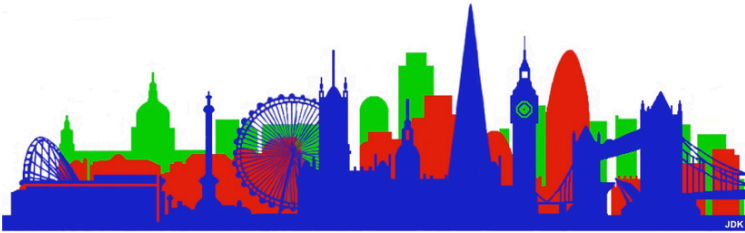


# Treating jet correlations in high pile-up at hadron colliders

**QCD@LHC 2015** Queen Mary University of London  
1<sup>st</sup> – 5<sup>th</sup> September 2015



Multi-parton dynamics session - 02/09/15

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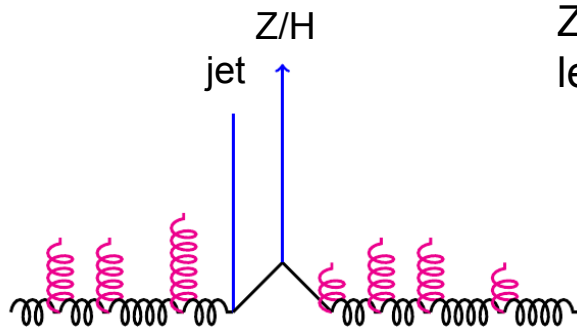
# Introduction

- 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

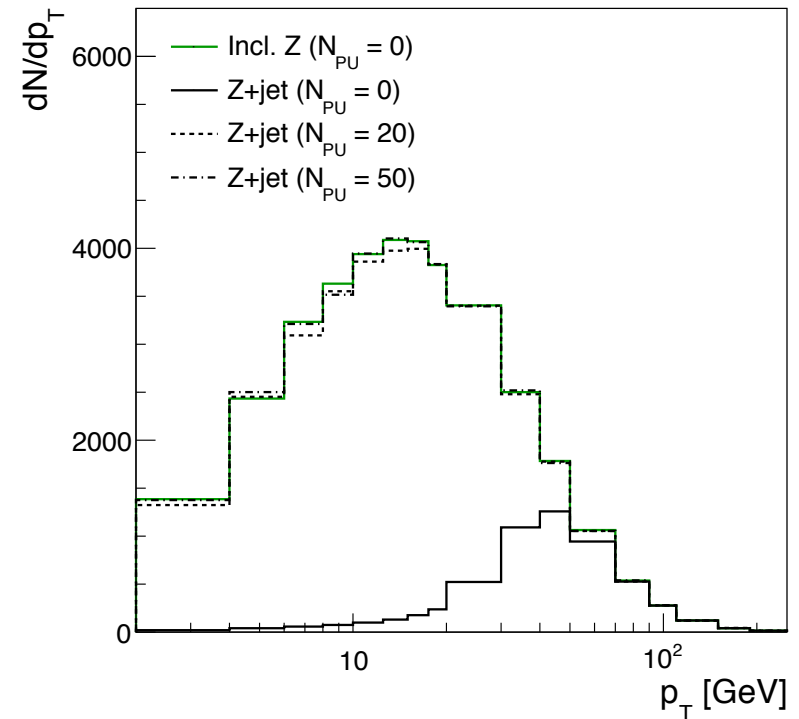
- Additional pp collisions (pile-up): large effect on Z + jet correlations



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

- $p_T$  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:

Soft particles from (multiple) pile-up events fake a high  $p_T$  jet  
→ Ok, can be treated:  
e.g. pile-up jet id techniques

