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

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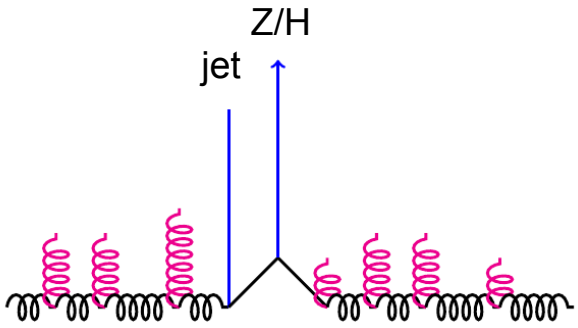
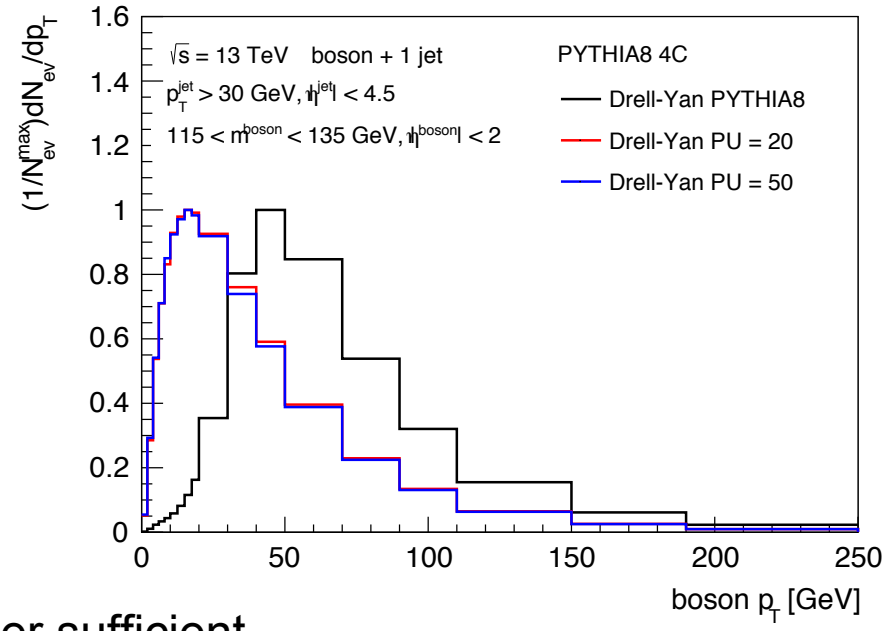
Introduction

- 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)

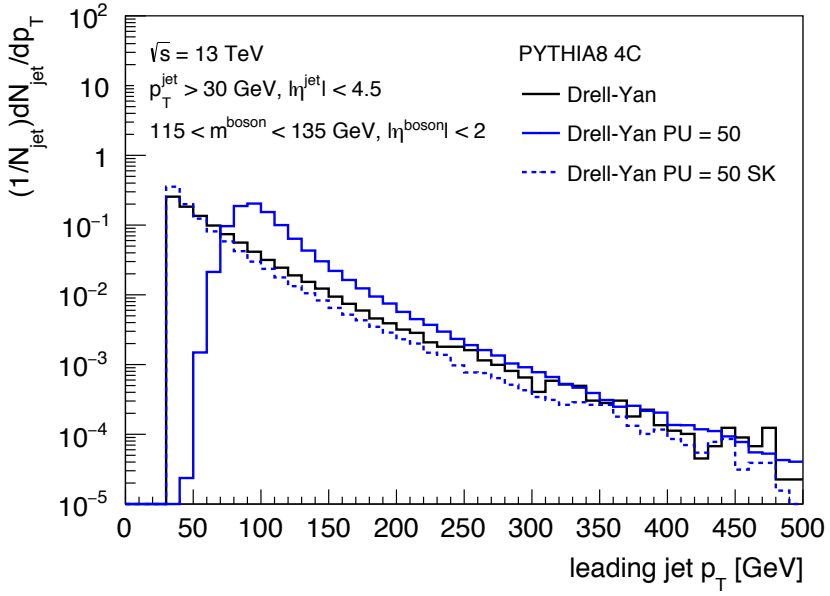
  ➔ jet p_T > 30 GeV requirement no longer sufficient
  ➔ signal process drowns in pile-up

