Treating jet correlations in high pile-up at hadron colliders

7th International Workshop on

Multiple Partonic Interactions

at the LHC

23 - 27 November 2015

Miramare, Trieste, Italy

Minimum Bias and Underlying Event WG
23/11/15

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Introduction

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

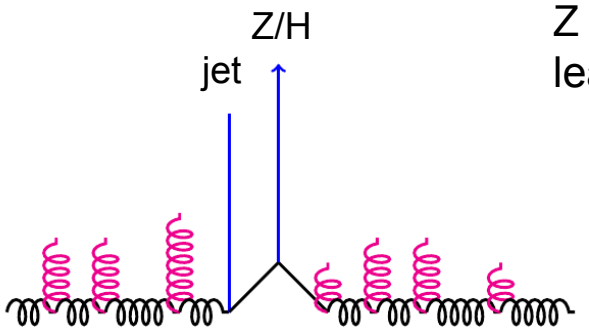
- Current techniques allow for inclusive measurements and can correct transverse momenta by utilizing precise vertex and track reconstruction

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

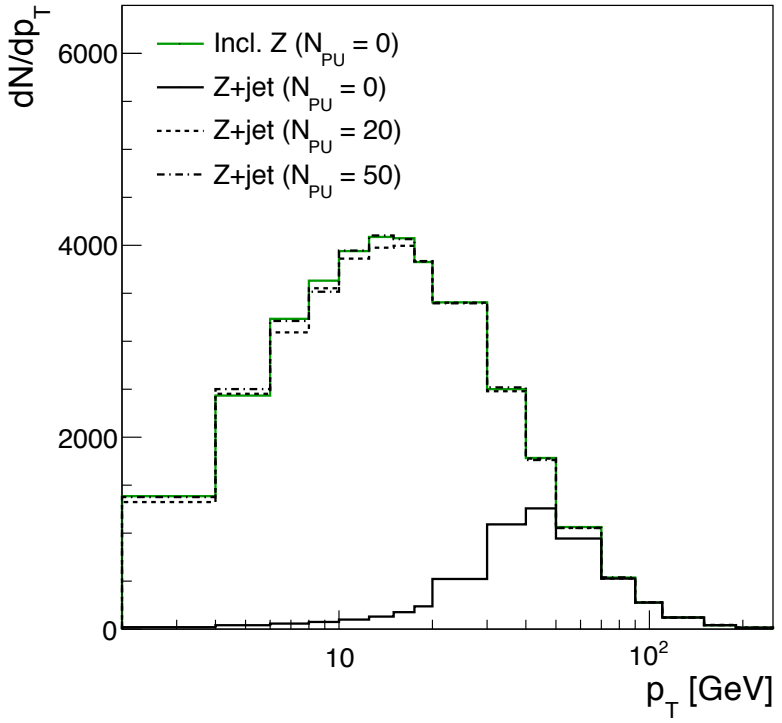
- The purpose of our work is to explore techniques that:
  - can be used outside tracker acceptances
  - do not rely on Monte Carlos
  - restore correlations between final state objects