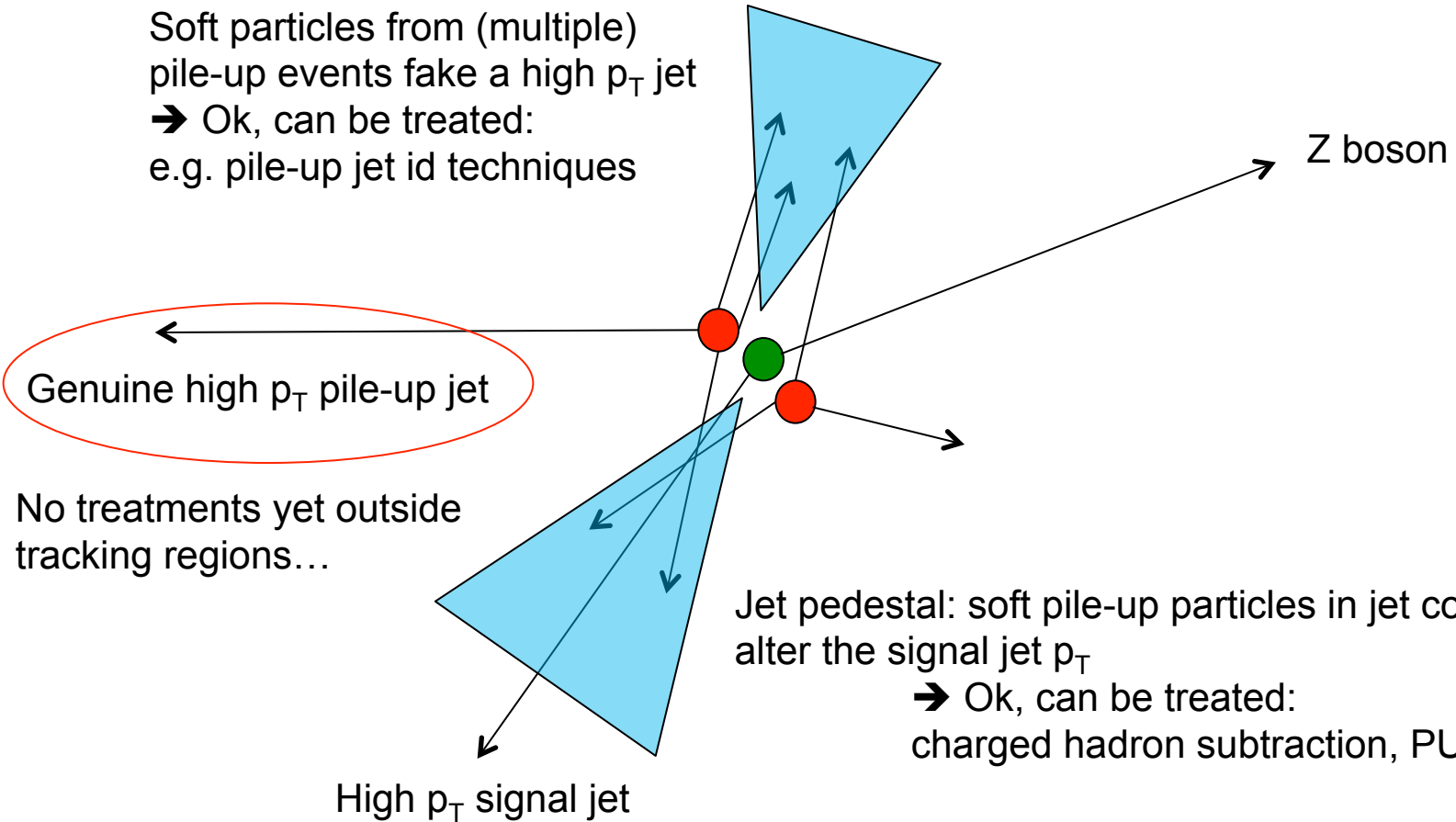
Genuine high  $p_T$  pile-up jet

No treatments yet outside tracking regions...

High  $p_T$  signal jet

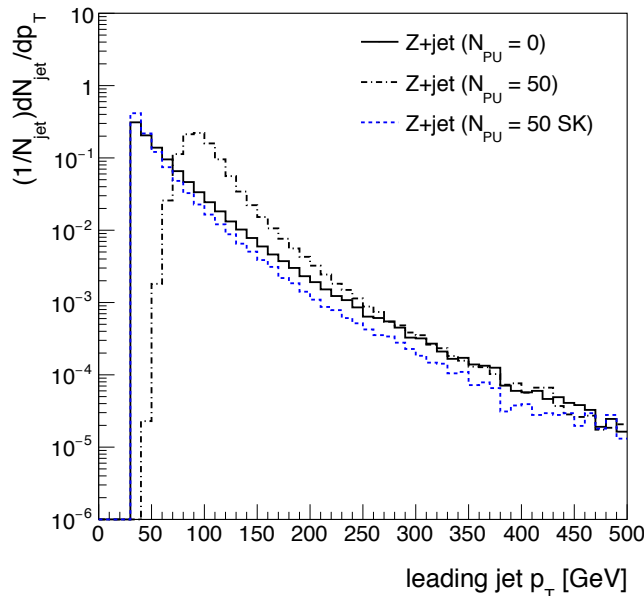
Jet pedestal: soft pile-up particles in jet cone alter the signal jet  $p_T$   
→ Ok, can be treated:  
charged hadron subtraction, PUPPI, ...

