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Azimuthal correlations in Z+jets events in pp collisions at CMS

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Introduction

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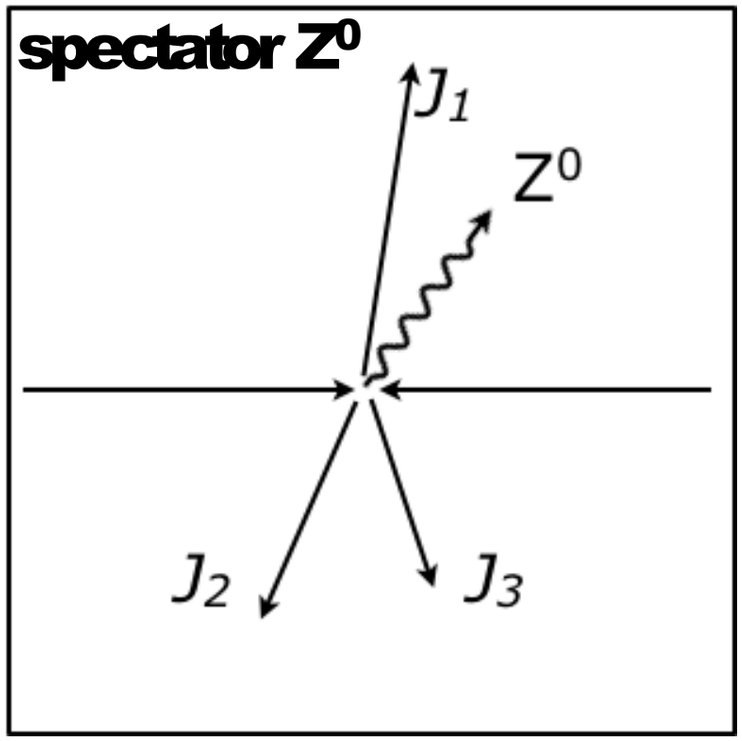
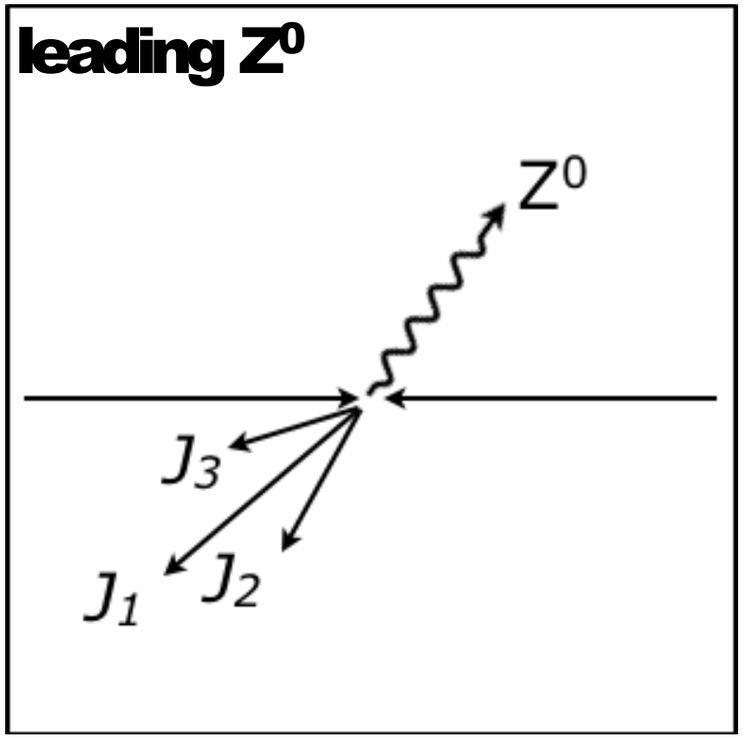
- $\Delta\Phi(Z,J_i)$, $\Delta\Phi(J_i,J_j)$ measured differentially
  - $N_{Jets} \geq 1,2,3$
  - $p_T(Z) > 0$, 150 GeV
- 5fb-1 @ 7 TeV LHC data
- $Z \rightarrow ll$ (l=e,mu) both channels considered
- Provide input to the theory for extreme kinematic selections
- Quantify DATA/Theory agreement in regions interesting for NP searches in the Jets+MET
  - $Z \rightarrow \nu\nu$ irreducible background
    - MET ~ $p_T(Z)$
    - $\Delta\Phi(MET,J_i) \sim \Delta\Phi(Z,J_i)$
    - $\Delta\Phi(J_i,J_j)$ is the visible part of $Z \rightarrow \nu\nu$ + jets





Event Selection & Objects

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Leptons (e,mu):

- $P_T > 20$ GeV
- $|\text{eta}| < 2.4$
- $71 \text{ GeV} < M_{ll} < 111 \text{ GeV}$
- PU corrected isolation $DPt/Pt < 0.15$ in a cone of $\Delta R = 0.3$

Jets:

- $P_T > 50$ GeV
- $|\text{eta}| < 2.5$
- `Anti-kT R=0.5 clustering`
- $\Delta R > 0.4$ from each leading lepton

Kinematics distributions

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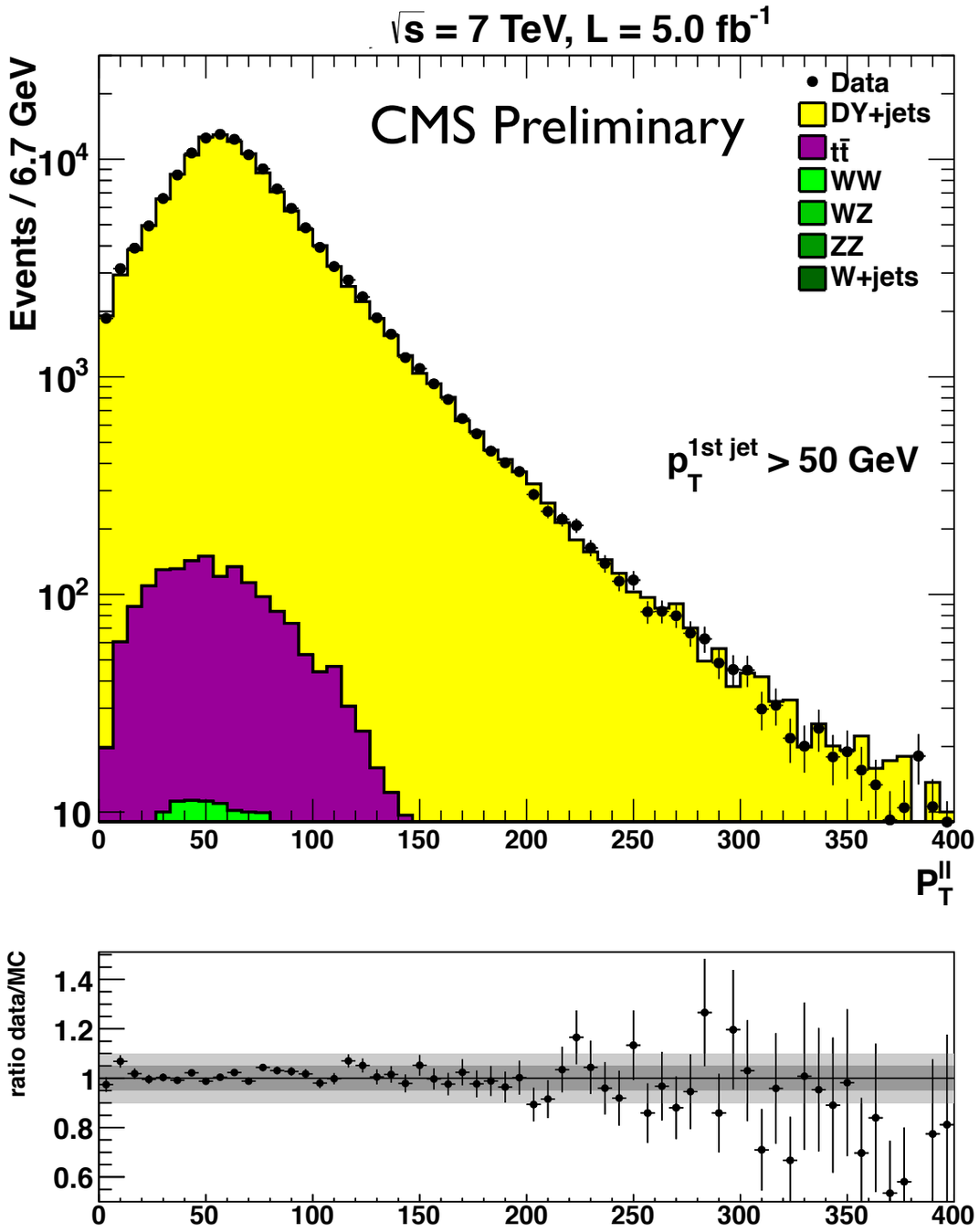

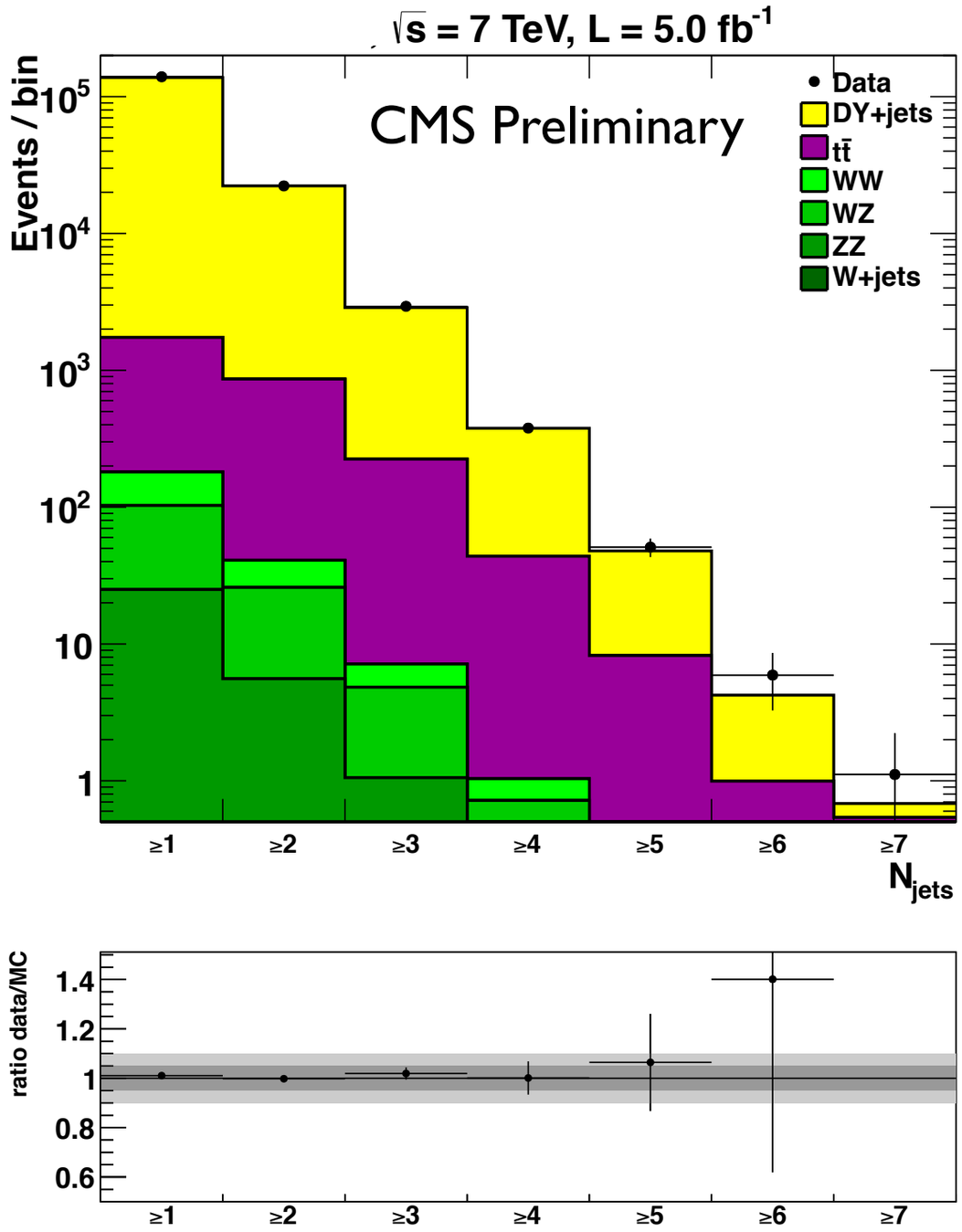

- Very good agreement: difference DATA-MC <5%
- High purity signal candidates (>90% for $N_{Jets} \geq 3$)