Pile-up effects: Z + jet case study

- Additional pp collisions (pile-up): large effect on Z + jet correlations



Z boson: 60 < M < 120 GeV
leading jet: p_T > 30 GeV; |η| < 4.5

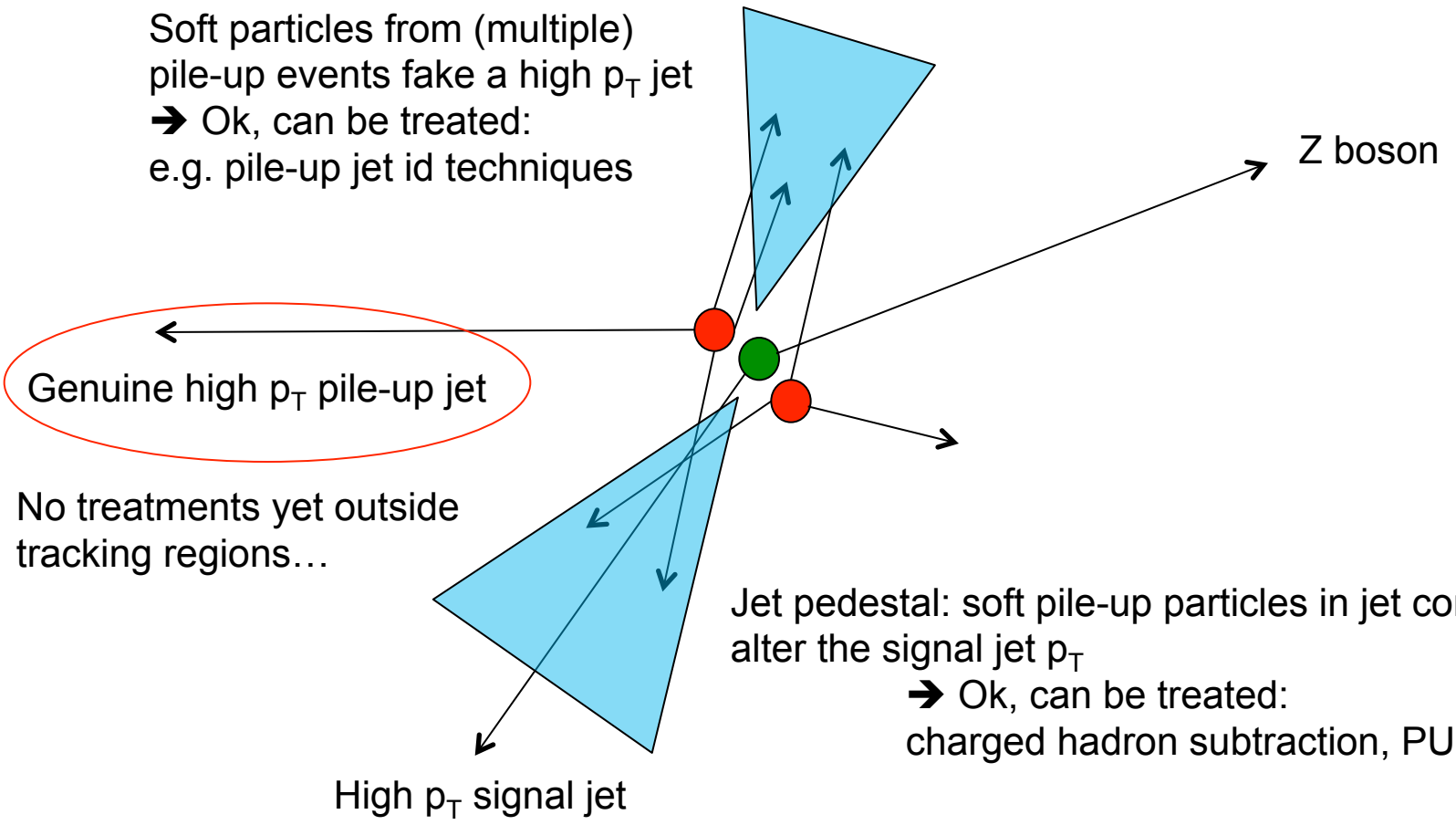


- p_T spectrum shifts to lower values (inclusive spectrum)

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

Pile-up effects: different contributions

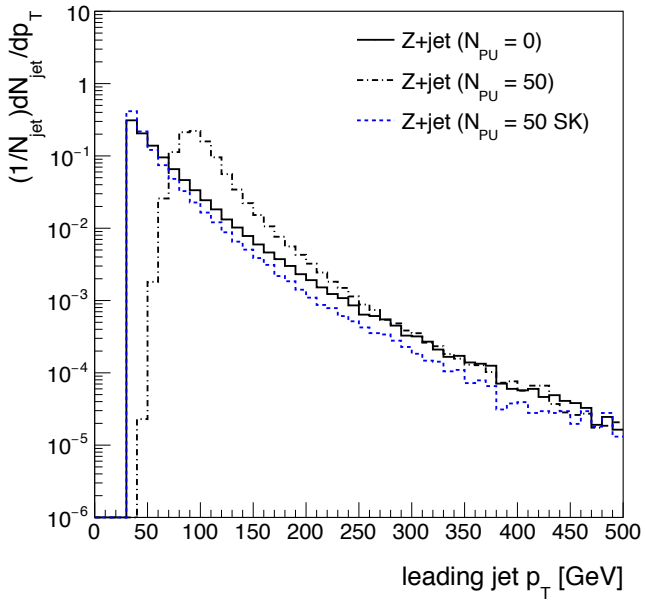
- Z + jet correlations are affected by:



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)

