Study of observables for measurement of MPI using Z+jets process

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7th International Workshop on Multiple Parton Interactions at the LHC

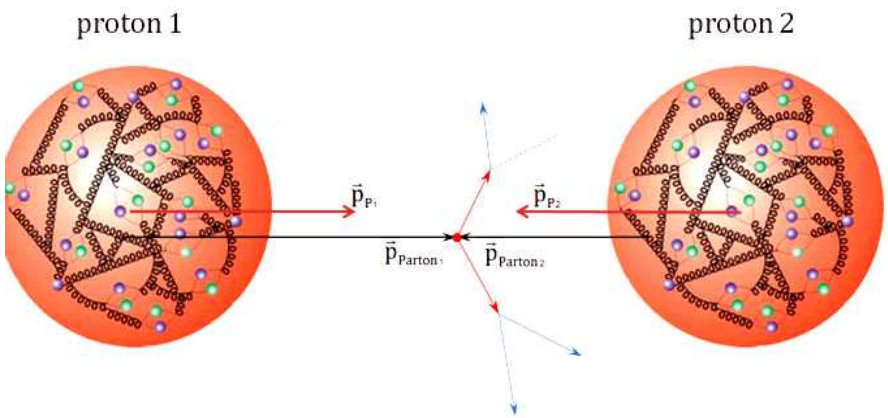
November 23-27, 2015

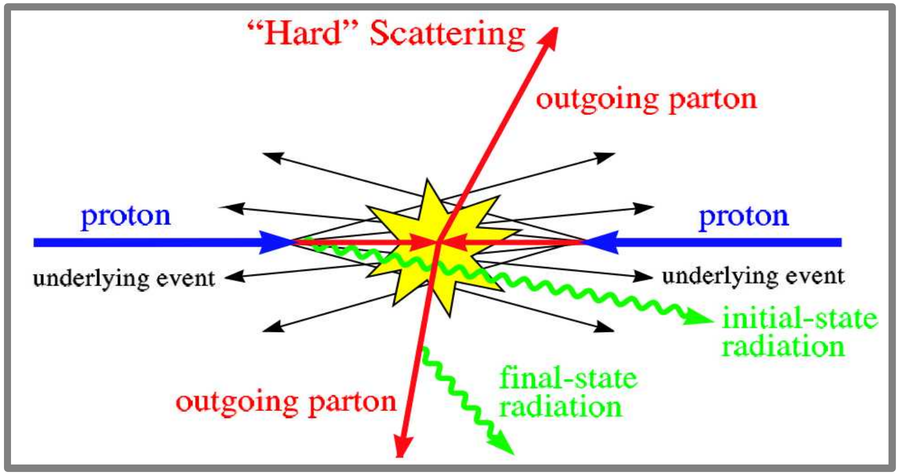
ICTP, TRIESTE, ITALY

Introduction

- **Multiple Parton Interactions (MPI)**: More than one parton-parton scatterings in a single proton-proton collision.

- At very high energy collisions, MPI matters more due to interactions at short distance scale.





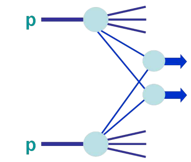
Presence of MPI in hadron collisions:

- *experimentally established in SPS experiments (UA1, UA2, UA5, etc. in p-pbar collisions).*

MPI is significant at LHC

- It contributes significantly to interesting single parton processes as background.
- MPI studies provide information on matter overlap & multi-parton correlations.

Effective Cross-section



Effective cross-section, σ_{eff} regarded as most natural link to the theories.

- Measure of the matter overlap in hadron-hadron interactions.
- Dependence (slight) on collision energy. *(Model predictions)*
- Independent of the physics channel and scale of interactions.
- Experimental proof required!

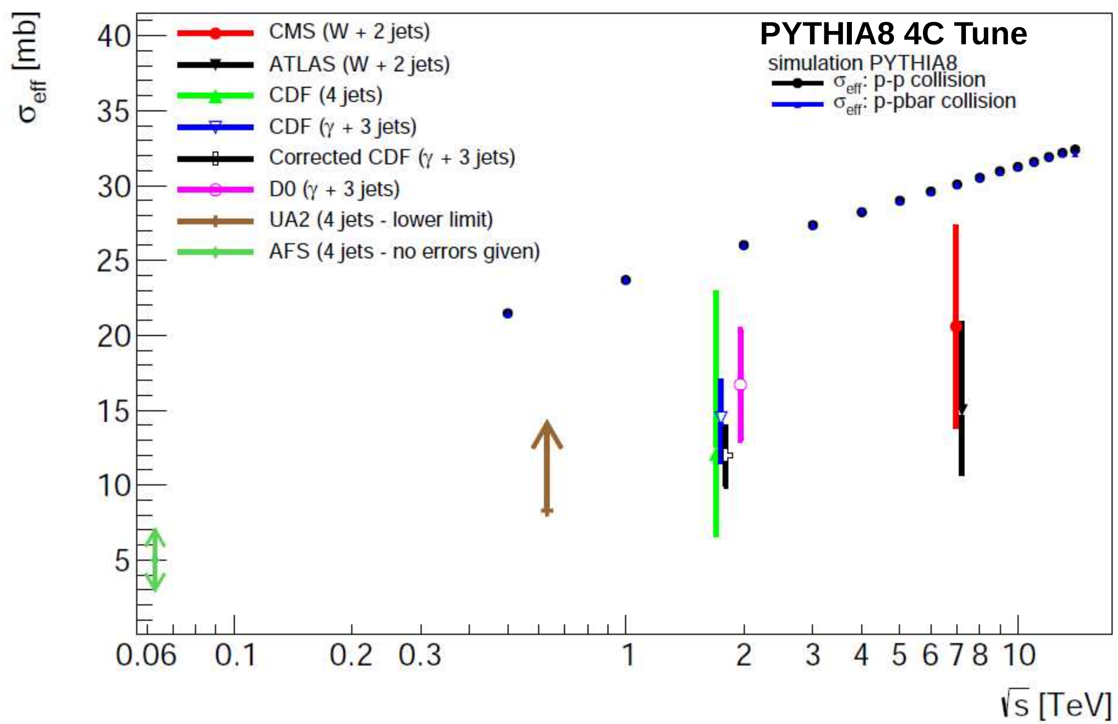
$$\sigma_{eff} = \frac{\sigma_{non-differactive}}{f}$$