Unfolding from data→true

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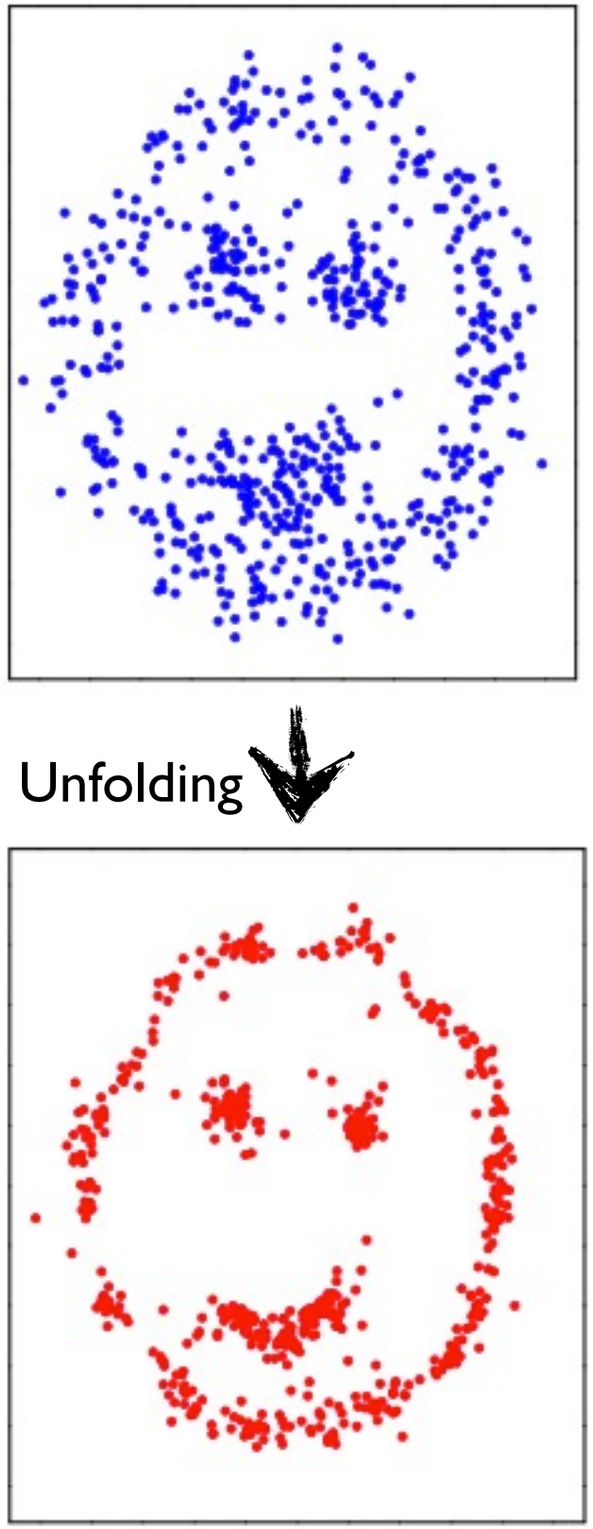
Particle Level DATA/Theory

- Background subtraction
  - (Madgraph/data-driven when possible)
  - Phase space Bkg subtraction
- Undo detector effects (efficiencies/smearing)
  - **S**ingular **V**alue **D**ecomposition method
  - Alternative models also studied (Bayesian, Inversion, Bin-Bin corr.)



SVD Unfolding

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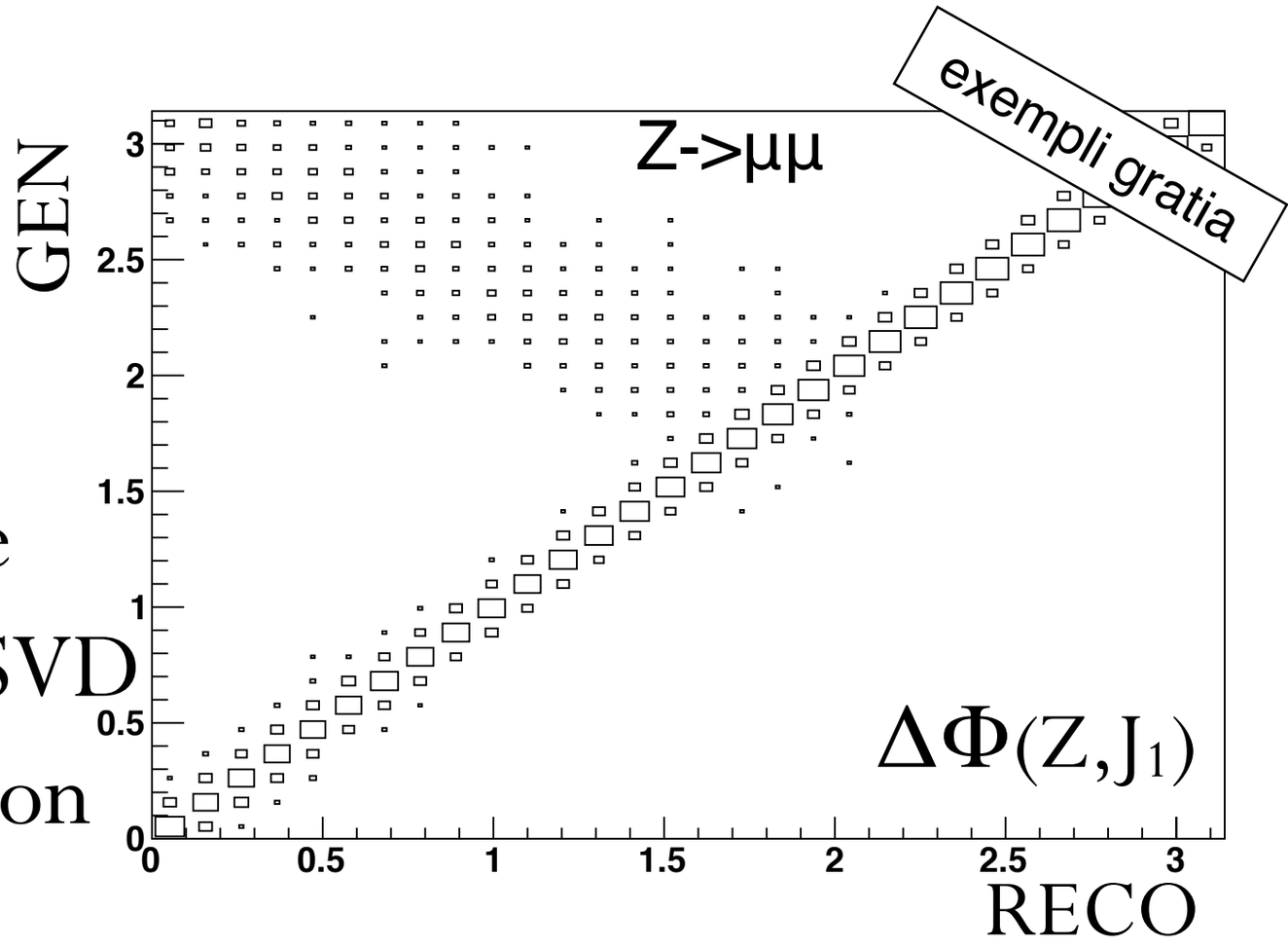
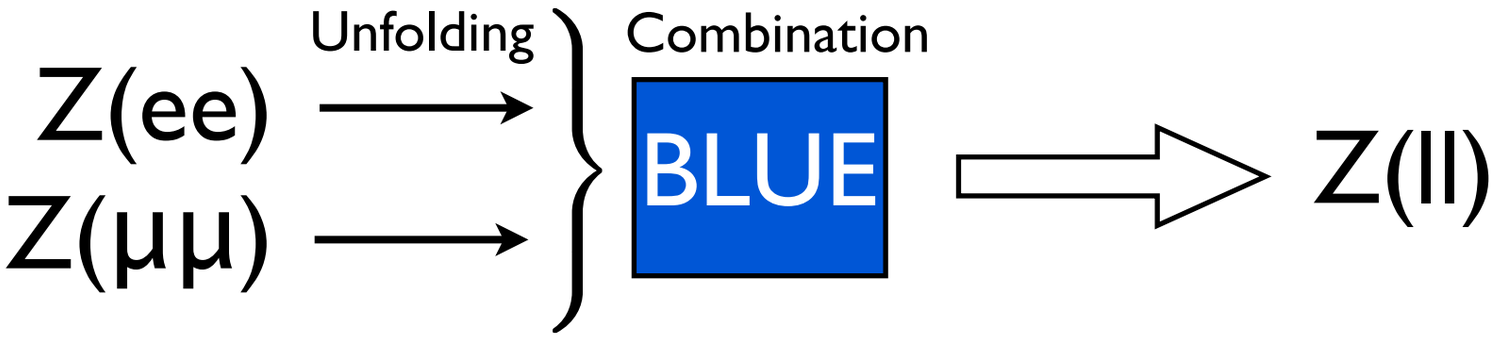
- Response Matrix
  - Madgraph (baseline)
  - Sherpa
- Regularization is done wrt the matrix inversion through the SVD
- Best Linear Unbiased Estimation





A. Hocker and V. Kartvelishvili, "SVD approach to data unfolding", *Nucl. Instrum. Meth.* *A* **372** (1996) 469, doi:10.1016/0168-9002(95)01478-0.