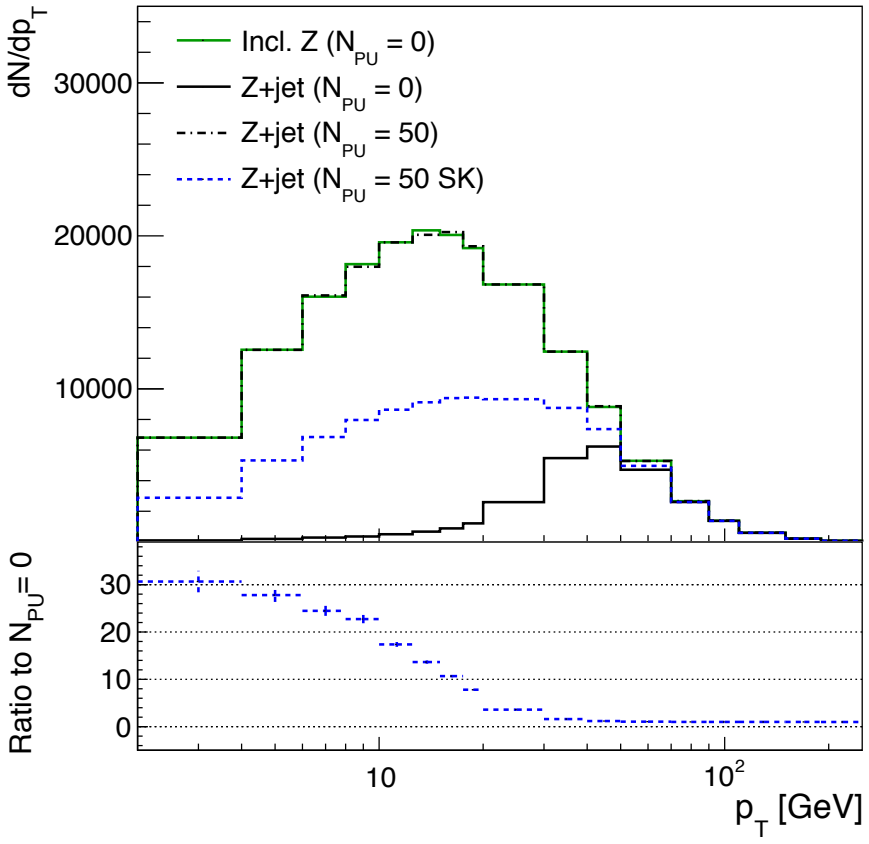
Can be used with calorimeter information only

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

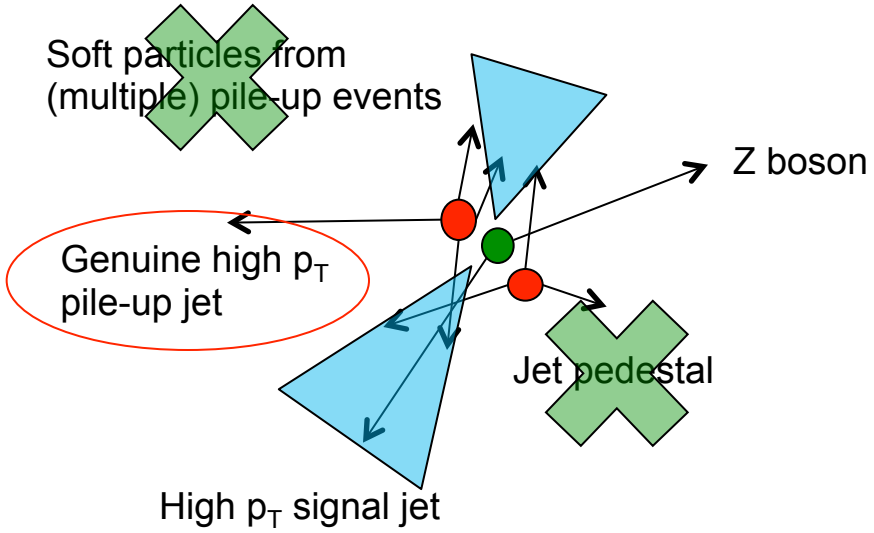
- Correct transverse momenta of individual objects, but not any misidentifications

Apply SoftKiller to Z boson p_T spectrum

- SoftKiller correction on Z boson + jet p_T spectra:



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

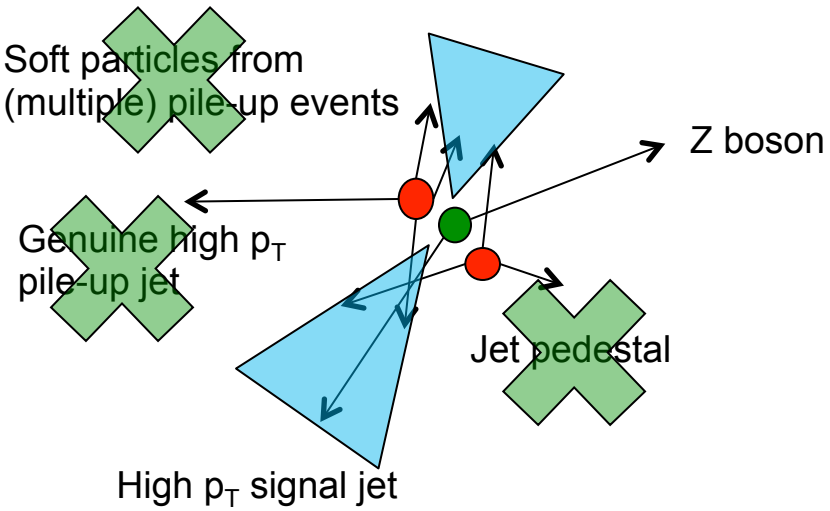


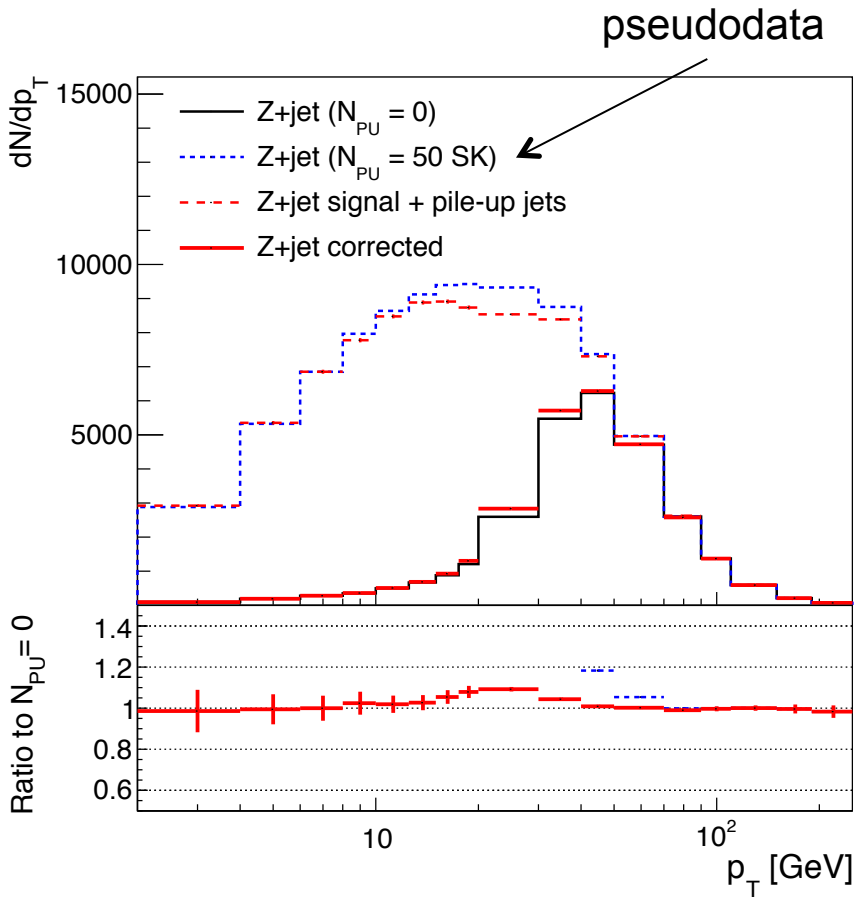
Data-driven pile-up treatment

- Obtain signal distribution with a jet mixing technique
- Use minimum bias sample of real data in high pile-up
- Mix this independent sample with signal events without pile-up
- Extract unbiased signal independent of MC

Z boson + jet p_T spectrum with jet mixing applied

- Extract signal without relying on Monte Carlos
- From mixed sample can extract true signal succesfully
- Advantages:
  - ➔ works in high N_{PU} regime
  - ➔ no data at low pile-up needed
  - ➔ no Monte Carlo needed