- Pre-LHC: Results available for collision energy from 63 GeV (AFS) to 1.96 TeV (Tevatron).

- Focus on (photon + 3-jet) process & (4-jet) process.

- LHC Measurements: from ATLAS and CMS collaborations (7 TeV and 8 TeV).

- (photon + 3-jet) processes, (4-jet) processes, W + 2-jet and ssWW processes



Experimental Techniques

- Two different approaches towards MPI measurements:
  - Kinematics of particles from MPI are different from that from SPS processes.
  - Correlation observables sensitive to MPI are investigated.

Approach I

Fitting of Observables sensitive to DPS;

Extraction of DPS in data using templates;

Calculation of effective cross-section

$$\sigma_{XY} = \frac{m}{2} \cdot \frac{\sigma_X \cdot \sigma_Y}{\sigma_{eff}} \quad \begin{cases} m = 1 \text{ when } X = Y \\ m = 2 \text{ when } X \neq Y \end{cases}$$

Approach II

Variation in MPI parameters (Pythia8);

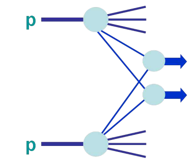
Matching of experimental data;

Calculation of effective cross-section

$$\sigma_{eff} = \frac{\sigma_{non-differactive}}{f}$$

Impact parameter enhancement factor; Dependent on MPI parameters (tune)

Experimental Techniques



Approach I

Template fitting

- Low senstivity & Large systematics
- Exclusive selection following experimental challenge. ***JHEP03(2014)032***
- Limited to Double parton scattering. Correction required for higher order parton scatterings. (As done in D0 measurement) ***Phys.Rev.D81(2010) 052012***

Approach II

Internal fitting

- Low senstivity & Large systematics

CMS PAS GEN-14-001

Investigation of new observables and phase space

- ***increased sensitivity***
- ***minimum ambiguity***

Event generation

From 13 TeV pp collisions *(Simulations)*

Z + jets events → Generated using → **POWHEG 2** (MiNLO) → Parton showered & hadronized using → **PYTHIA8** V8.205

- **POWHEG** describes data well for W/Z +jets events.

  JHEP10(2012)155

- **PYTHIA8** provides an accurate MPI model.

  JHEP05 (2006) 026, Comput. Phys. Comm. 178 (2008) 852

- **ATLAS A14** tune with PDF set **NNPDF 2.3LO**.

  ATL-PHYS-PUB-2014-021

Selection Criteria

Z + jets events from pp collisions @13 TeV

Two opposite sign Muons:

p_T (μ) > 20 GeV/c

|η| (μ) < 2.5

Jets:
(Tracker jets reconstructed using charged particles)

p_T (jet) > 20* GeV/c

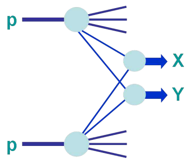
|η| (jet) < 2.0

Tracker jets are considered
(better reconstruction efficiency at low tranverse momentum)