Z boson



# 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 ( $\rho$ ) = 0
- re-cluster jets (Anti- $k_T$ ,  $R = 0.5$ )

Can be used with calorimeter information only

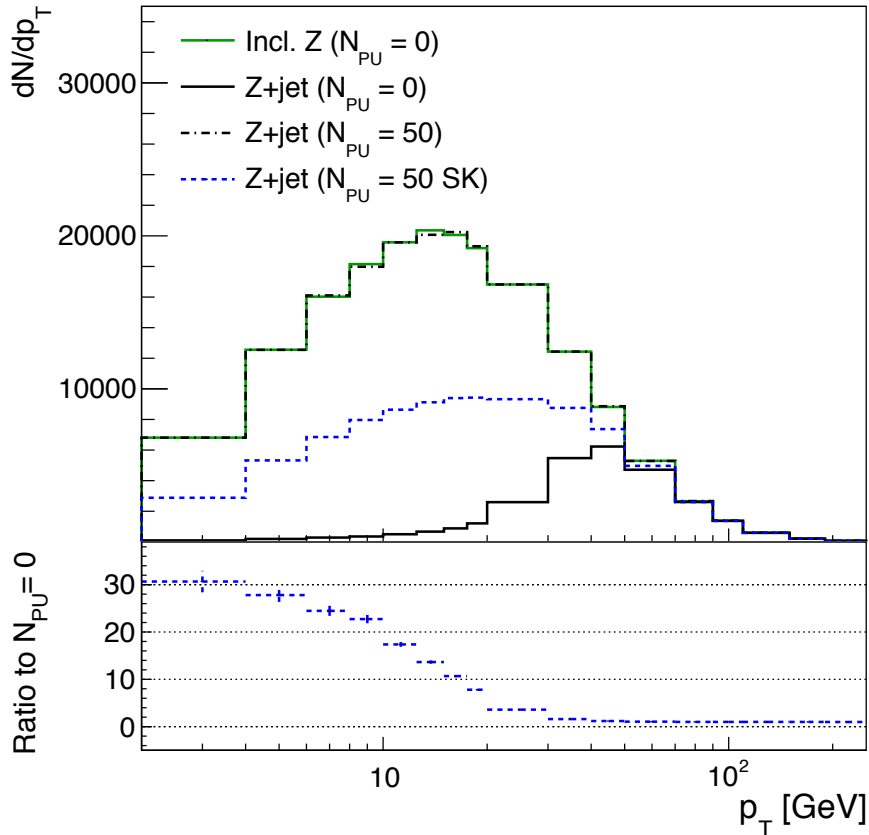
$$\rho = \text{median}_{i \in \text{patches}} \left\{ \frac{p_{Ti}}{A_i} \right\}$$