$N_{PU} = 50$

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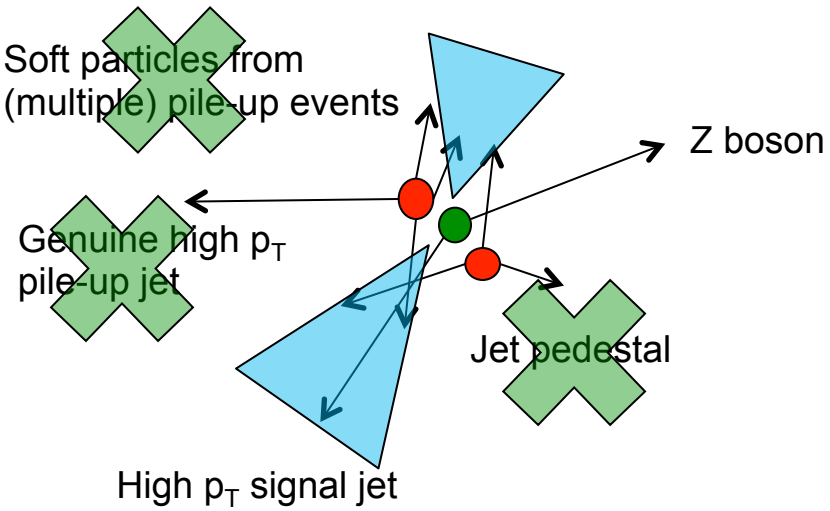
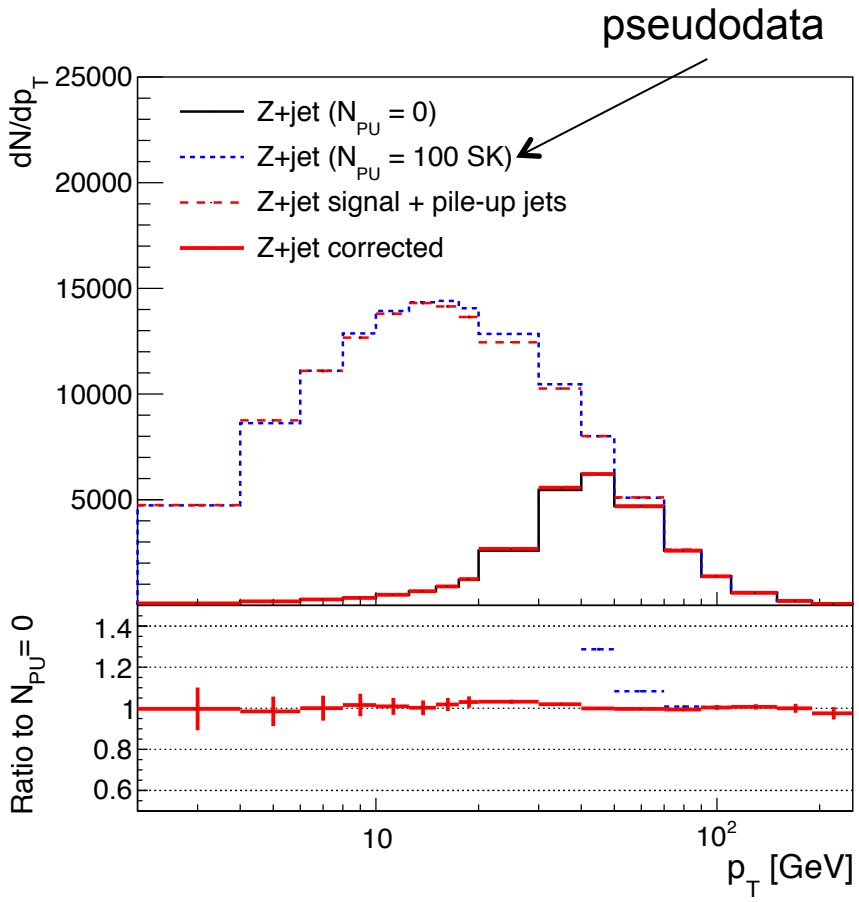
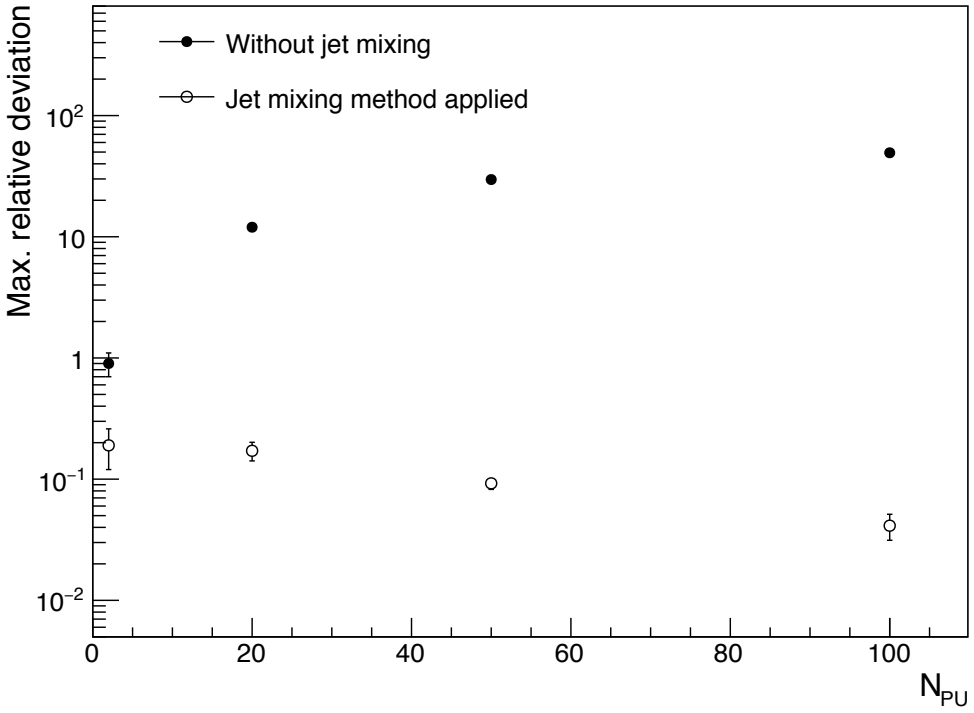