60 < M^{inv}(μμ) < 120 GeV/c^2

** A study with low $\boldsymbol{p_T}$ (10 GeV/c) jets is also done.*

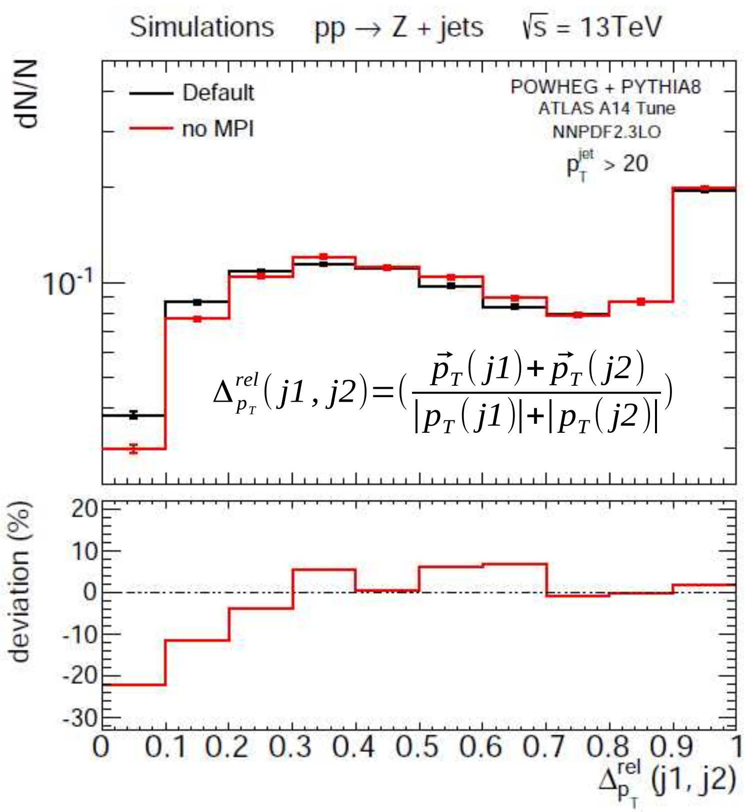
Observavbles sensitive to MPI



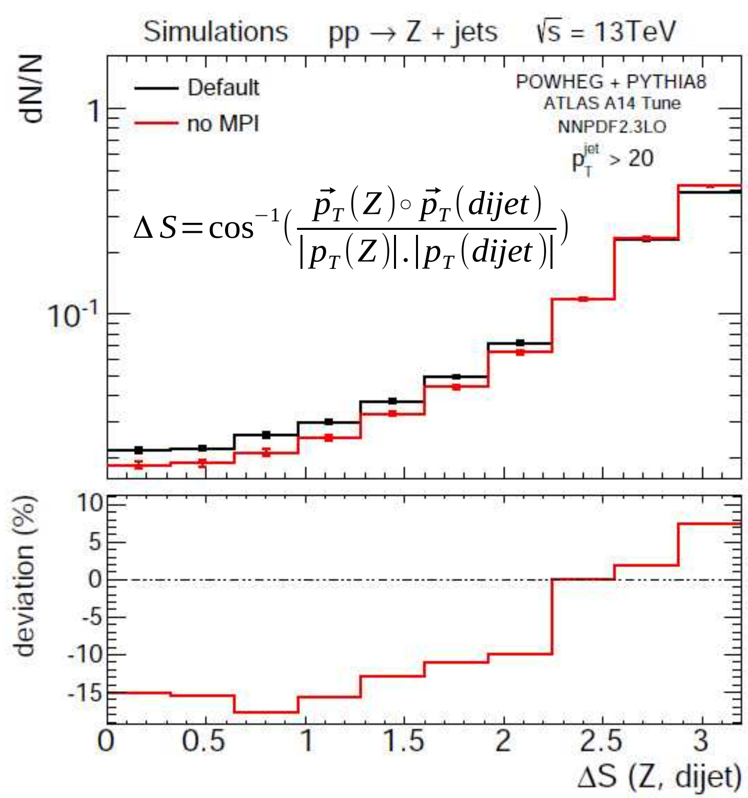
- Kinematics of particles from MPI are different from that from SPS processes.
- Correlation observables sensitive to MPI are investigated in *previous measurements.*
- **10-20 %** deviation is observed for the events without MPI.

Phys.Rev.D81(2010)052012
NewJ.Phys.15(2013)033038
Phys.Rev.D89(2014)092010
JHEP03(2014)032

Transverse momentum imbalance b/w two jets



Azimuthal separation b/w Z boson and dijet system



Looking for new observables

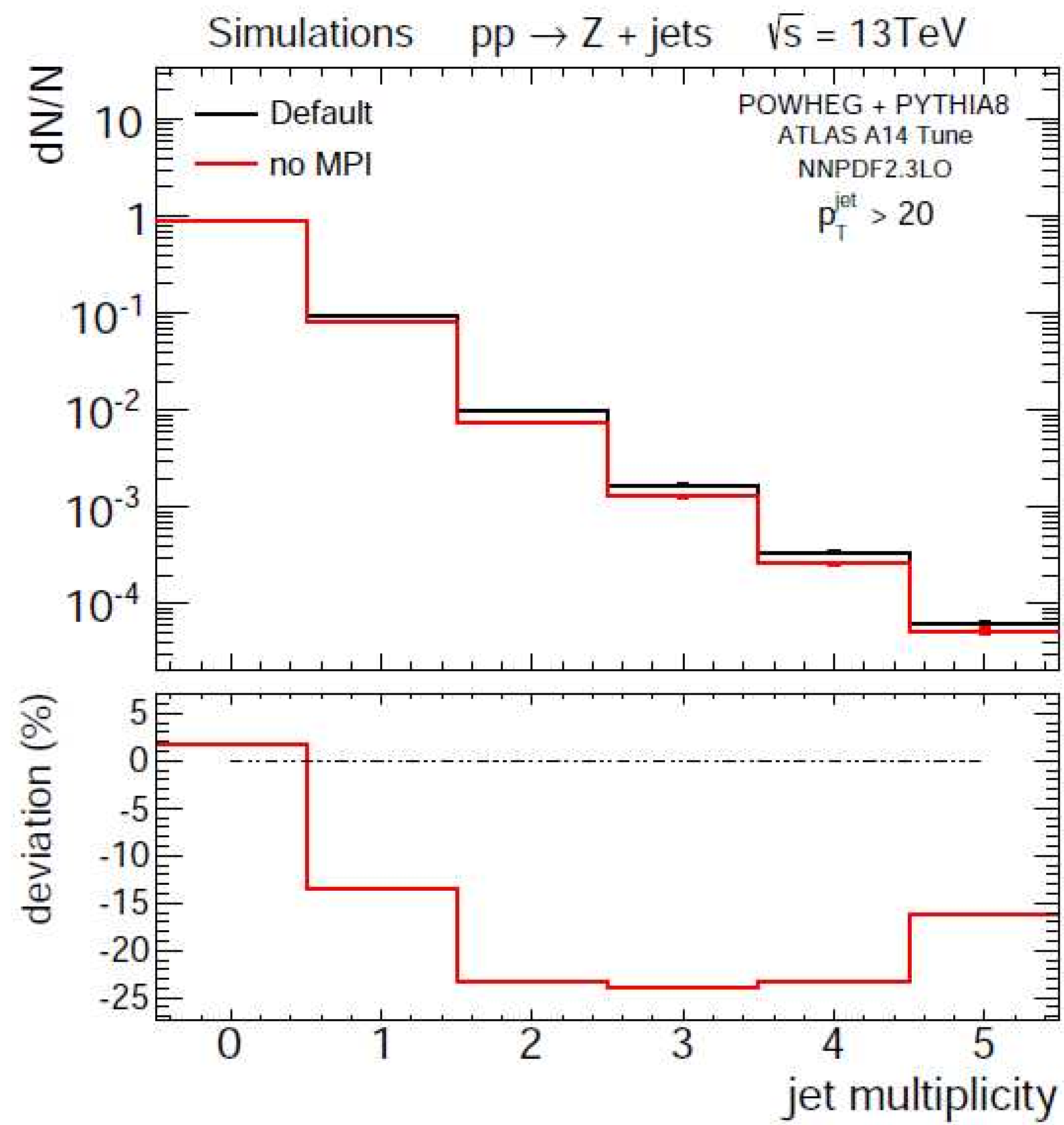
?