- 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
  e.g. Charged Hadron Subtraction (CHS): H. Kirschenmann et al. CERN-CMS-CR-2013-325.
  PUPPI: Bertolini D. et al. JHEP 1410 (2014) 59
  SoftKiller: Cacciari, M. et al. Eur.Phys.J. C75 (2015) 2

- 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 (ρ) = 0
- re-cluster jets (Anti-k_T, R = 0.5)

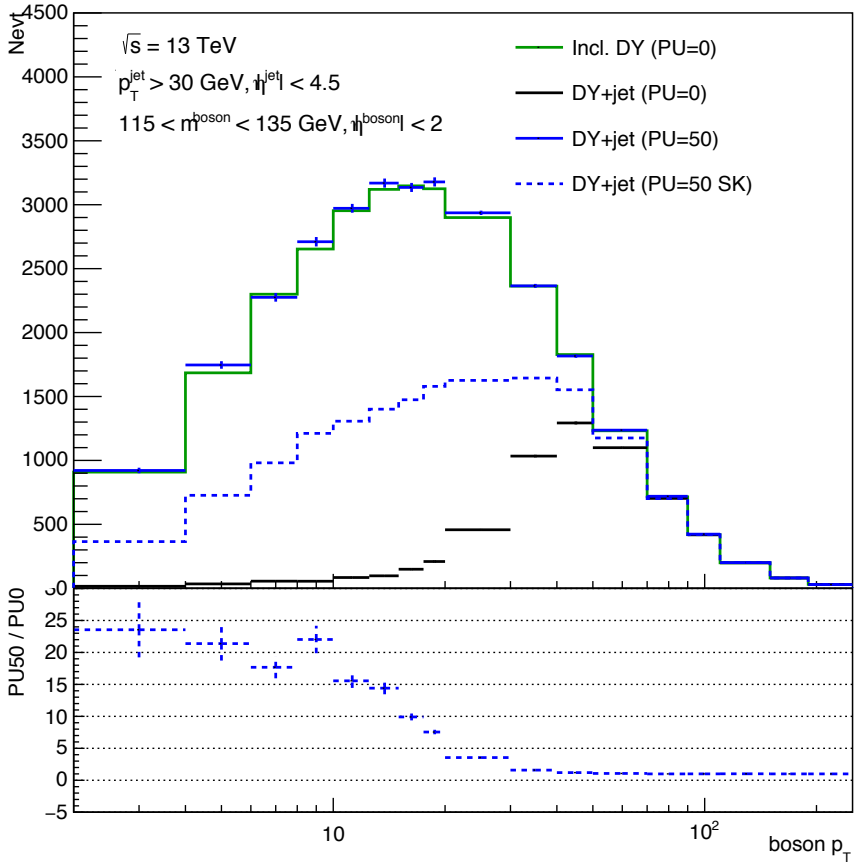
Can be used with calorimeter information only

$$\rho = \underset{i \in \text{patches}}{\text{median}} \left\{ \frac{p_{ti}}{A_i} \right\}$$

