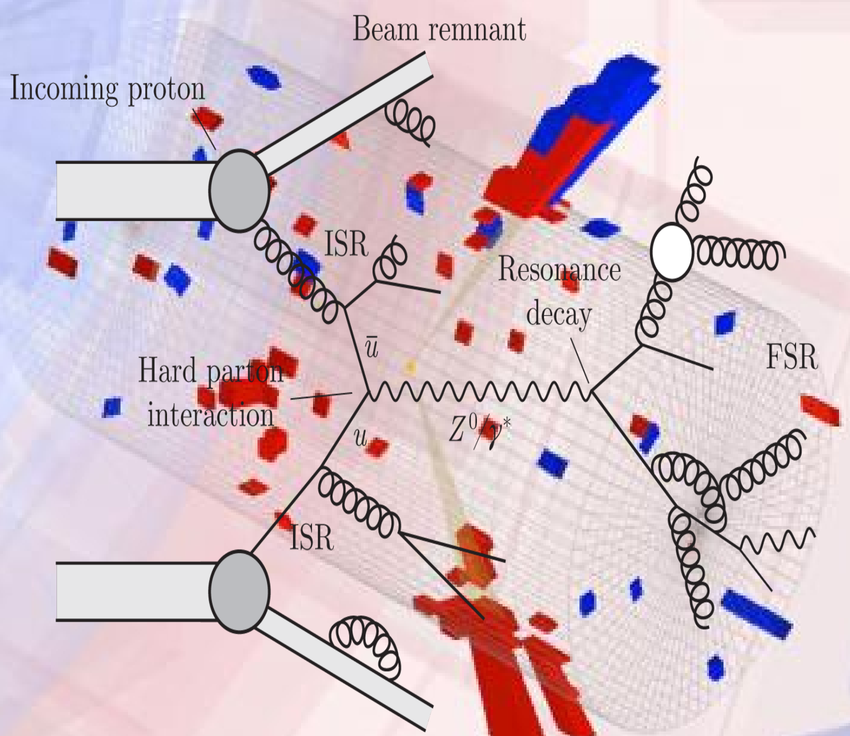
CMS Experiment at LHC, CERN
Data recorded: Tue May 5 11:05
Run/Event: 243484 / 35552557
Lumi section: 50
Orbit/Crossing: 12904927 /

Search for BFKL signatures in CMS



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Adiyaman University
On behalf of the CMS Collaboration

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Low-x 2021

26 September 2021 to 1 October 2021
Europe/Zurich timezone

Outline

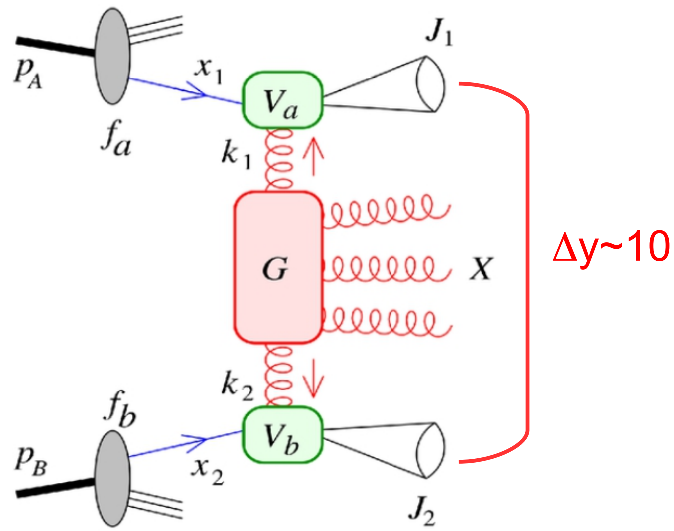
- Introduction
- Overview of recent measurements by CMS
    - Azimuthal decorrelation of jets widely separated in rapidity in pp collisions at 7 TeV JHEP 08 (2016) 139
    - Study of dijet events with large rapidity separation between the jets in pp collisions at 2.76 TeV **(CMS PAS FSQ-13-004, will be submitted to JHEP soon)**
    - Hard color-singlet exchange in dijet events in pp collisions at 13 TeV (Phys. Rev. D **104**, 032009) (details in **C. Baldenegro's talk!**)
- Summary

Motivation

- **At high $\sqrt{s}$,** a kinematical domain can be reached where semi-hard parton interactions with **p_T << $\sqrt{s}/2$** play a substantial role.