Systematic Uncertainties

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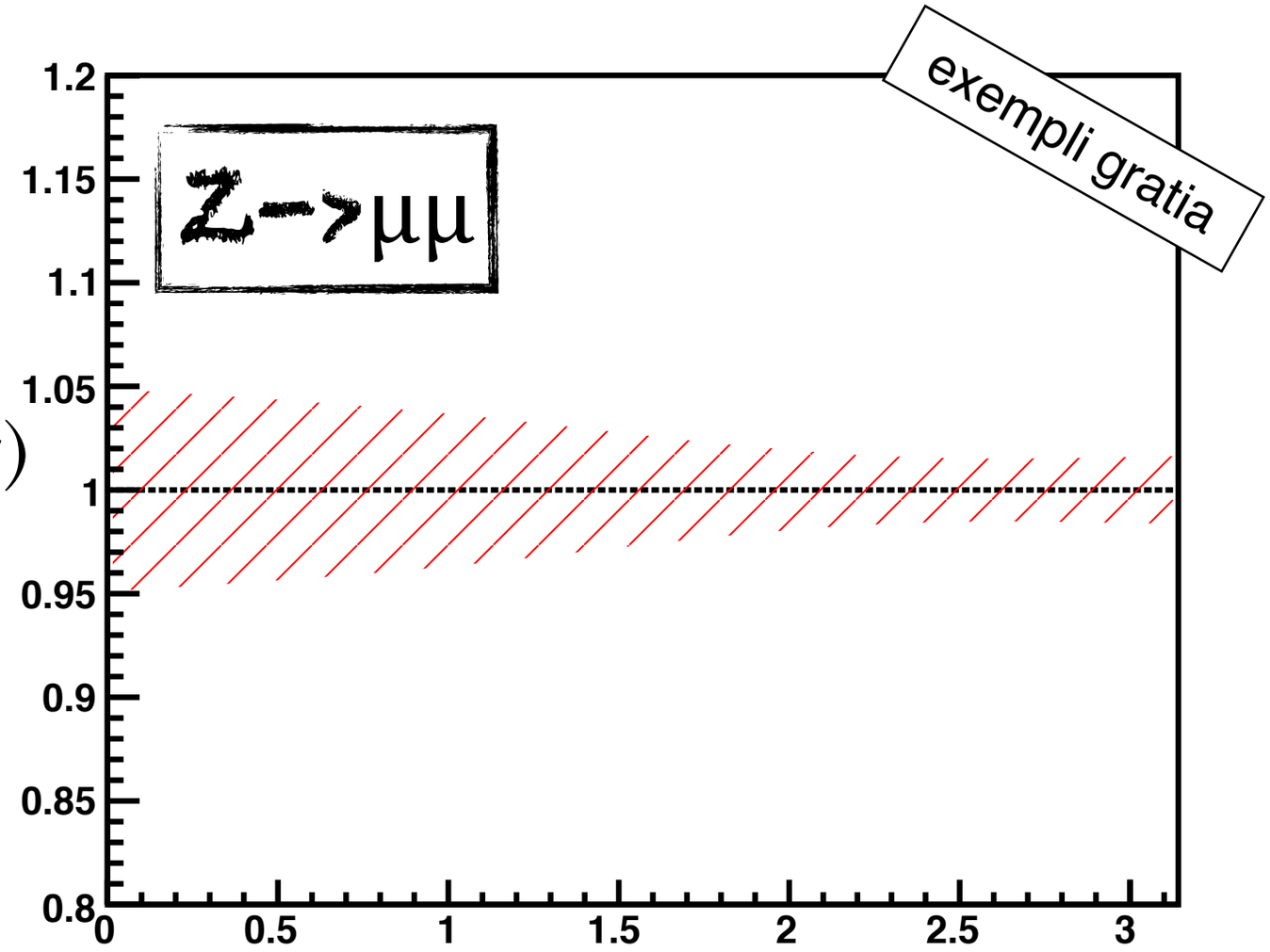
- **J**et **E**nergy **S**cale (5%)
- **J**et **E**nergy **R**esolution
- **B**ackground Subtraction (ttbar)
- **U**nfolding procedure (6%)
- **P**ile-**u**p (5%)



Tot. Sys. $\Delta\Phi$ (Z,J_1)

Background Subtraction

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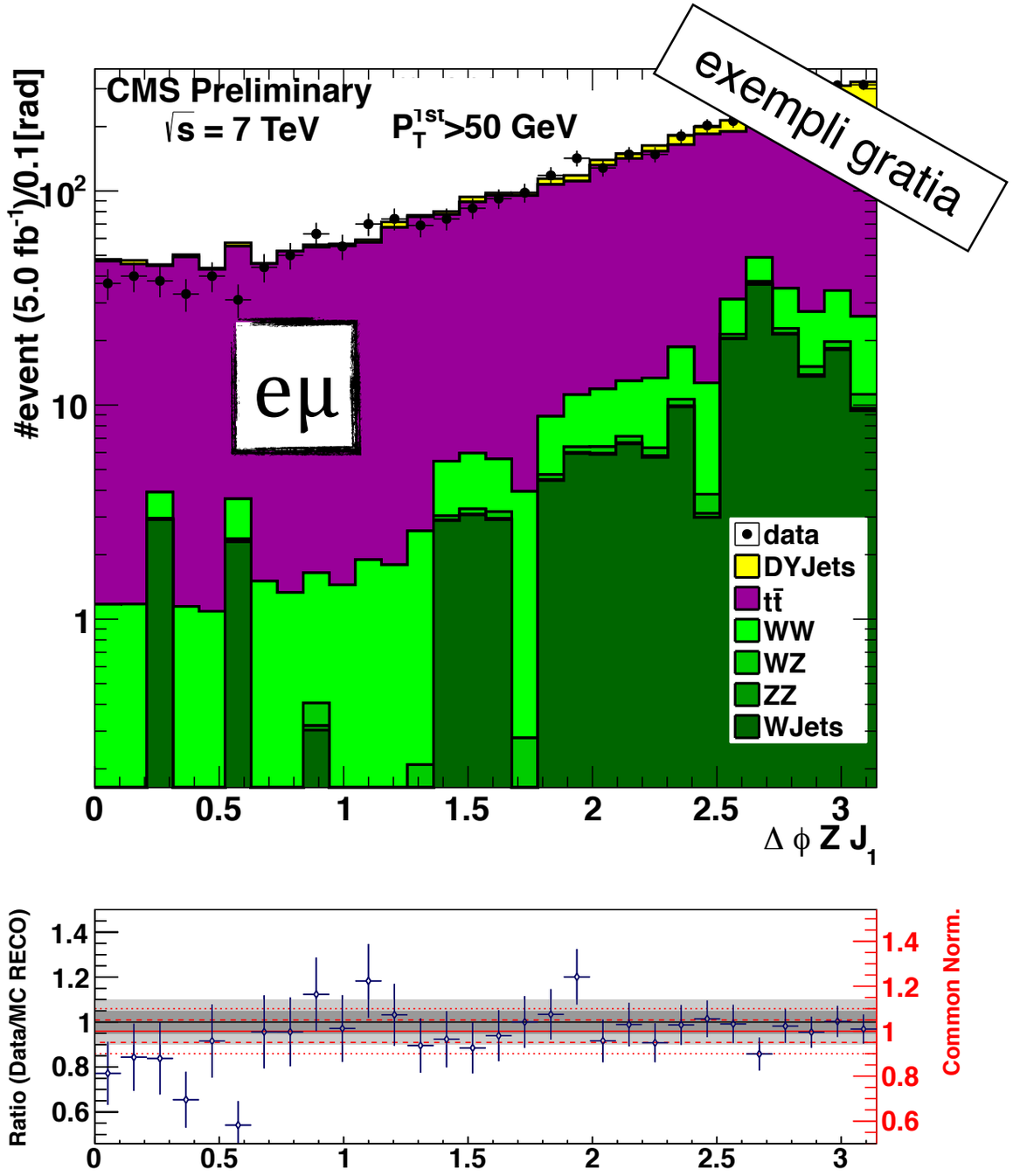
- Main bkg is ttbar
- MC evaluation & data-driven from opposite flavor channel
- shapes differences are evaluated by changing the ttbar yields by 10%.
  This is conservative.
  Total syst is anyway less than 1%.
- Fits are performed
- Uncertainties are propagated through unfolding procedure



Jet Energy Resolution

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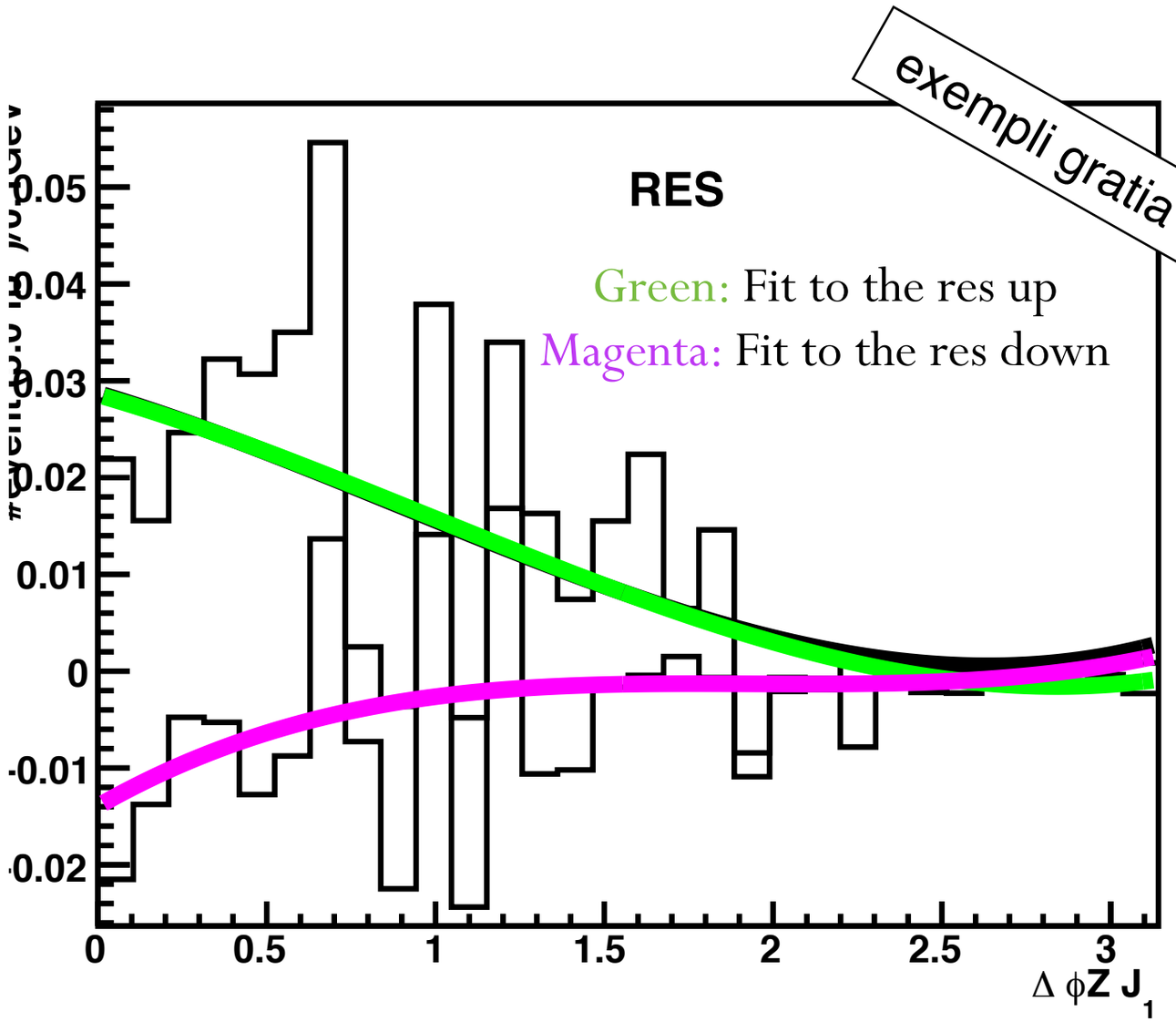
- Shapes are changed by the introduction of a variation on the JER.
- Jets are sorted and maximum difference is taken as uncertainty
- Fit are performed in order to be less sensitive to fluctuations.
- Errors are propagated through the unfolding procedure