- 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

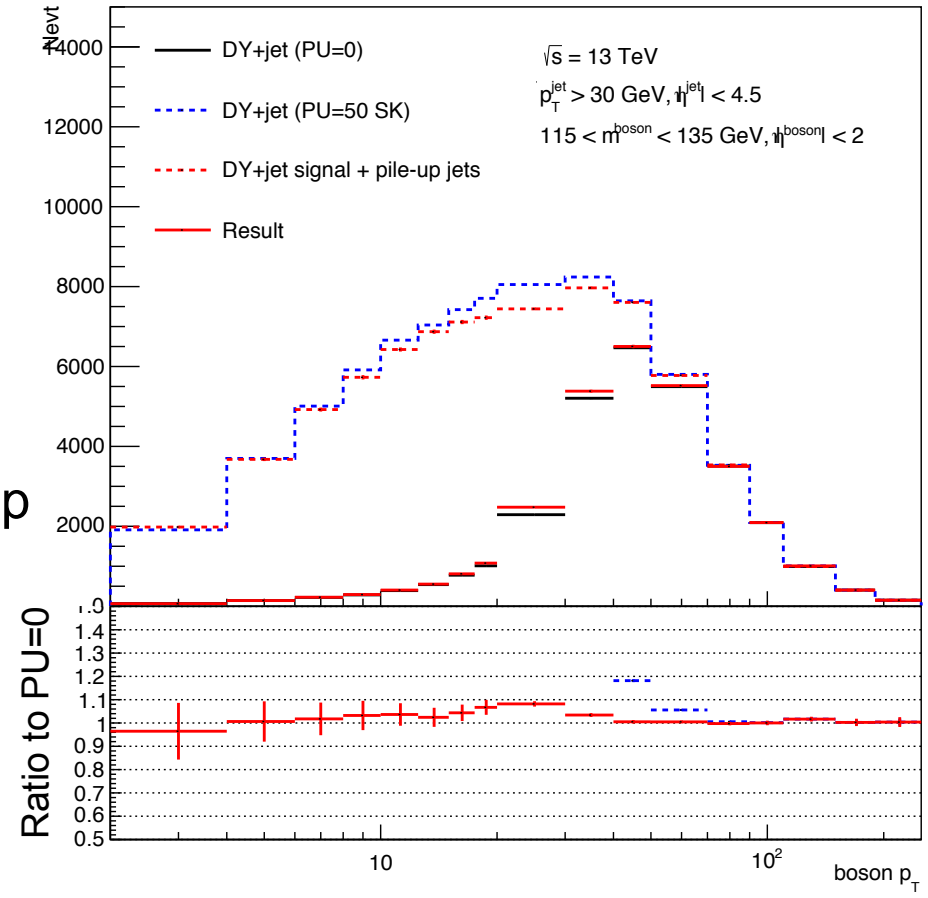
➔ need to treat this remaining contribution

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

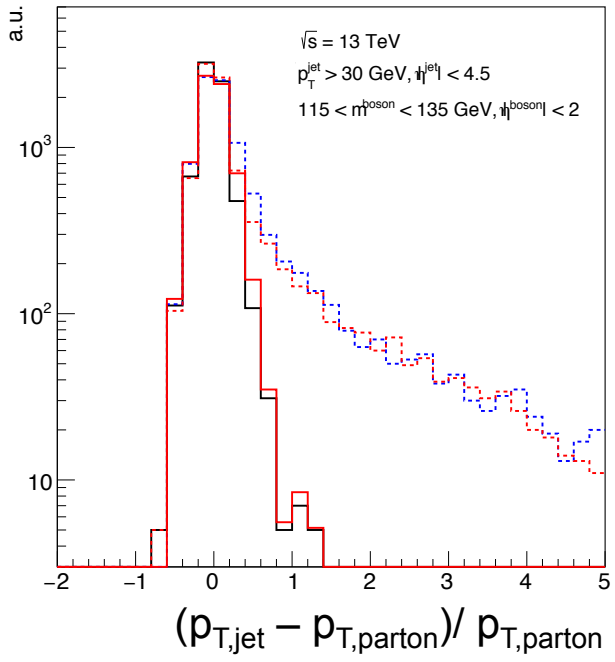
Drell-Yan p_T spectrum with pile-up construction

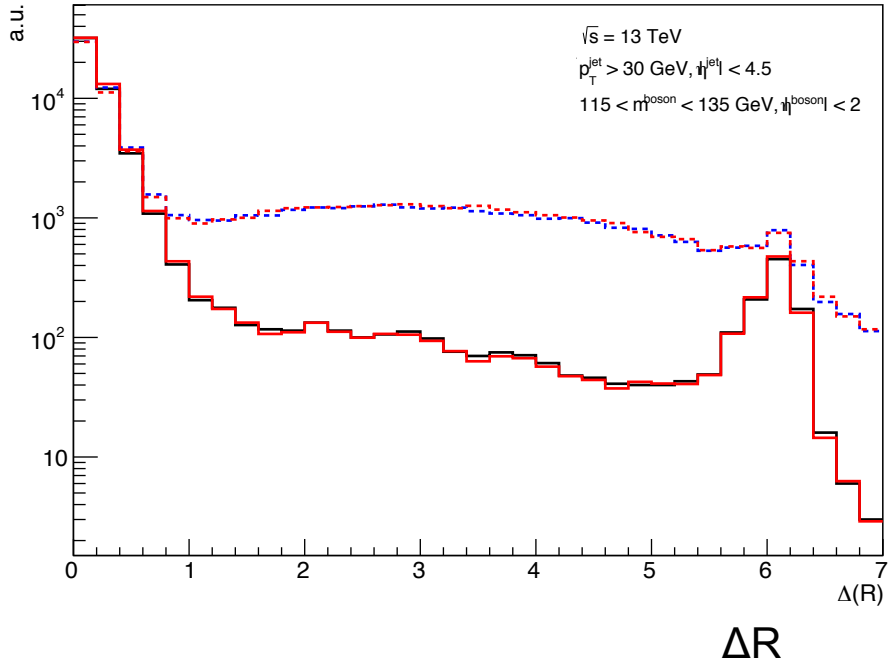
- Extract signal without relying on Monte Carlos
- From mixed sample can extract true signal perfectly
- Advantages:
  - ➔ use data recorded in high pile-up
  - ➔ no Monte Carlo needed