This asymptotical domain is described by **Balitsky-Fadin-Kuraev- Lipatov (BFKL)** .

- One of the most famous testing grounds for BFKL physics are the **Mueller - Navelet jets** with large **y** separation



- Differential cross section of the two jets production

$$\frac{d\sigma}{d|\mathbf{k}_{J,1}|\, d|\mathbf{k}_{J,2}|\, dy_{J,1}\, dy_{J,2}} = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2\, f_a(x_1) f_b(x_2) \frac{d\hat{\sigma}_{ab}}{d|\mathbf{k}_{J,1}|\, d|\mathbf{k}_{J,2}|\, dy_{J,1}\, dy_{J,2}}$$

Collinear PDF

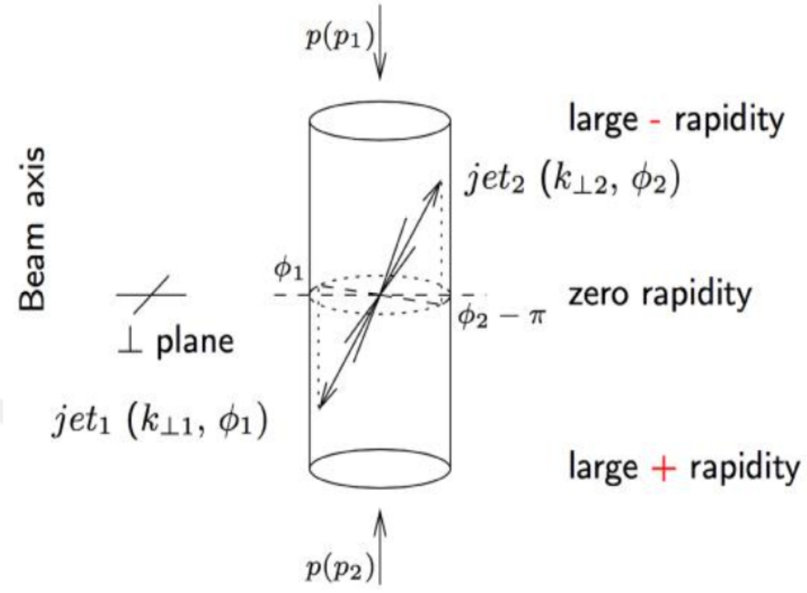
- Partonic cross section in the BFKL framework:

$$\int d\phi_{J,1}\, d\phi_{J,2} \int d^2\mathbf{k}_1\, d^2\mathbf{k}_2\, V_a(-\mathbf{k}_1, x_1)\, G(\mathbf{k}_1, \mathbf{k}_2, \hat{s})\, V_b(\mathbf{k}_2, x_2)$$

$V_{a,b}$: jet vertices
G: BFKL Green's function

Motivation

- **Two jet production at LO:**
  - deal with a **back-to-back** reaction
  - expect the azimuthal angles of the two jets always to be π
  - hence completely correlated!
- When **y between these jets increase**, the phase space allows for more and more emissions leading to an **angular decorrelation** between the jets.