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

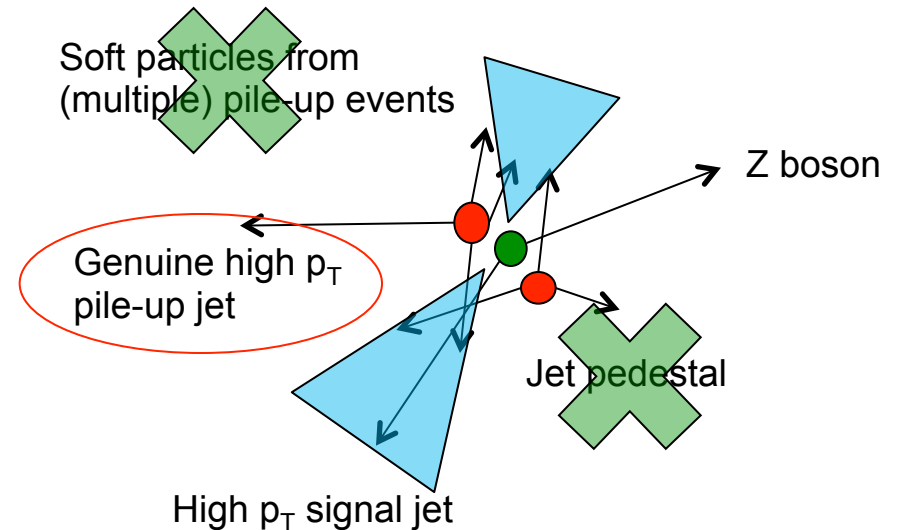


# Apply SoftKiller to Z boson $p_T$ spectrum

## ➤ 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



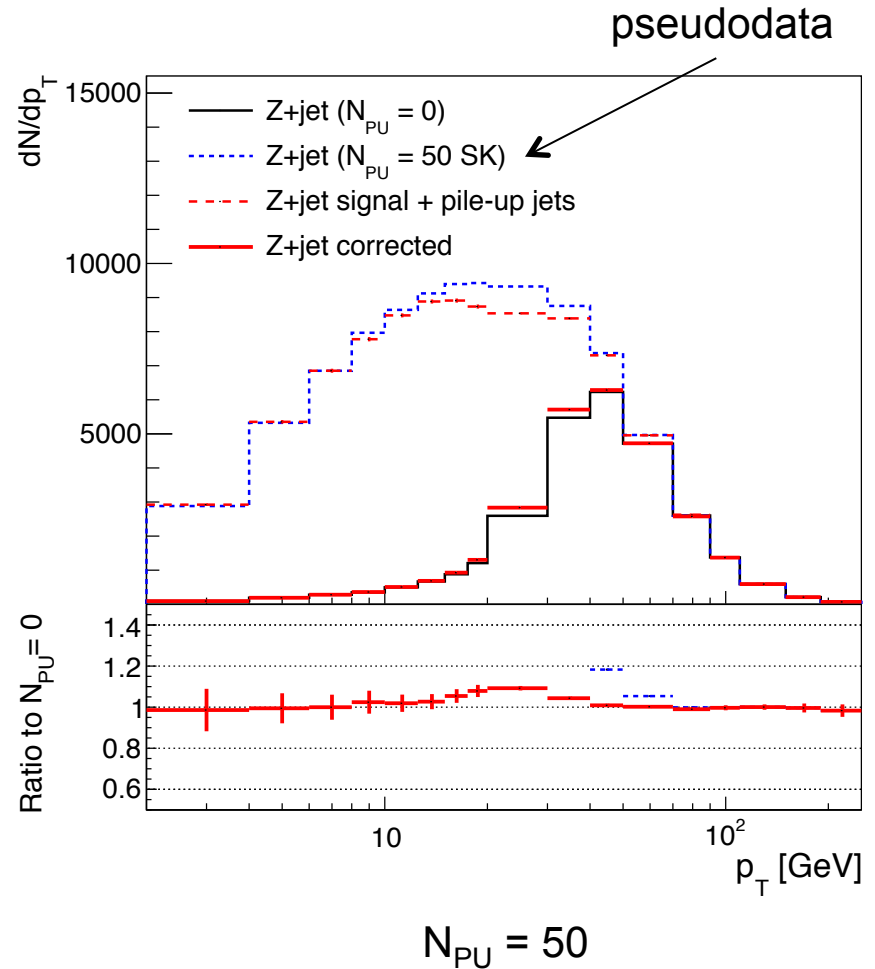
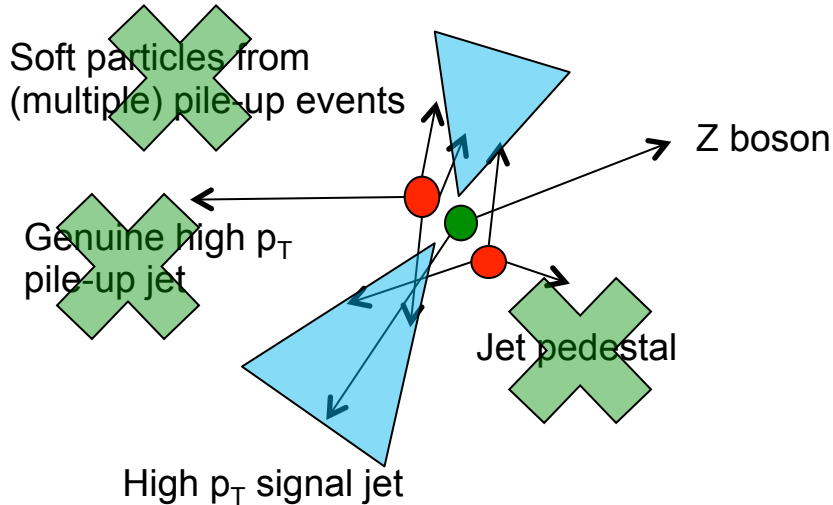
# Data-driven pile-up treatment