$\Delta\Phi(Z,J_1)$

Unfolding

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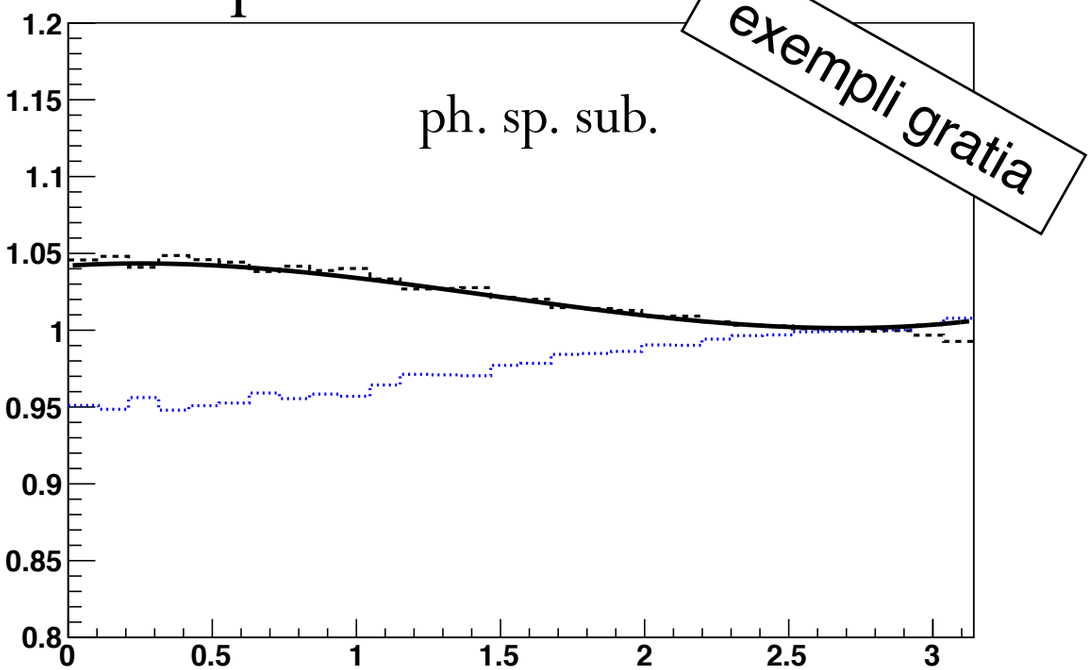
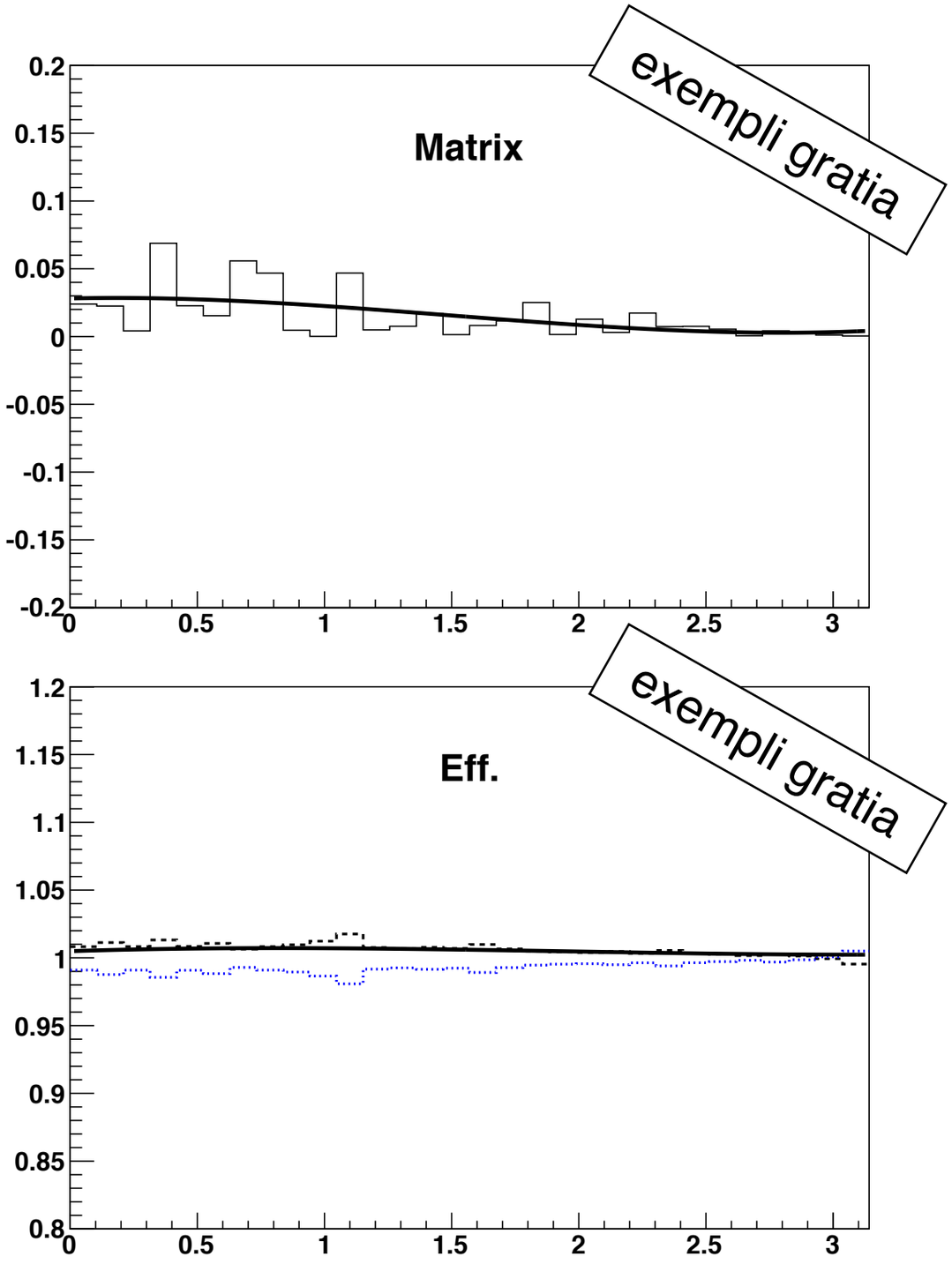
- Each step of the unfolding has a syst. error evaluation
- Variation of 20% of the yields in Monte Carlo are used for the phase space sub. and for the efficiencies corr.
- Difference between sherpa & madgraph matrix are used to evaluate syst uncertainties due to the detector smearing.
- Fit are performed.





$\Delta\Phi(Z,J_1)$

Pile-Up

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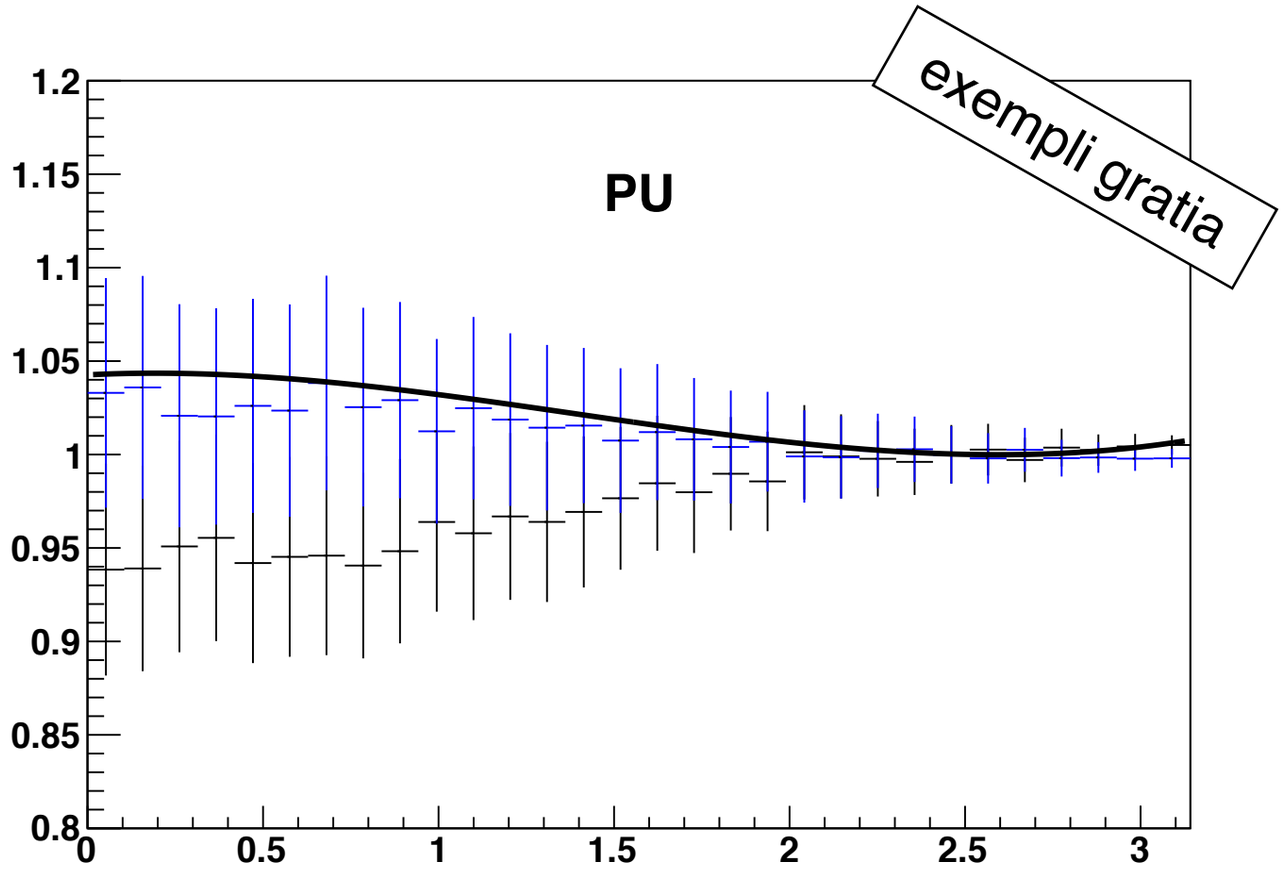
- PU-reweighting to match $N_{MinBias}$ interactions between DATA/MC
- $\sigma_{MinBias}$ varied $\pm 5\%$
- Differences between the new shapes and the reference are fitted
- Negligible in most distributions