N_{PU} = 100

Accuracy of corrections in low and high pile-up

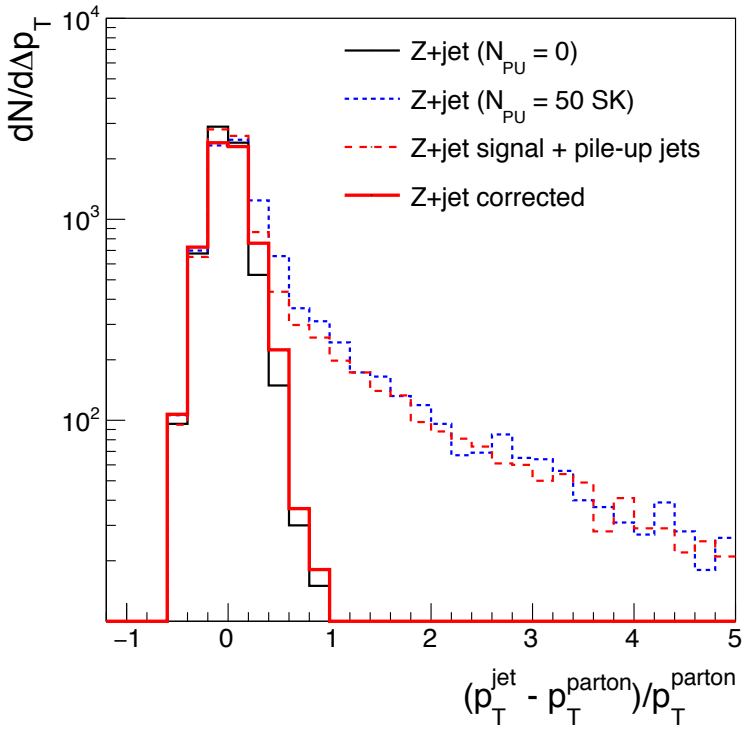
- Behaviour of maximum relative deviation as function of N_{PU}
- (corrected - true) / true
- Without jet mixing: deviation larger at high N_{PU}
- With jet mixing: improvement with increasing N_{PU}