- > Obtain signal using a jet 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



# Z boson + jet $p_T$ spectrum with jet mixing applied

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





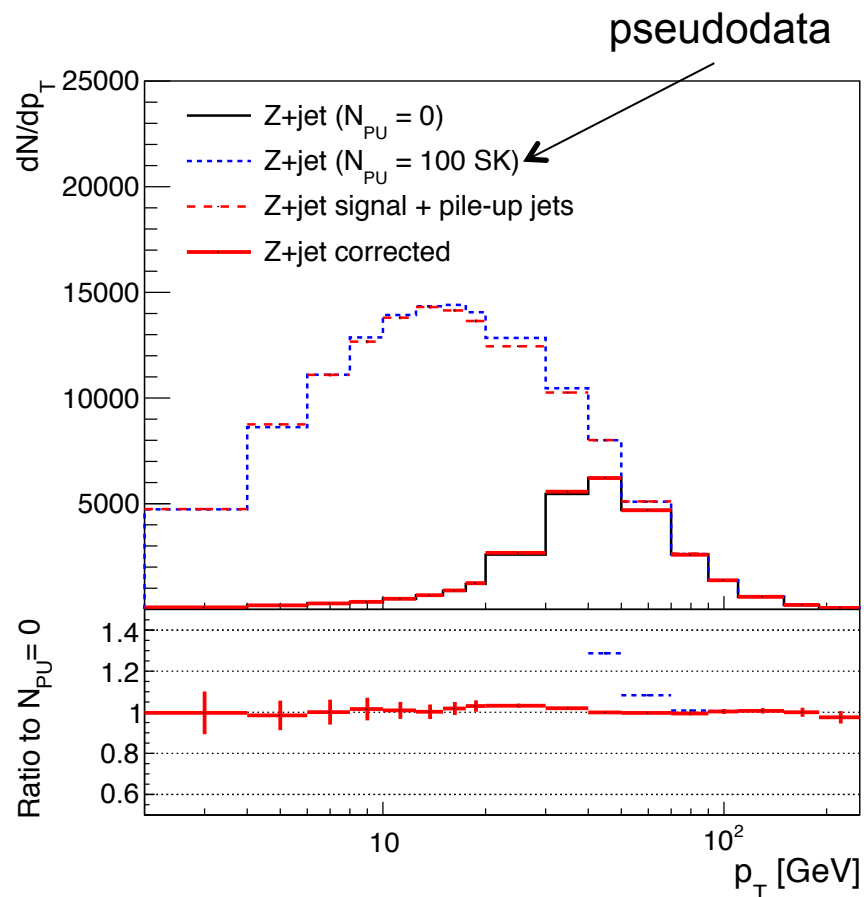
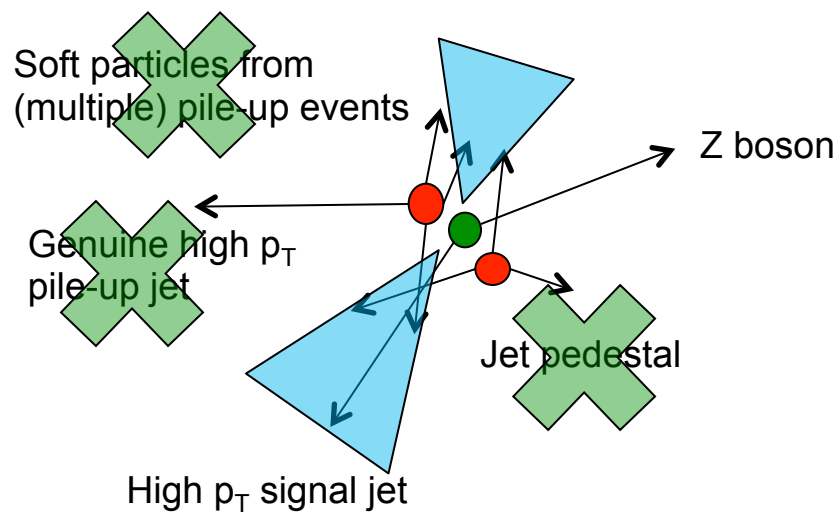