Results

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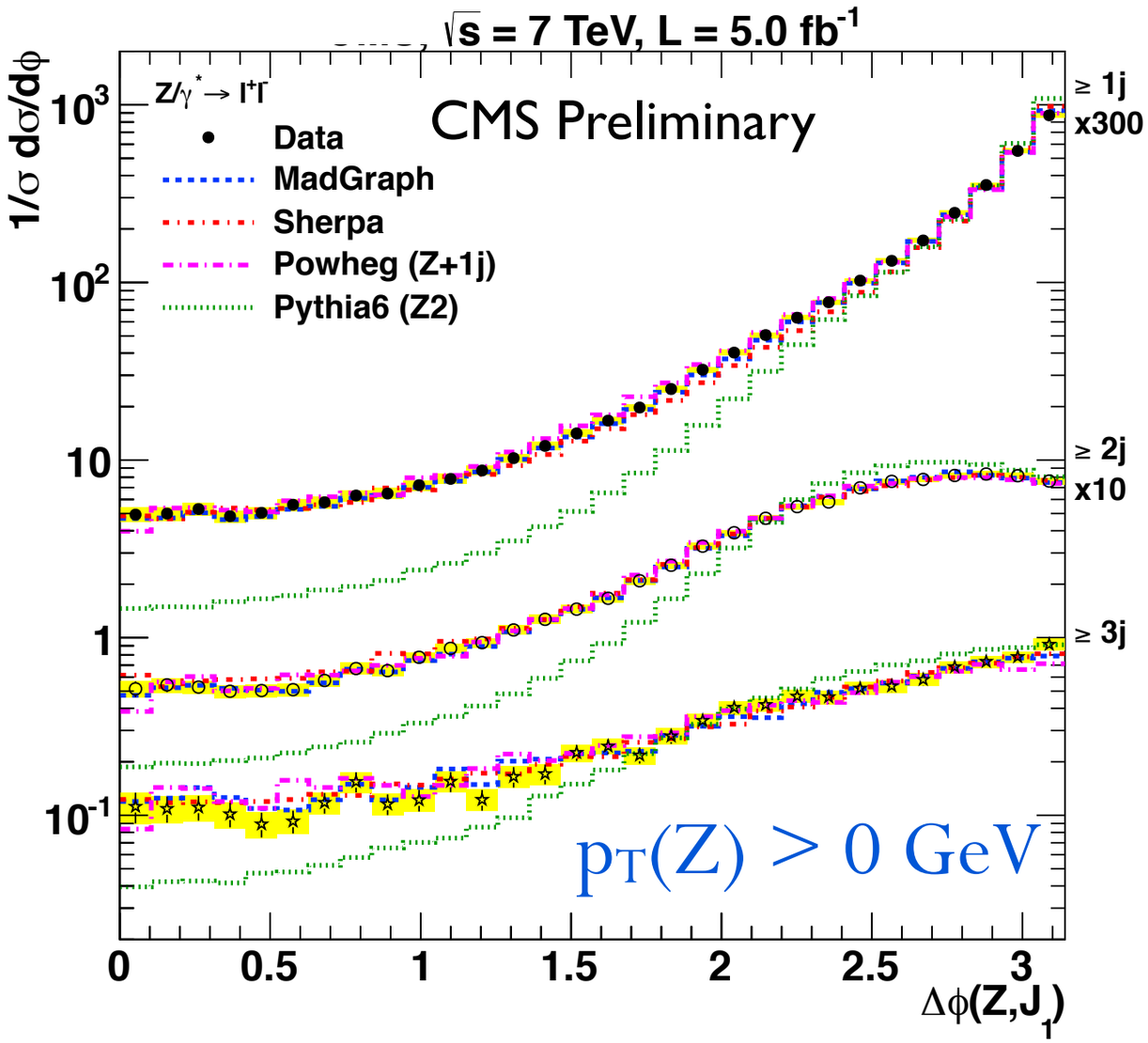

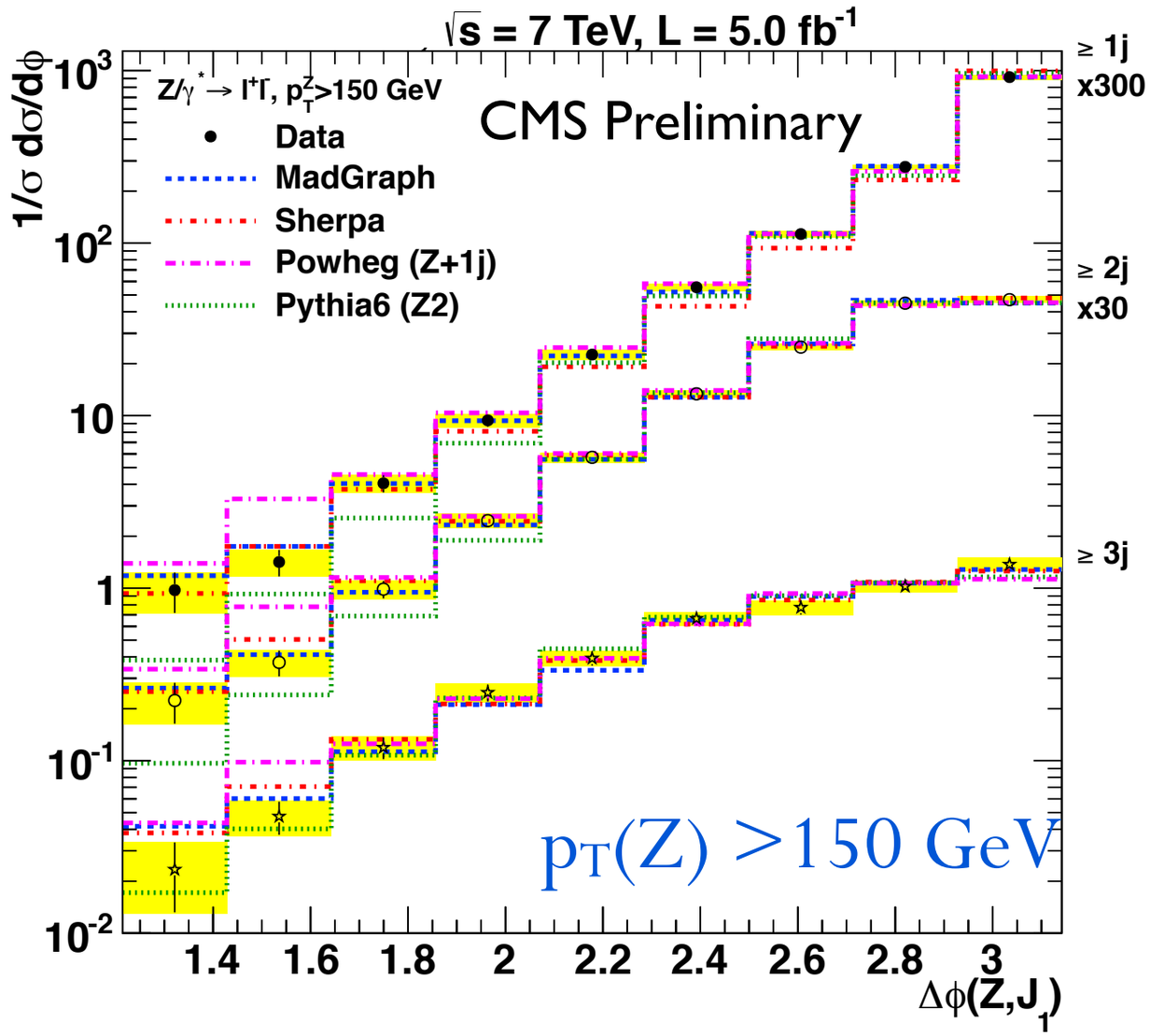

- DeltaPhi(Z,J_1) as function of N_{Jets}
- Madgraph and Powheg are interfaced with Pythia PS
- Standalone Pythia shown for reference to gauge the importance brought by ME/NLO+PS

Results

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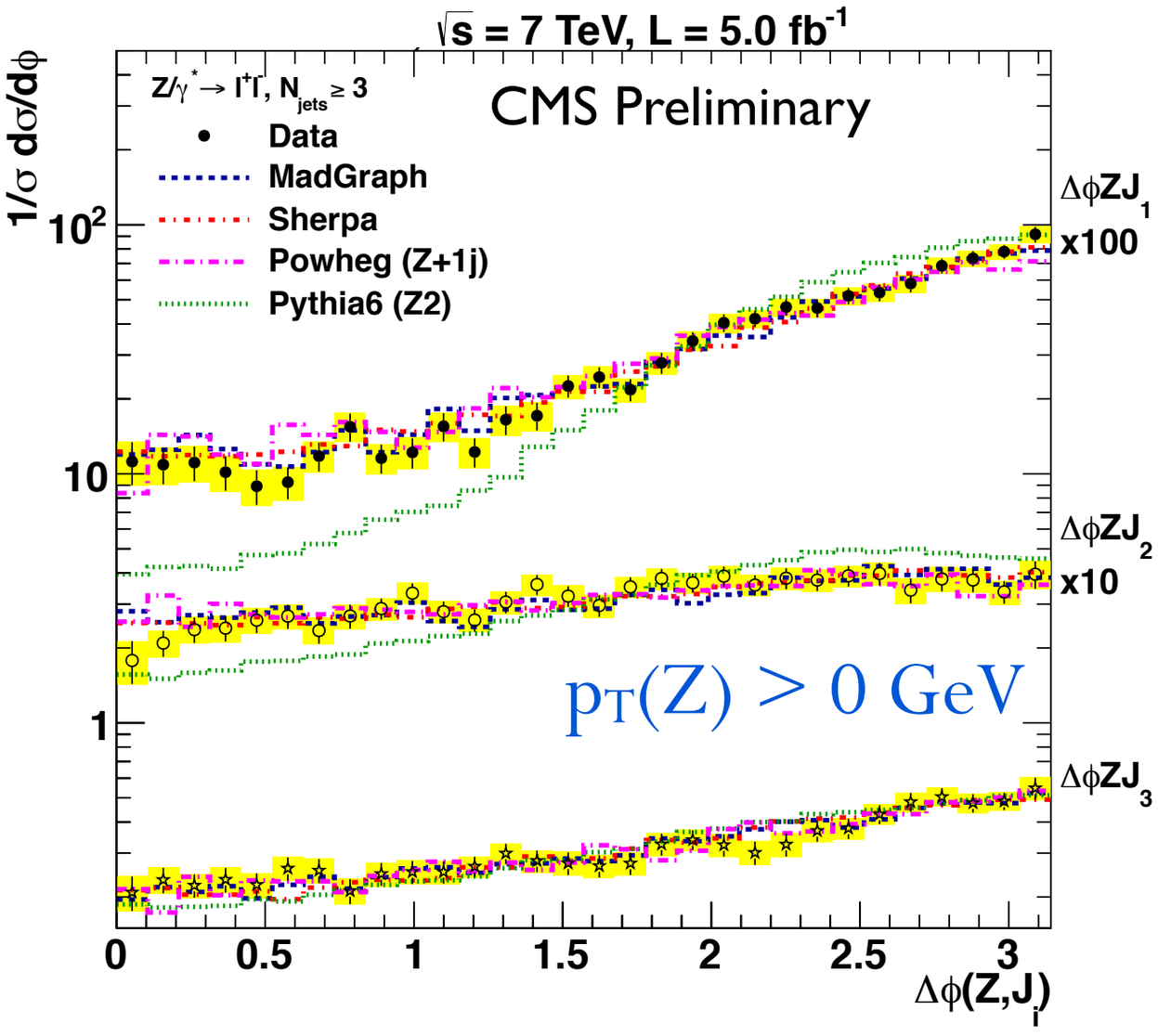

