ➢ no Monte Carlo dependence

➢ Good prospects for precision SM studies & BSM searches in high pile-up
Study QCD with Drell-Yan and Higgs production

> Ideal processes to study quark and gluon structure functions, parton showers, underlying event, ...

> Especially boson + jet topologies: map correlations between the two objects

> $\Delta \phi$ decorrelations: study effect of multiple parton interactions (MPI) and initial an final state radiation (ISR/FSR))

> Go beyond central tracker acceptances (e.g. jets in $|\eta| < 4.5$): increase sensitivity to quark vs gluon radiation effects

[arXiv:1407.2815]

Delta phi distribution

Jets: Anti-$k_T$ $R=0.5$, $p_T > 30$ GeV, $|\eta| < 4.5$
$115 < m_{boson} < 135$ GeV, $|\eta_{boson}| < 2$
$\sqrt{s} = 13$ TeV

$\nu_T^{m_0} > 30$ GeV, $|\eta| < 4.5$
$115 < m_{boson} < 135$ GeV, $|\eta_{boson}| < 2$

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Higgs

Drell-Yan
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[arXiv:1407.2815]

![Diagram of boson transverse momentum](image)

Boson transverse momentum: probe soft resummation behaviour

> Go beyond (e.g. jets in |\eta| < 4.5) central tracker acceptances: increase sensitivity to quark vs gluon radiation effects