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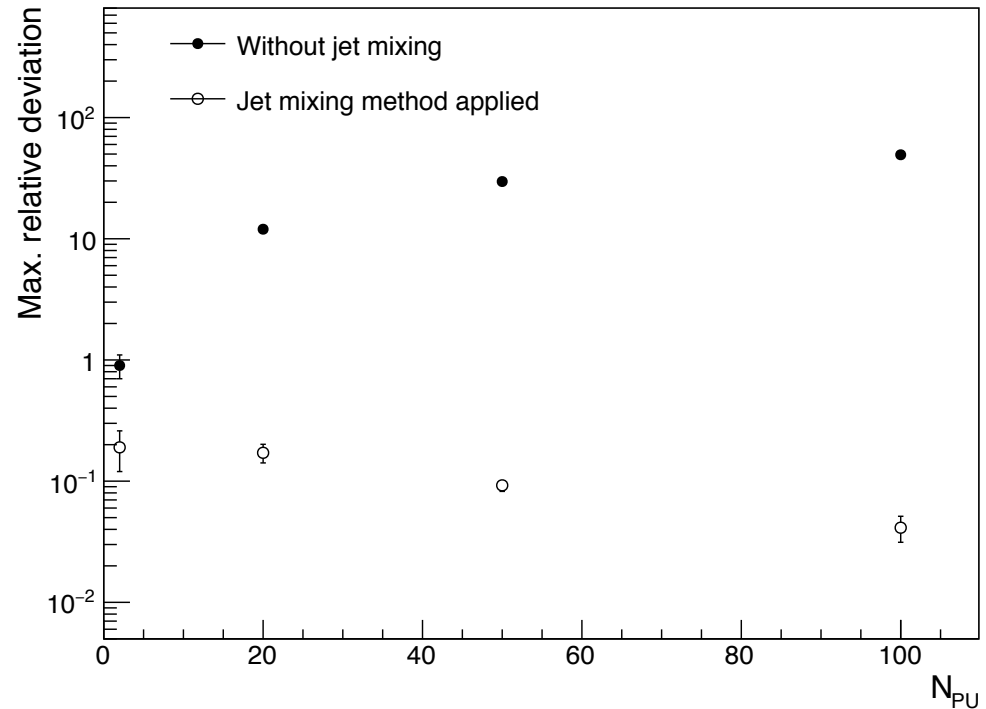
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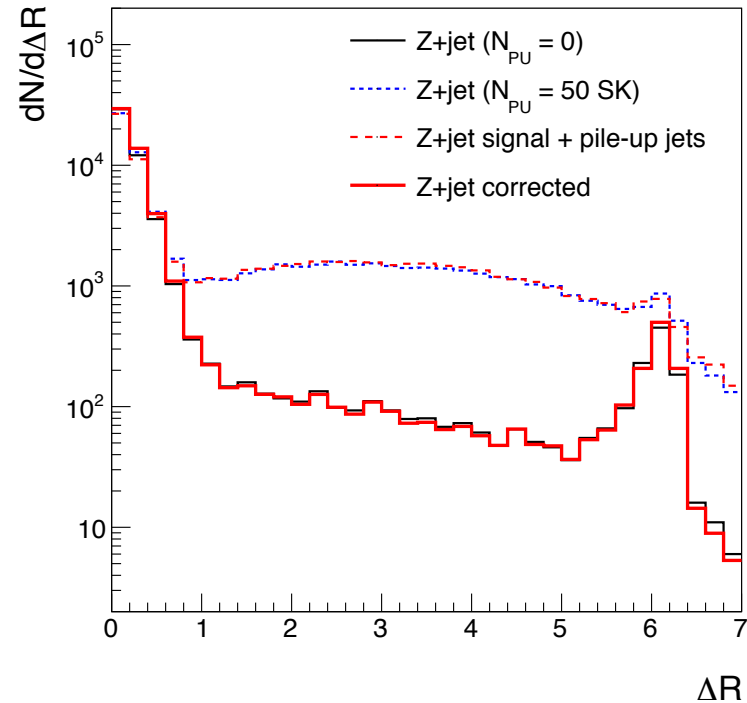
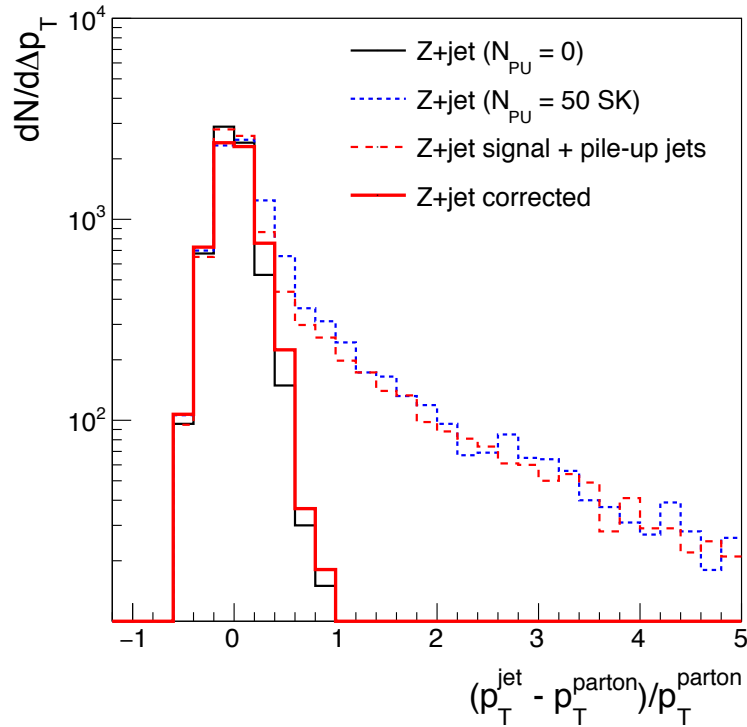
# Accuracy of corrections in low and high pile-up