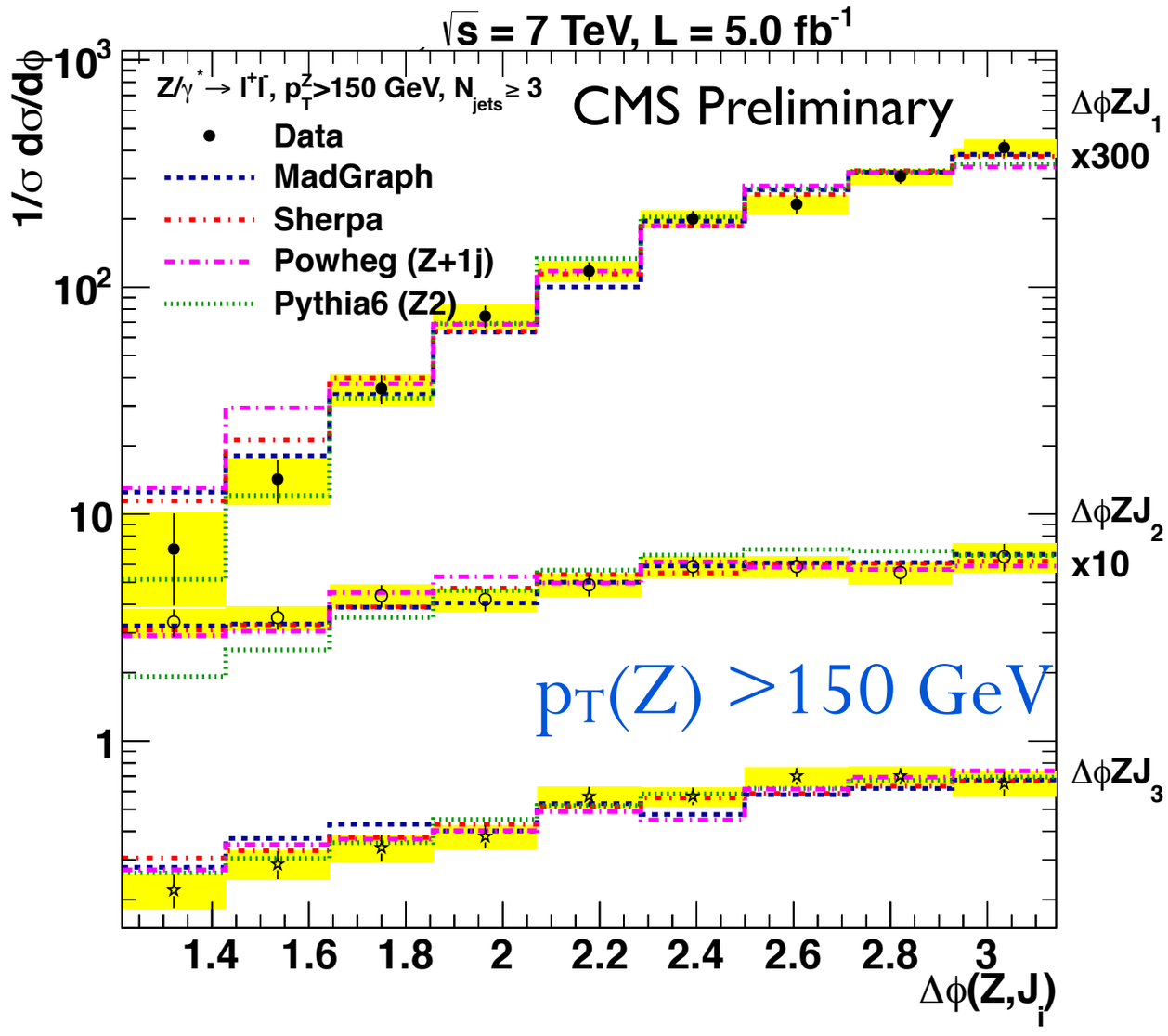

- DeltaPhi(Z,J_i) for Z + ≥ 3Jets
- Madgraph/Powheg/Sherpa are spot-on <10% (ratios on the backup)
- Pythia: description improves for high N_{Jets}/$p_T(Z)$

Results

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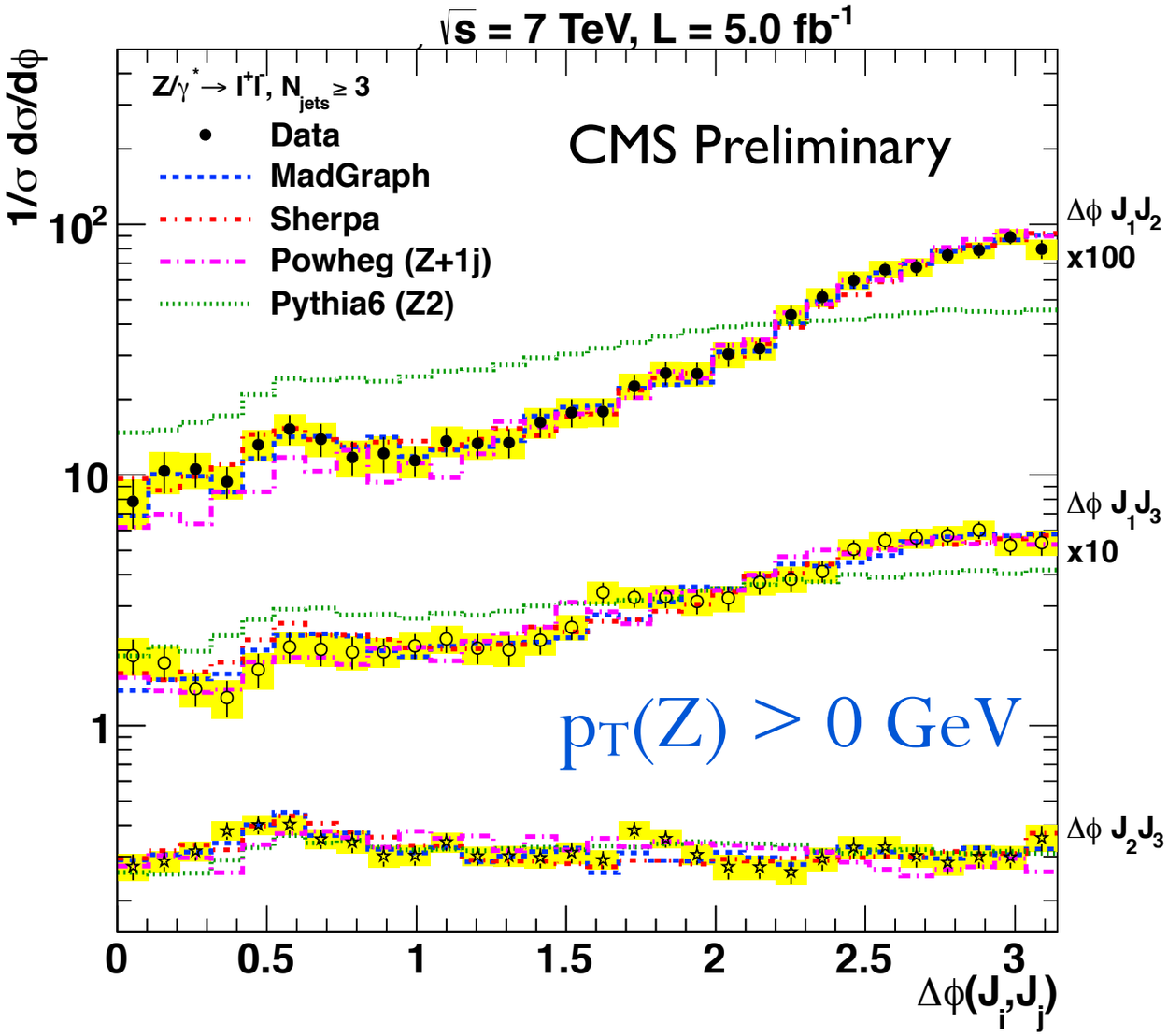

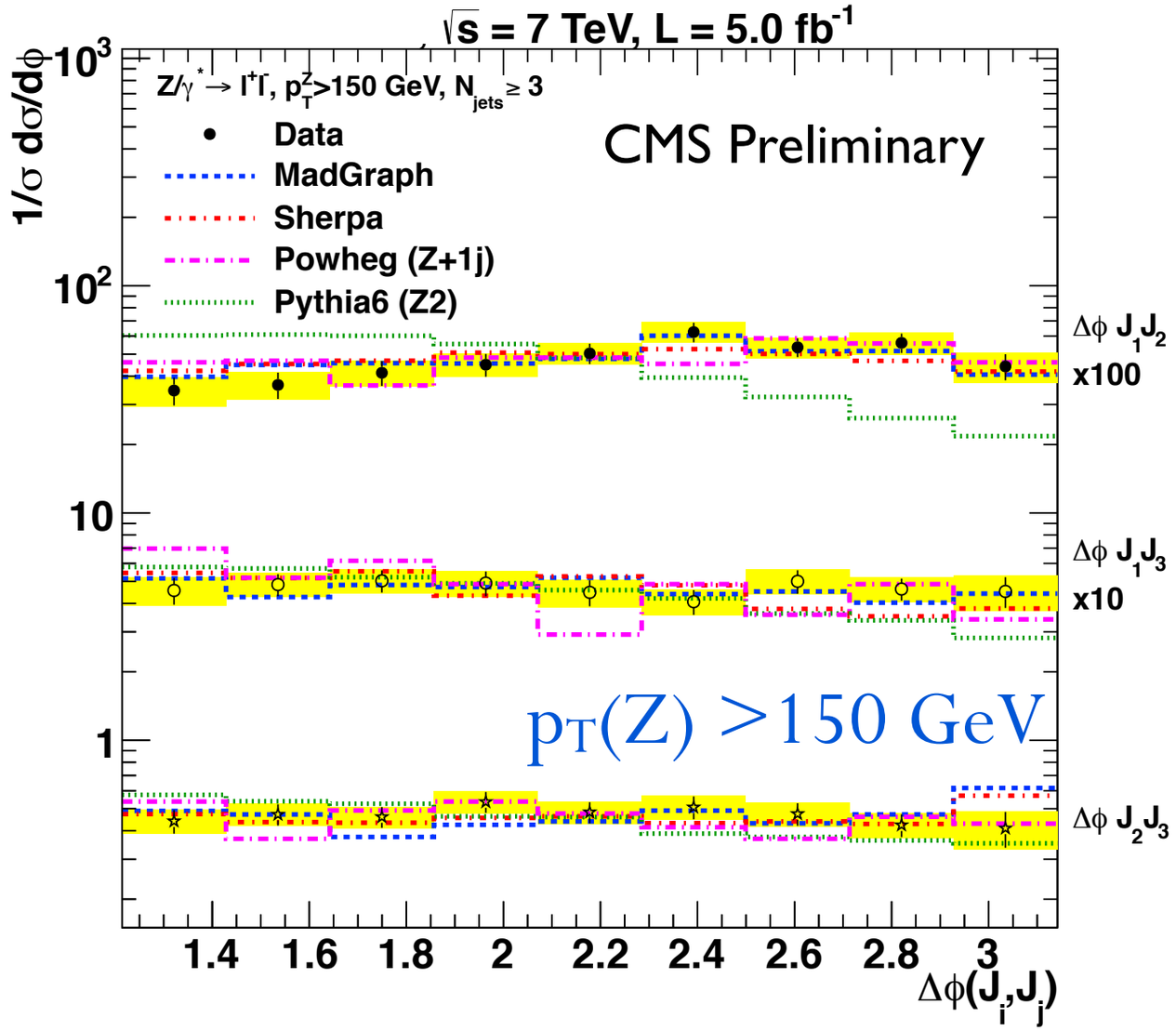

- DeltaPhi(J_i,J_j) for Z + ≥ 3Jets
- Madgraph/Powheg/Sherpa are spot-on <10% (ratios on the backup)
- DeltaPhi(J_i,J_j) angular randomization (flat pdf) at high

Summary

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- First measurement of its kind, binned in N_{Jets} and $p_T(Z)$
- Systematic Uncertainties
  - JES for most bins within 5%
  - PU for most bins within 3%
  - Unfolding for most bins within 6%
    - Small compared to statistical fluctuations
- ME+PS has good agreement in all regions probed
- PS becomes more important for subleading jets in boosted events
- NLO (Z+1 jet) merged with PS (Powheg) impressive performance
- Confidence in these MC models for SM description and for searches
- Analysis documented in EWK-11-021 aiming PLB