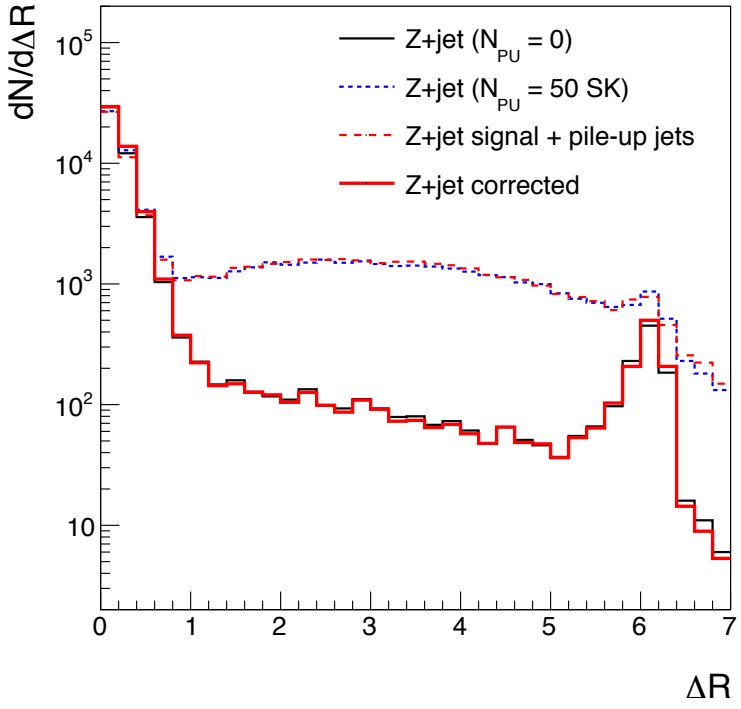


- Approach designed to treat high N_{PU} region: $(N_{PU} + 1) / N_{PU} \approx 1$

Improvement in jet resolution

- Control checks with p_T resolution and $\Delta R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$

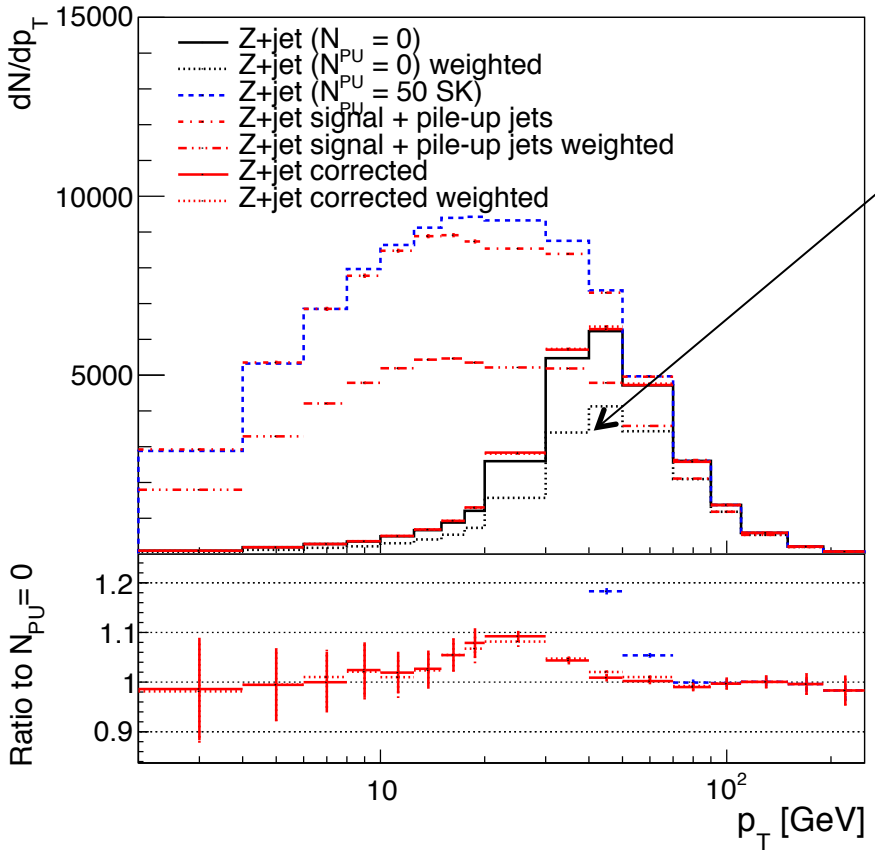




➔ true signal reproduced

Model independence

- Test jet mixing method with different starting signal distribution



- Reweight original signal distribution:
  $p_{T,jet}^2 / (p_{T,jet}^2 + p_{T,0}^2)$
  $p_{T,0}$ = 30 GeV

- Apply jet mixing method

➔ Able to reproduce original signal independent of starting model!

Analogy with the underlying event and MPI/DPS

- First idea to correct for pile-up decorrelations was similar to template method used to extract DPS contributions:

  in e.g. W + 2-jet analysis, create two independent data samples:
  - W + 0-jet events from high lumi data
  - 2-jet events from low lumi data

  and randomly mix two sets of events

- Was not able to fully correct for all pile-up effects:
  exclusive sample → miss part of the signal

- Current method still very similar to DPS extraction:
  $\sigma_{DPS} = \sigma_A * \sigma_B / \sigma_{eff}$
- Pile-up correction: $\sigma_{signal+PU} = \sigma_{signal} * \sigma_{PU} / \sigma_{inel}$

$\sigma_{eff} < \sigma_{inel}$
impact parameter dependence

Analogy with the underlying event and MPI/DPS

- Application of jet mixing method on DPS measurements?