- Increased senstivity
- Inclusive selection

Jet multiplicity-1/2

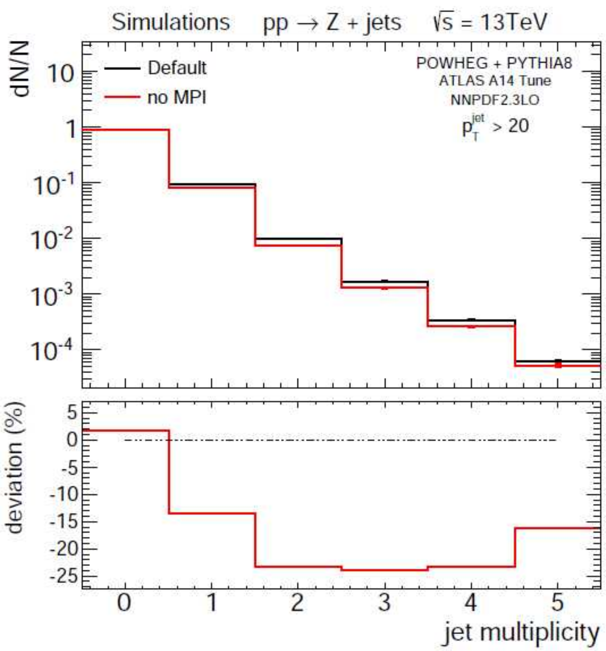
- Jet multiplicity provides handle to study MPI.
- Deviation **upto 25%** for events without MPI.

- ✔ **Increased senstivity**
- ✔ **Inclusive selection**
- ✔ **Sensitivity in all bins.**