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEWK11021

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Backup

Ratio I

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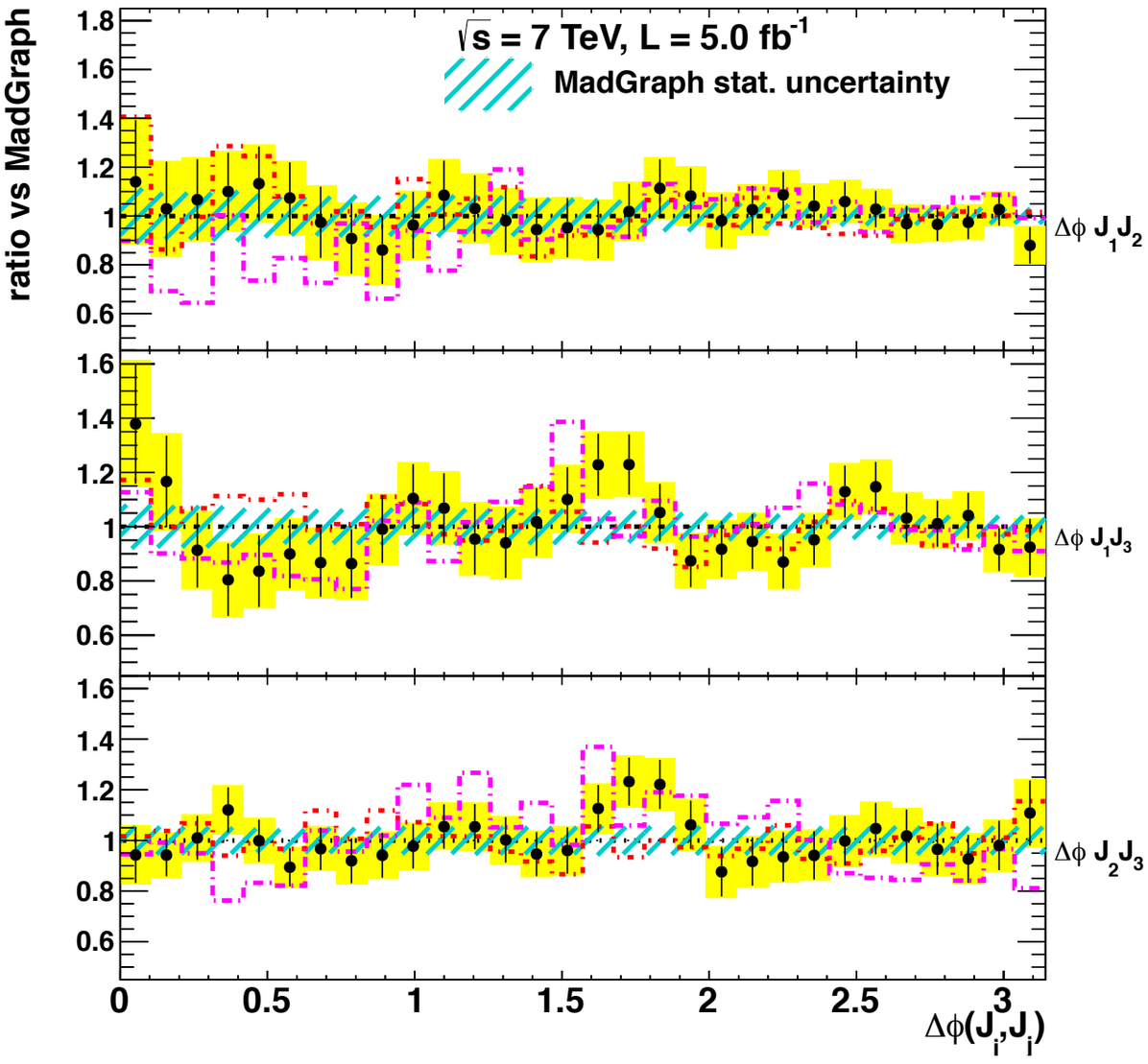
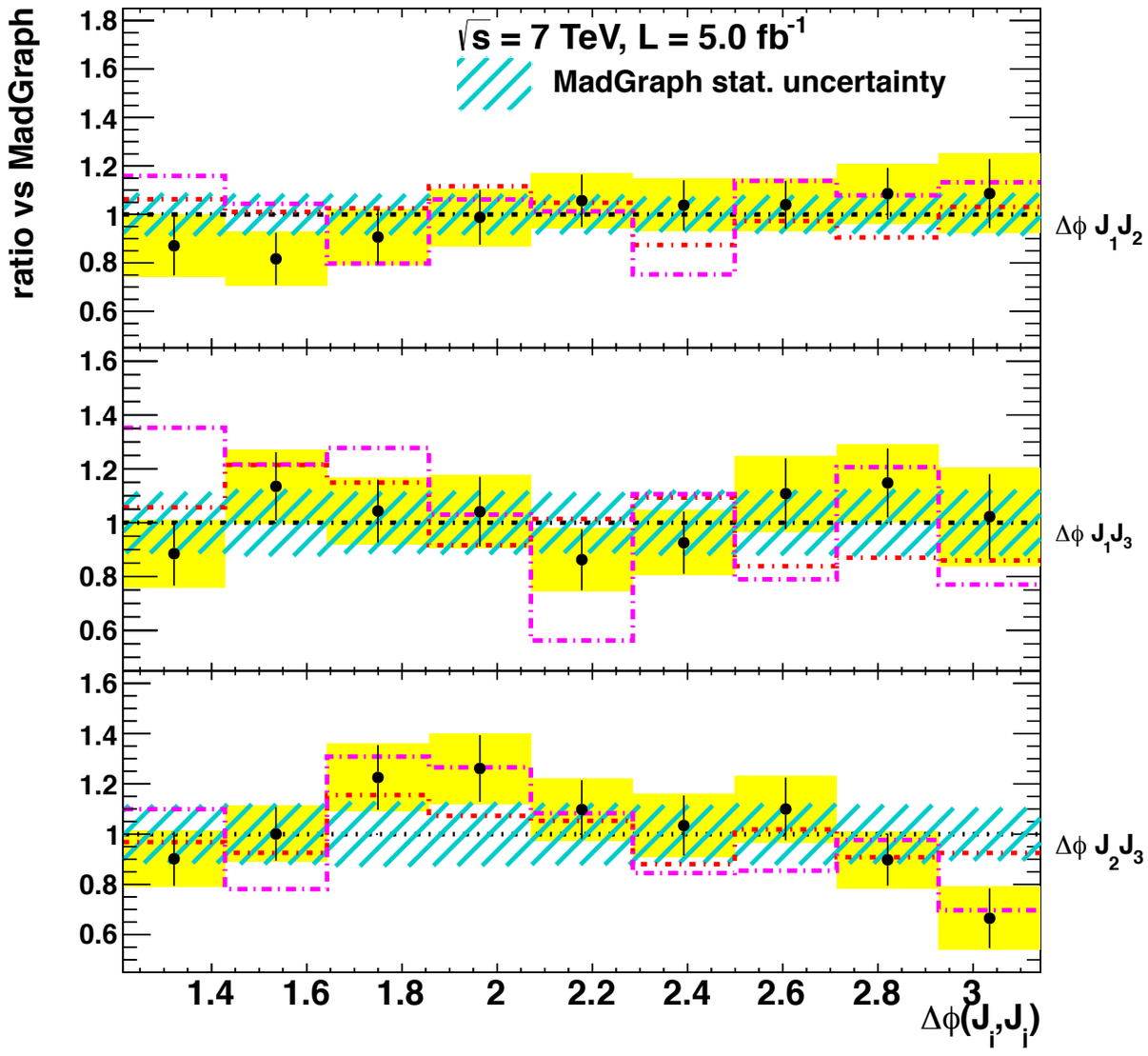
CMS Preliminary



CMS Preliminary



Ratio II

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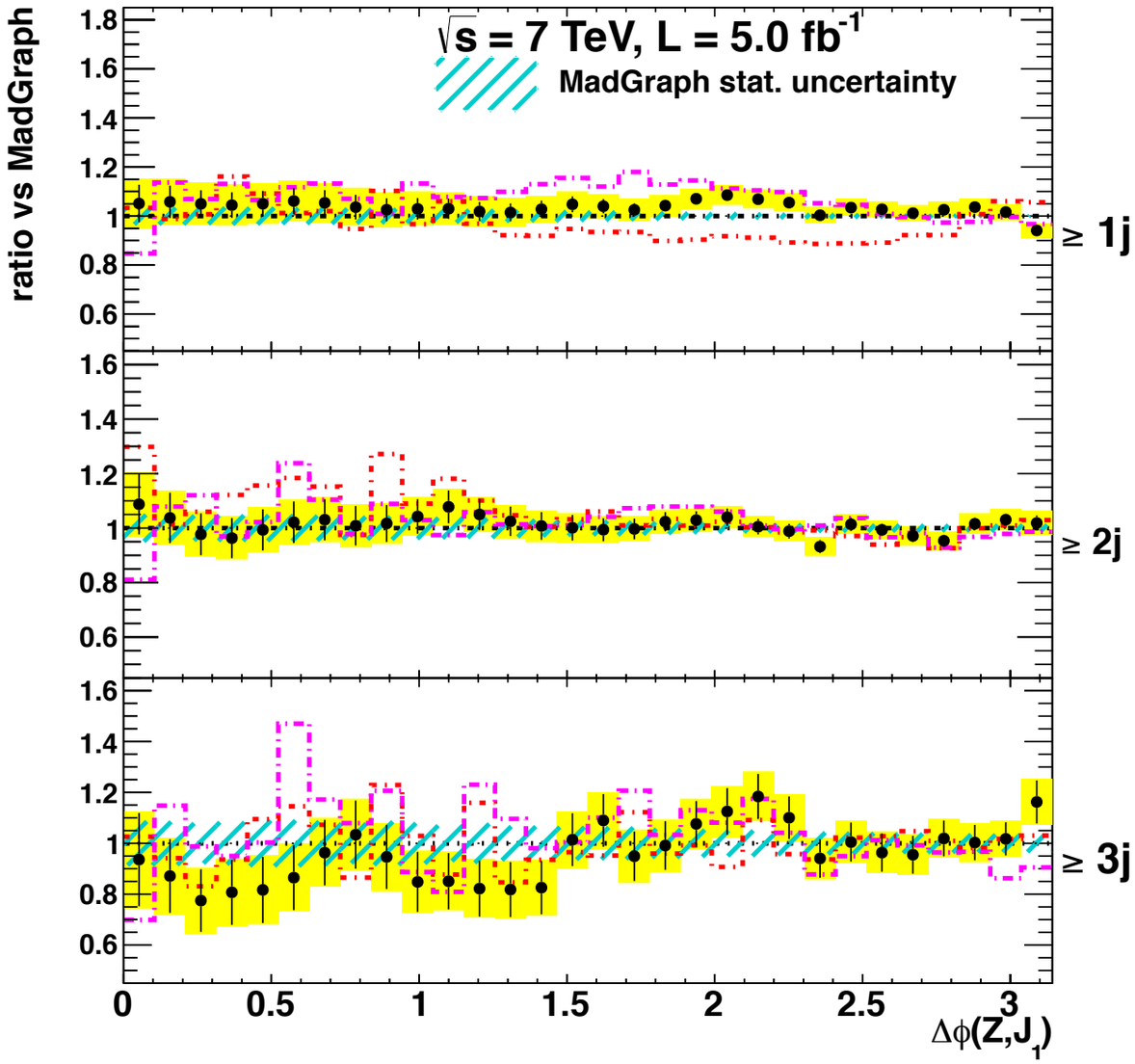
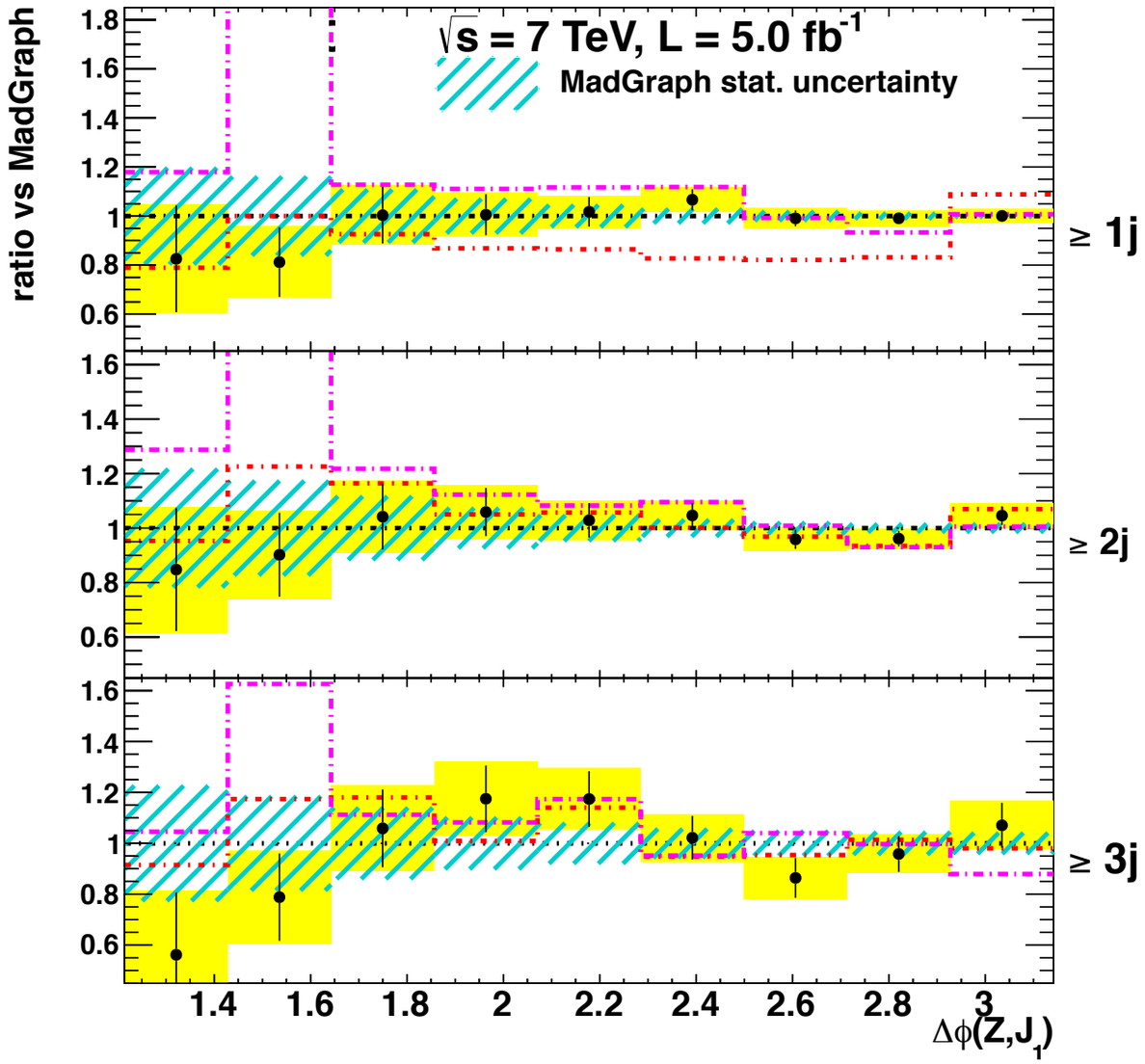
CMS Preliminary