Improvement in jet resolution

- 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

Backup

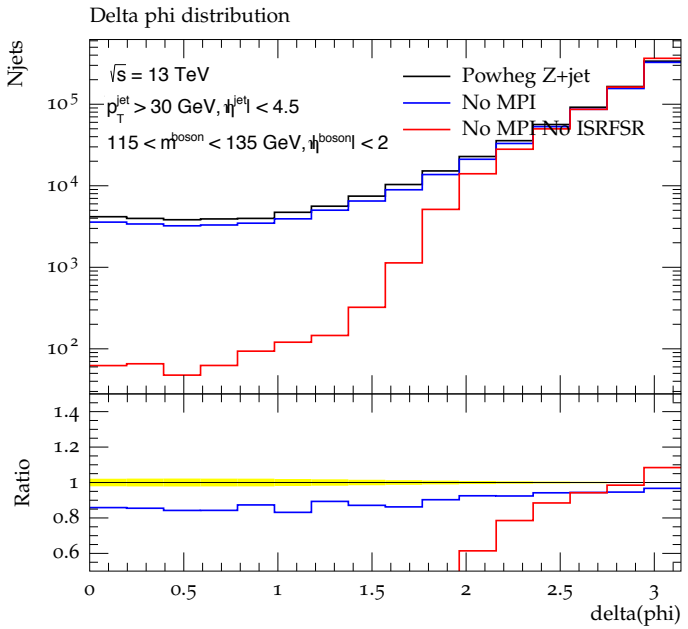
Study QCD with Drell-Yan and Higgs production

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

[Phys. Rev. D 88, 097501 (2013)]
[arXiv:1407.2815]

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

- Δϕ 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 |η| < 4.5):
  increase sensitivity to quark vs gluon radiation effects

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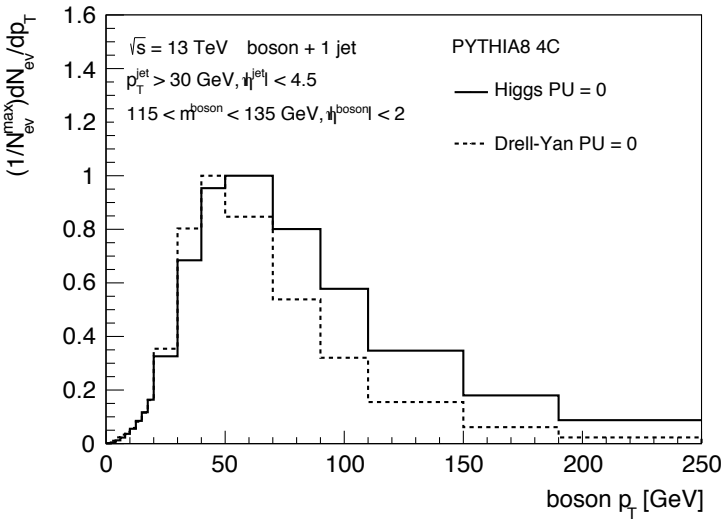

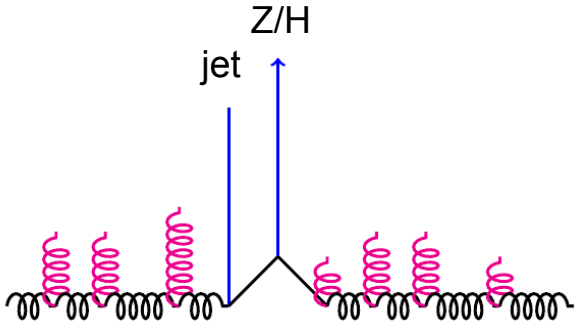

Boson transverse momentum:
probe soft resummation behaviour

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