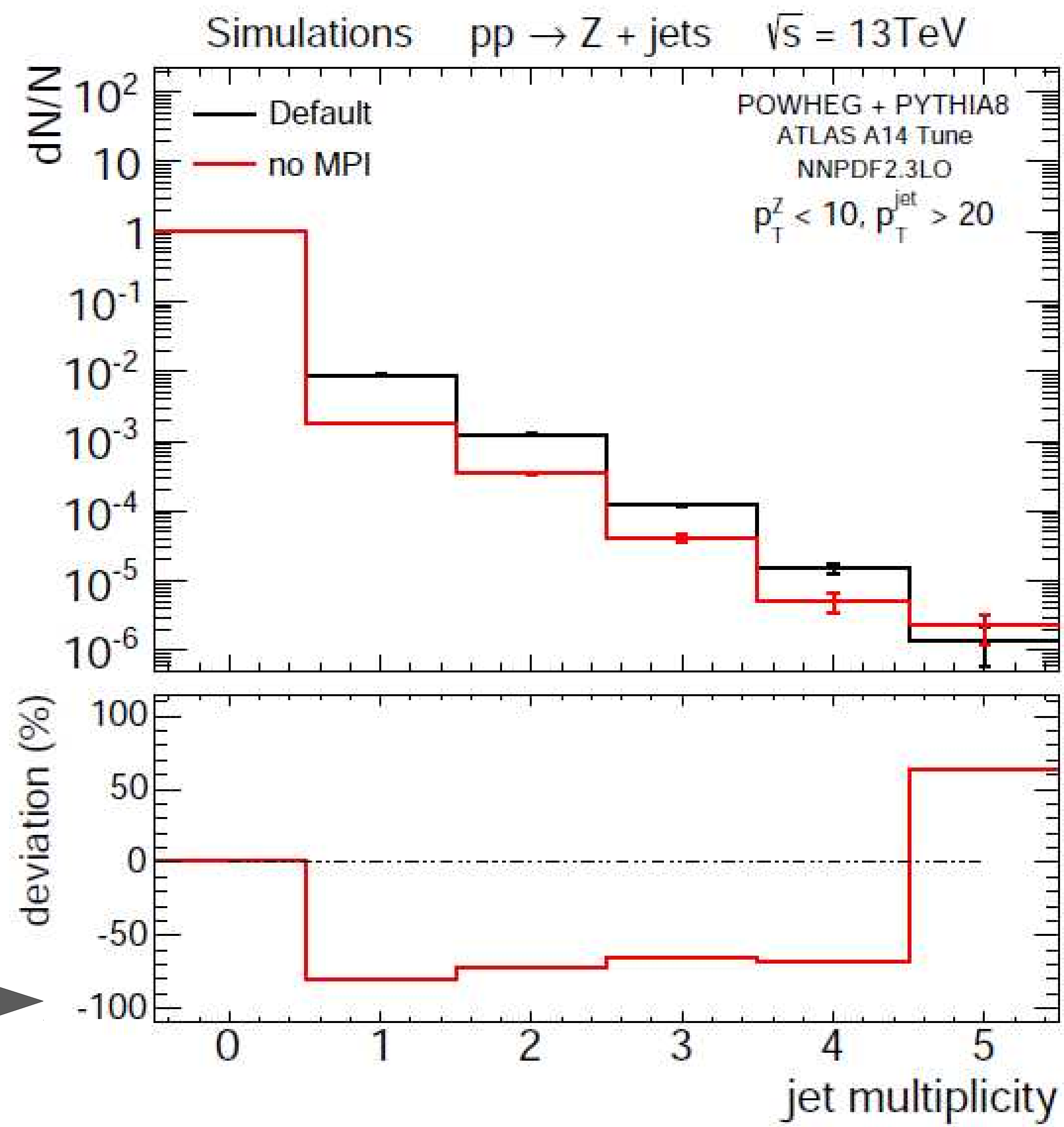


Jet multiplicity-2/2

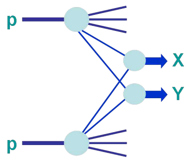
- **Sensitivity increases upto 80% by implying an upper cut on p_T (Z) .**
- ***SPS contribution is suppressed.***
- **NOT significant effect on correlation observables.**



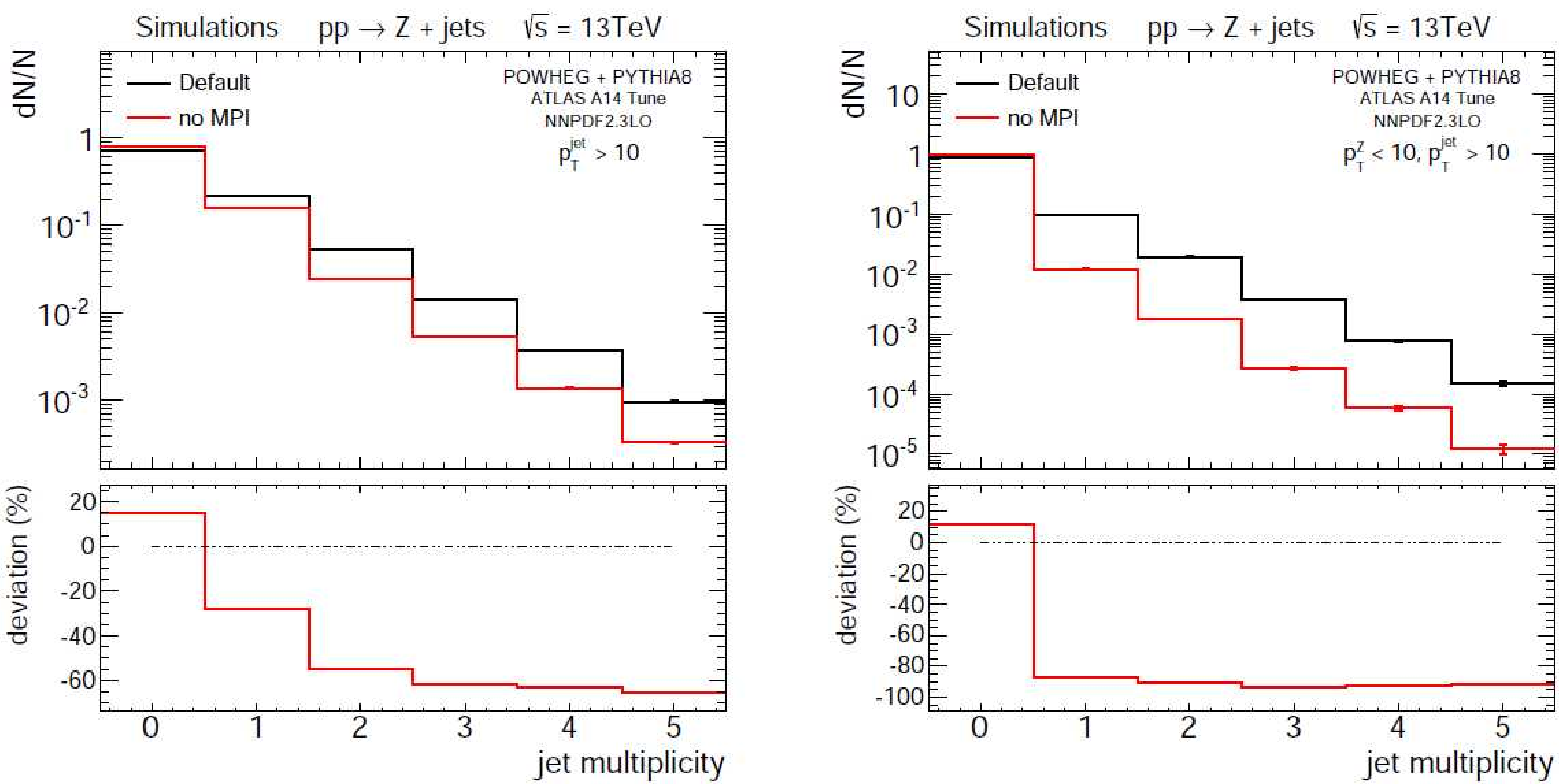
p_T (Z) < 10 GeV/c



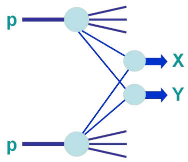
Variation with scale of 2nd interaction



- **The effect is still visible if scale of 2nd interaction is changed.**
- **Low p_T jets are studied (p_T > 10 GeV/c)**
- **Deviation even increases more (60-100 %)!**