CMS Preliminary



Ratio III

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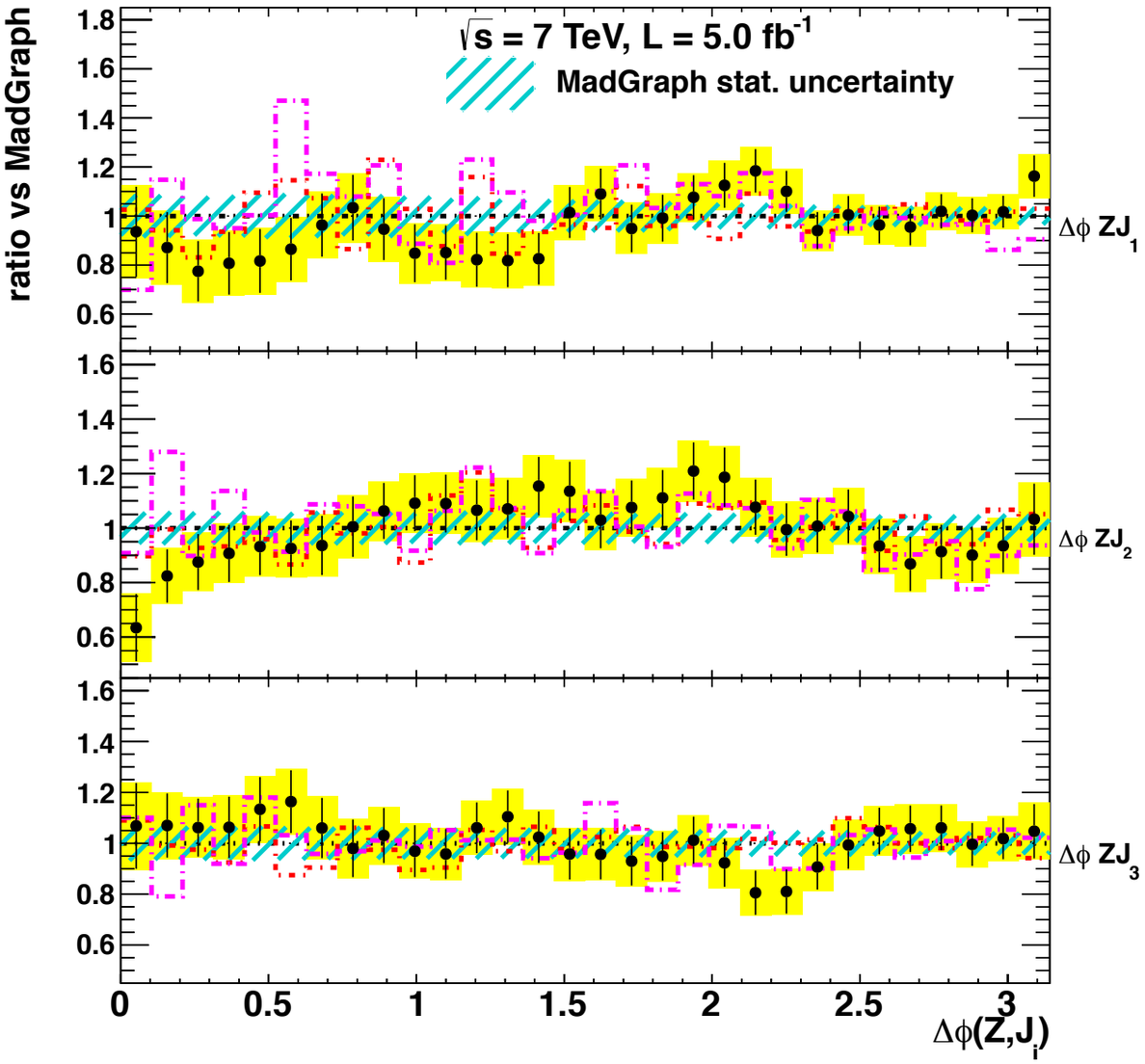
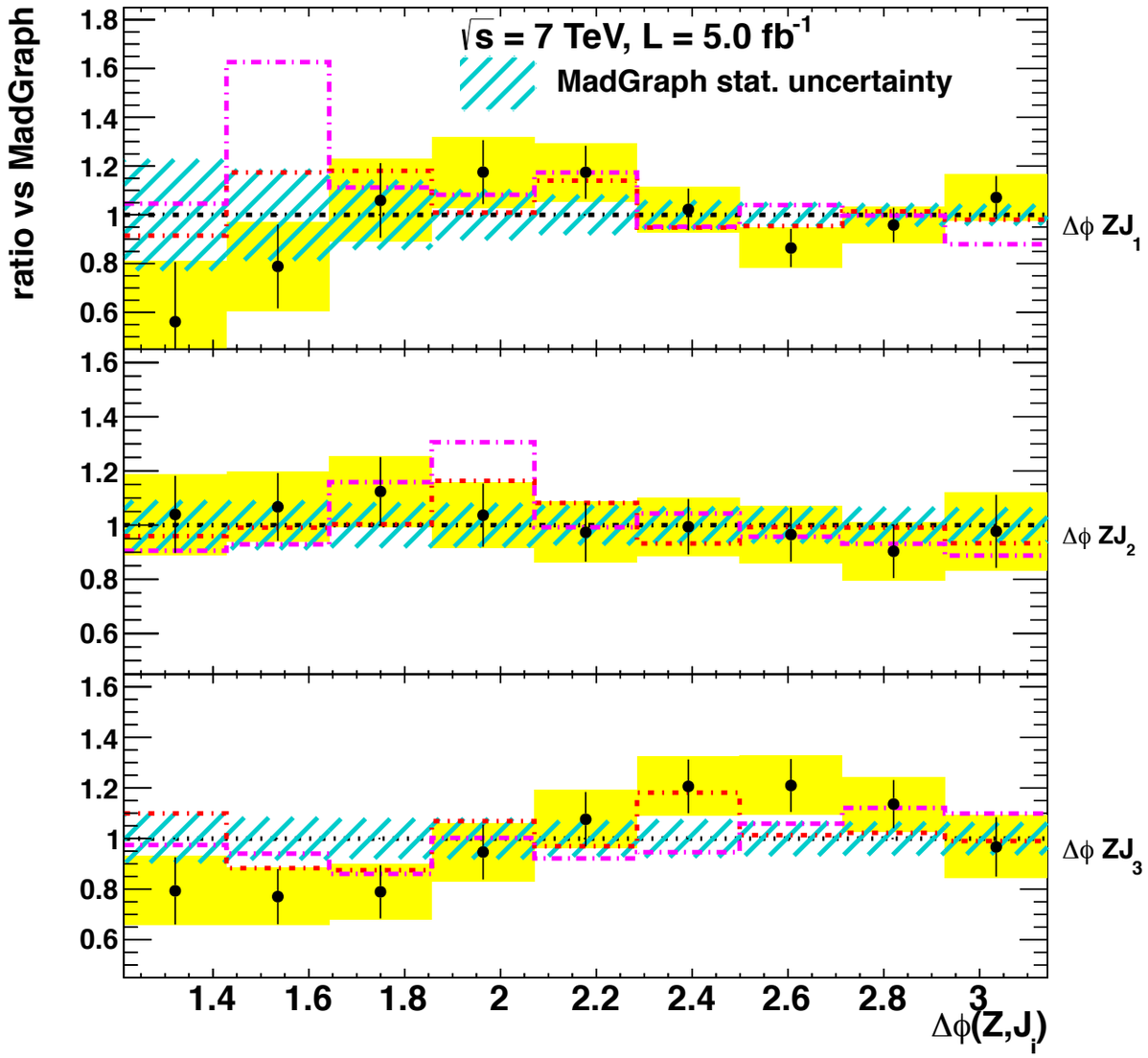
CMS Preliminary



CMS Preliminary



Distributions at detector level

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