- > Behaviour of maximum relative deviation as function of  $N_{PU}$
- >  $(\text{corrected} - \text{true}) / \text{true}$
- > 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  $\Delta R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$

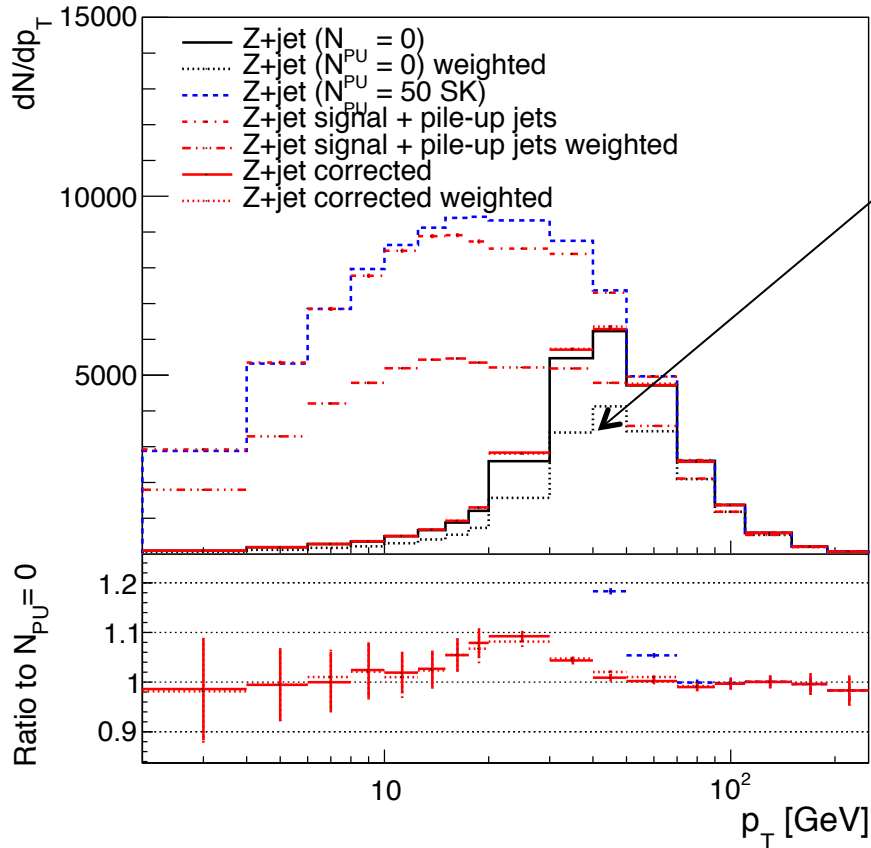


➔ true signal reproduced



# Model independence

- Test jet mixing method with different starting signal distribution



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

- Apply jet mixing method

➔ Able to reproduce original signal independent of starting model!