MPI parameters



Partonic cross-section **Reformulized** **Free parameter, pT0ref**

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \rightarrow \frac{\alpha_s^2(p_{\perp 0}^2 + p_\perp^2)}{(p_{\perp 0}^2 + p_\perp^2)^2} \quad \text{with} \quad p_{\perp 0}(E_{\mathrm{CM}}) = p_{\perp 0}^{\mathrm{ref}} \times \left(\frac{E_{\mathrm{CM}}}{E_{\mathrm{CM}}^{\mathrm{ref}}}\right)^{\epsilon}$$

1.8 TeV

Impact parameter profile for the incoming hadron beams

`MultipartonInteractions:bProfile = 3` (default)

Depends on an overlap function, i.e. the convolution of the matter distributions of the two incoming hadrons, of the form exp(-b^Z), where **Z** (expPow) is a free parameter.

- **Few MPI parameters studied** (with default A14 values):

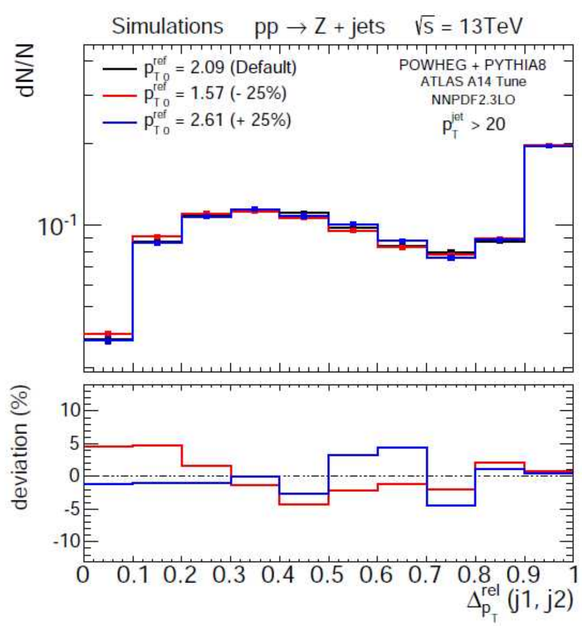
`PartonLevel:MPI` (= on) switched off/on

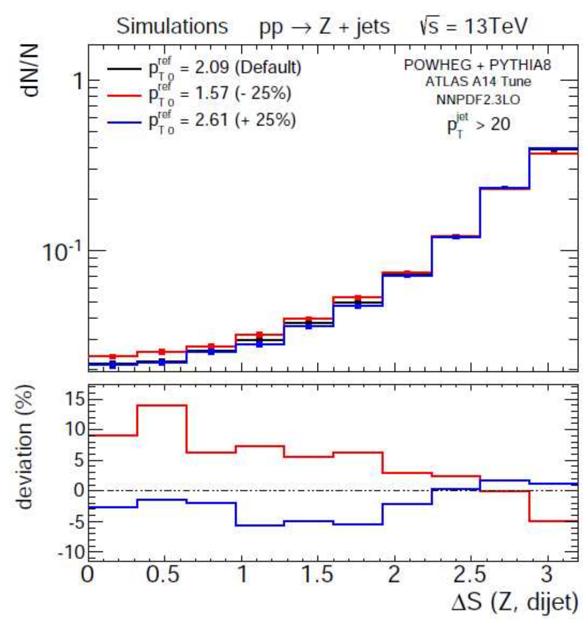
- ✓ `MultipleInteractions:pT0Ref` (= 2.09) varied by ± 25 %
- ✓ `MultipleInteractions:alphaS` (= 0.126) varied by ± 25 %
- ✓ `MultipleInteractions:expPow` (= 1.85) varied by ± 25 %

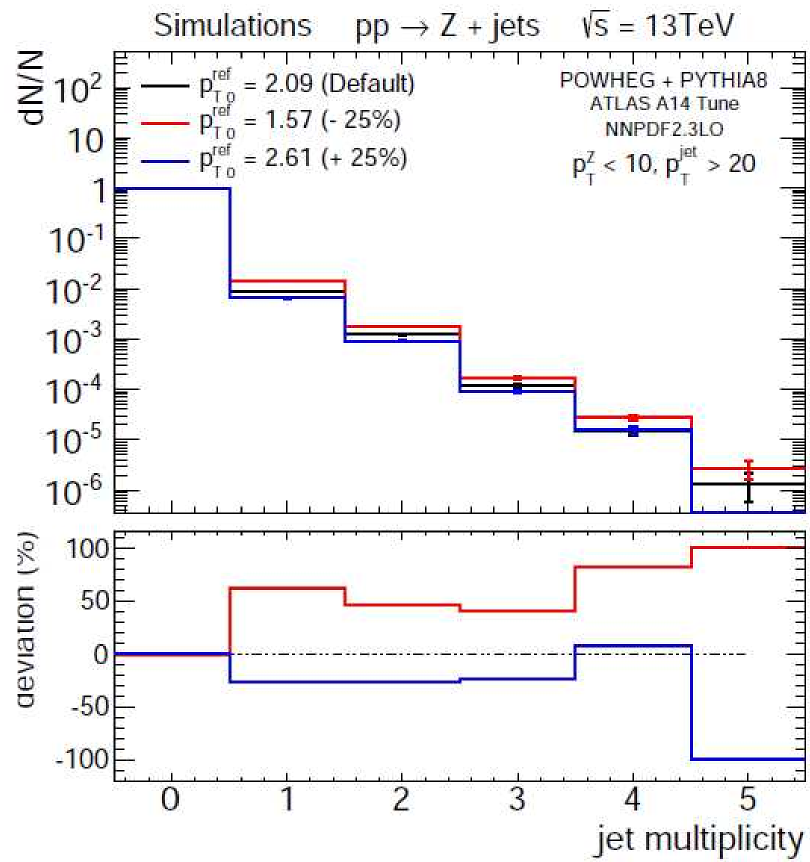
Sensitivity to MPI parameters-1/3

MultipleInteractions:pT0Ref (2.09) varied by ± 25 %

- The deviations of 50-100% are observed for jet multiplicty.
- More the sensitivity, more accurate be the MPI measurement.
- Correlation observables show little sensitivity! (5-10 %)