Pile-up correction

Mix MC signal sample without pile-up, with minimum bias data sample with pile-up

Unfold to correct get model independent pile-up correction

DPS extraction

Mix SPS MC signal sample without DPS, with minimum bias data sample with MPI/DPS

Compare to measured data (SPS + DPS) to determine DPS contribution

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
- Main pile-up effects 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 jet mixing to treat pile-up:
  - ➔ use data recorded at high pile-up
  - ➔ no Monte Carlo dependence

Results available in
arXiv:1508.07811 [hep-ph]

- Good prospects for precision SM studies & BSM searches in high pile-up

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Backup

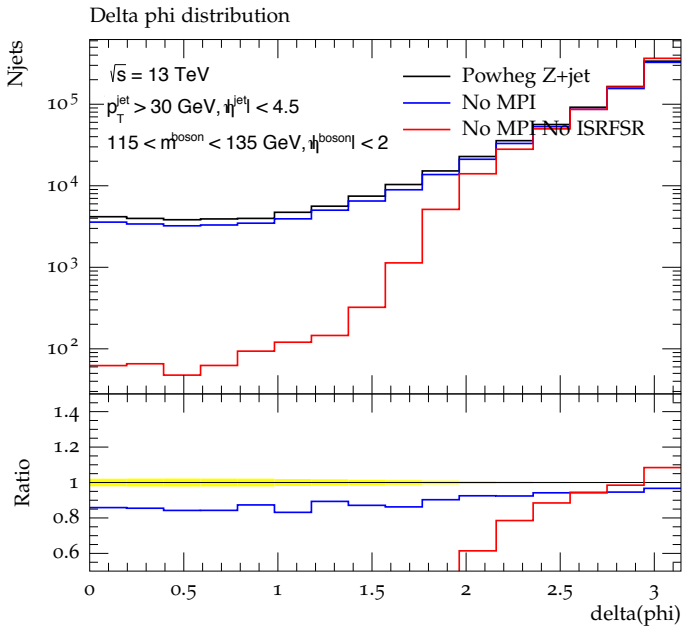
Study QCD with Drell-Yan and Higgs production

- 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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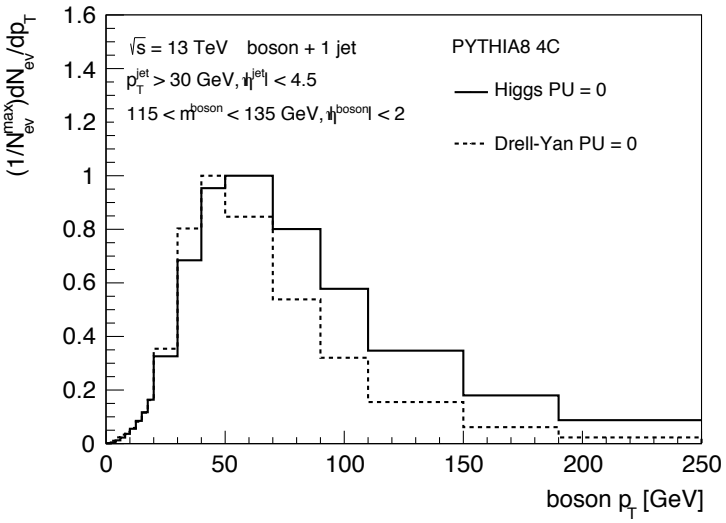

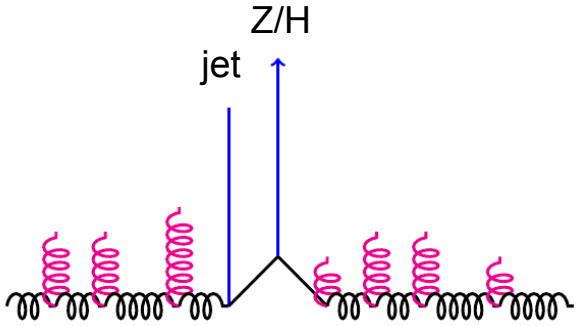

Boson transverse momentum:
probe soft resummation behaviour

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