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



# Backup



# Study QCD with Drell-Yan and Higgs production

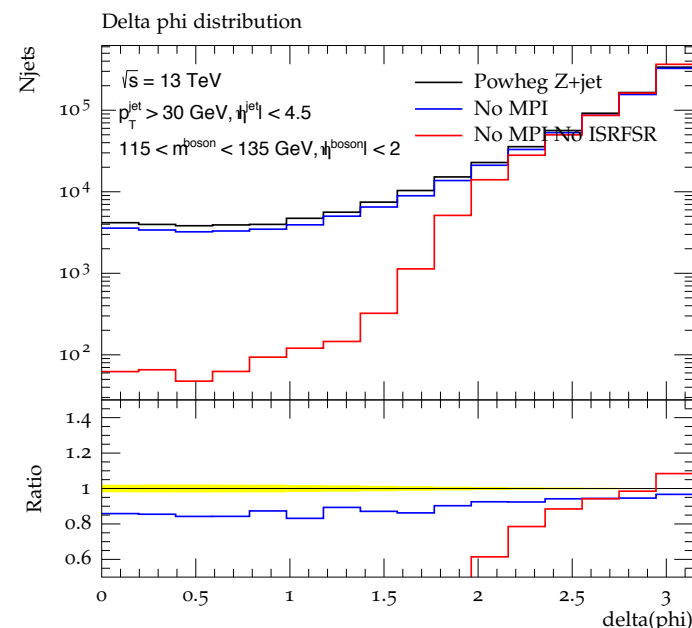
➤ Ideal processes to study quark and gluon structure functions, parton showers, underlying event, ...

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

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

➤  $\Delta\phi$  decorrelations:  
study effect of multiple parton interactions (MPI) and initial and 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

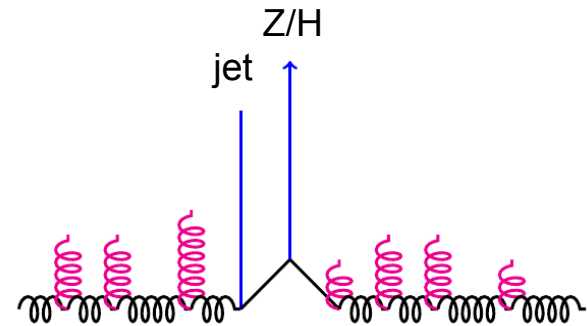
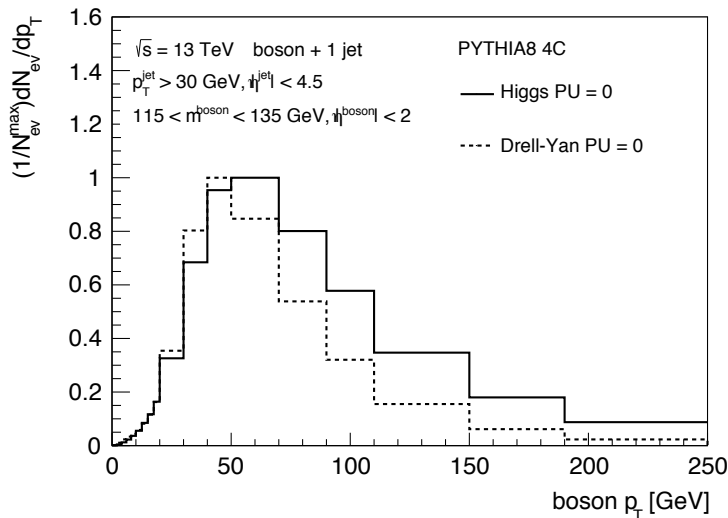


# Study QCD with Drell-Yan and Higgs production

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

[Phys. Rev. D 88, 097501 (2013)]  
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- Especially boson + jet topologies:  
map correlations between the two objects



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