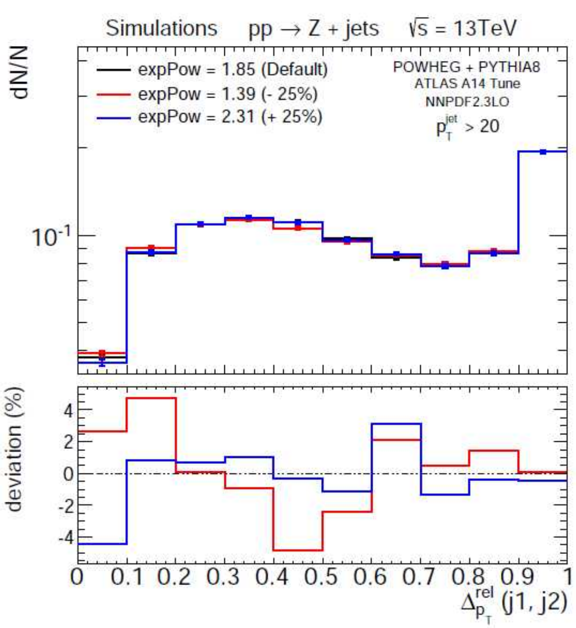


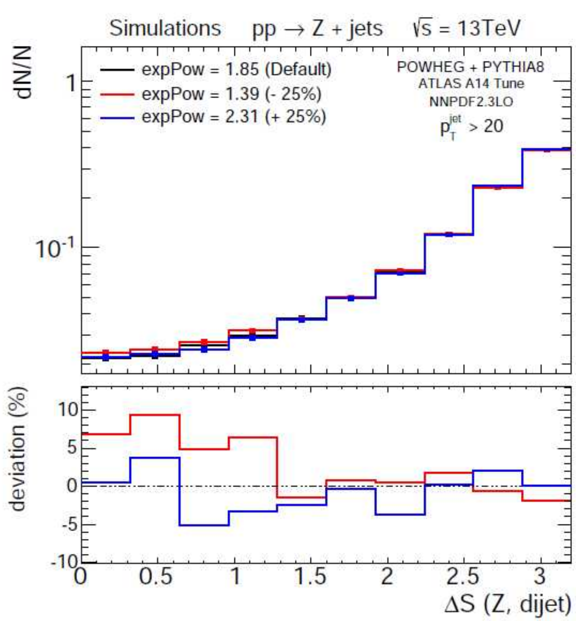


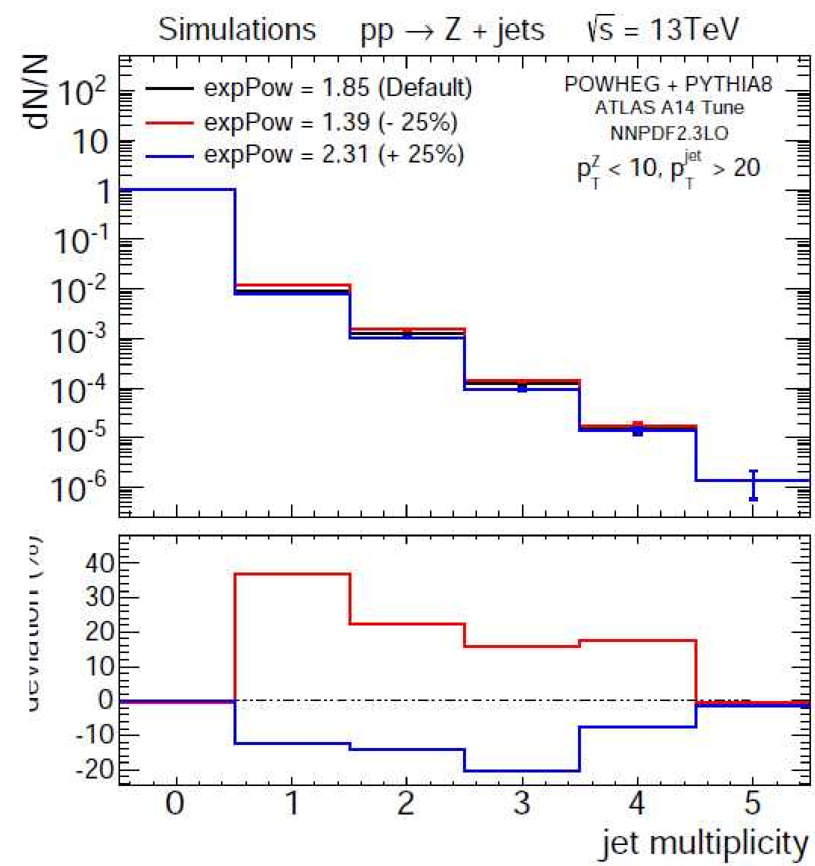
Sensitivity to MPI parameters-2/3

MultipleInteractions:expPow (1.85) varied by ± 25 %

- The deviations upto 30% are observed for jet multiplicty.
- More the sensitivity, more accurate be the MPI measurement
- Correlation observables show little sensitivity (< 10 %)



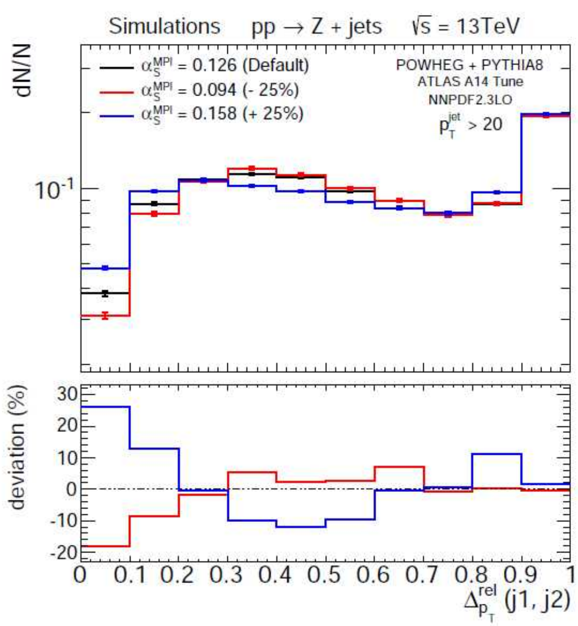


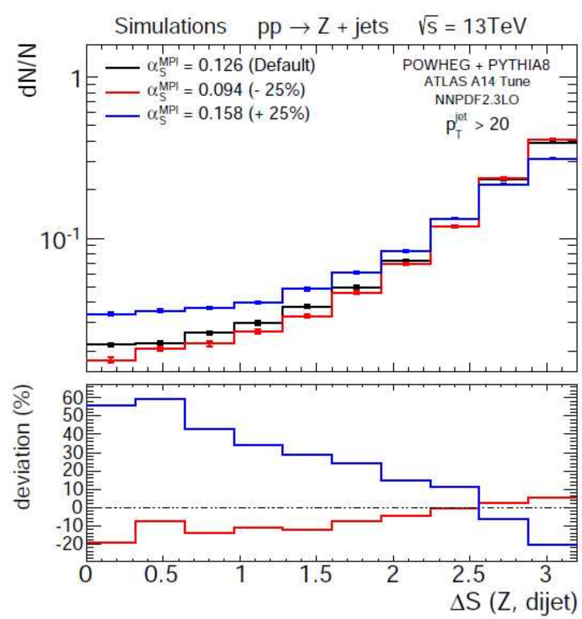


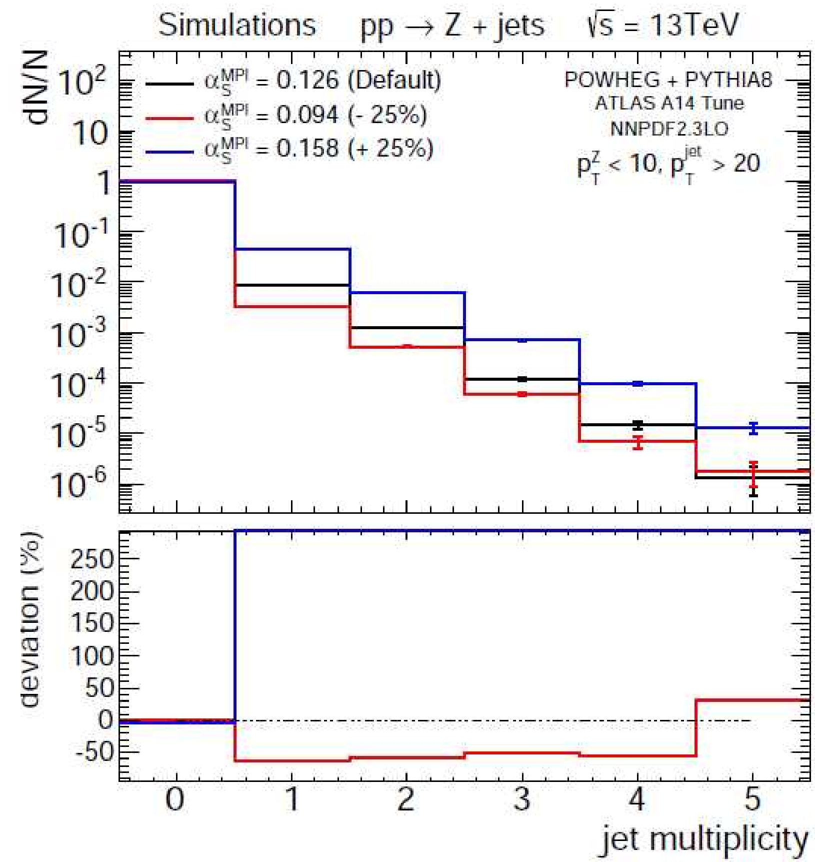
Sensitivity to MPI parameters-3/3

`MultipleInteractions:alphaS` (0.126) varied by ± 25 %

- The deviations greater than 300% are observed for jet multiplicty.
- More the sensitivity, more accurate be the MPI measurement.
- Traditional observables show little sensitivity! (25-60 %)







Summary/Conclusion

- A study of MPI using Z + jets events is presented.
- **Jet multiplicity**: a better handle to study MPI compared to correlation observables.

  (increased sensitivity to MPI, no ambiguity for inclusive selection)

- Sensitivity increases more with an upper cut on Z p_T.
- More sensitive to MPI parameters, more accurately can be MPI measurement.