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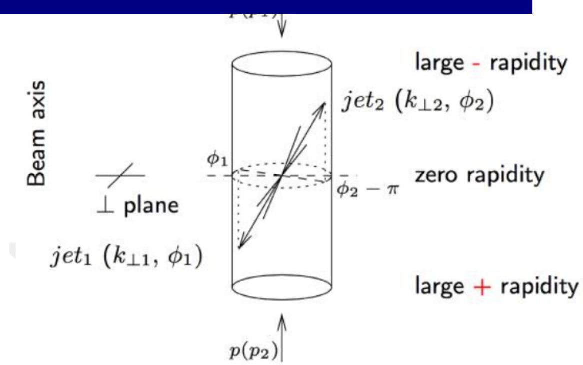
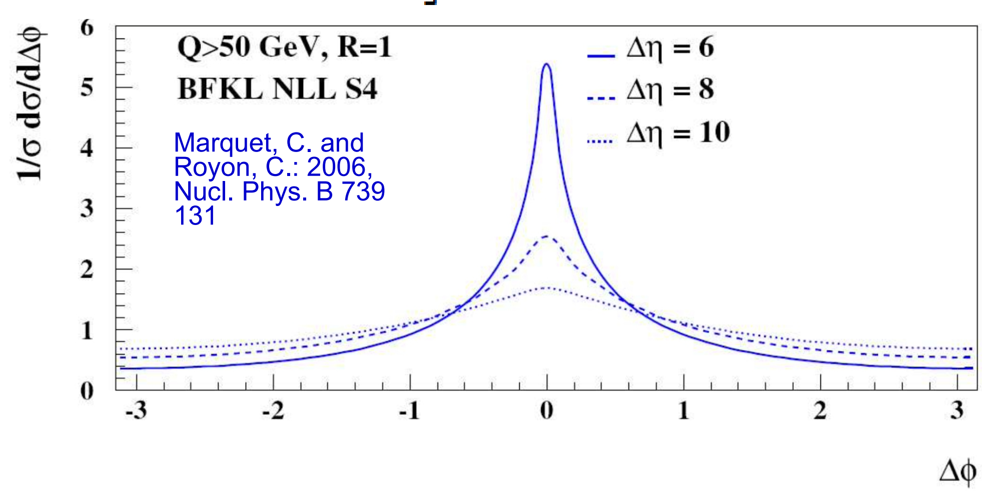


- When **y between these jets increase**, the phase space allows for more and more emissions leading to an **angular decorrelation** between the jets.

- Normalised cross section as a function of **azimuthal angle difference** ($\Delta\phi = \phi_1 - \phi_2$) between MN Jets

$$\frac{1}{\sigma}\frac{d\sigma}{d(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}}) \cdot cos(n(\pi - \Delta\phi))\right]$$



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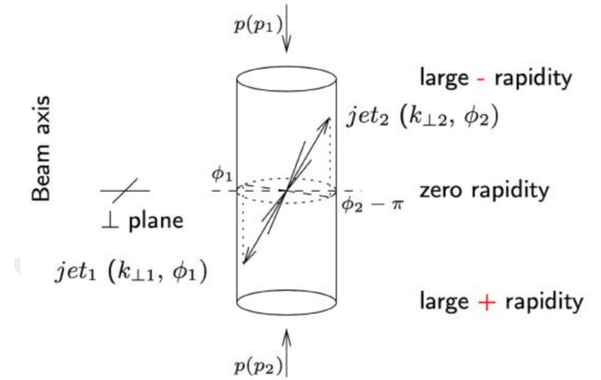

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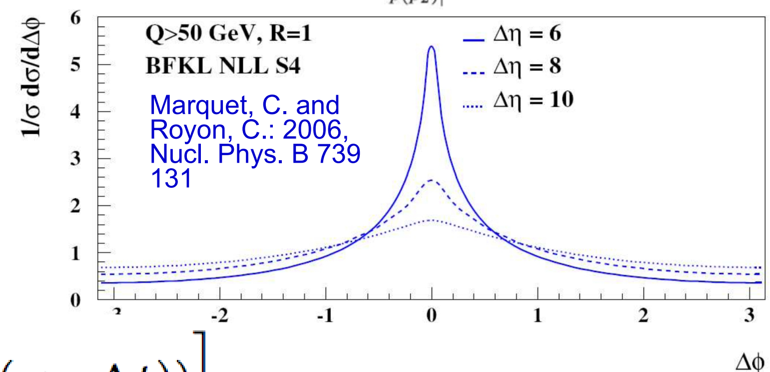

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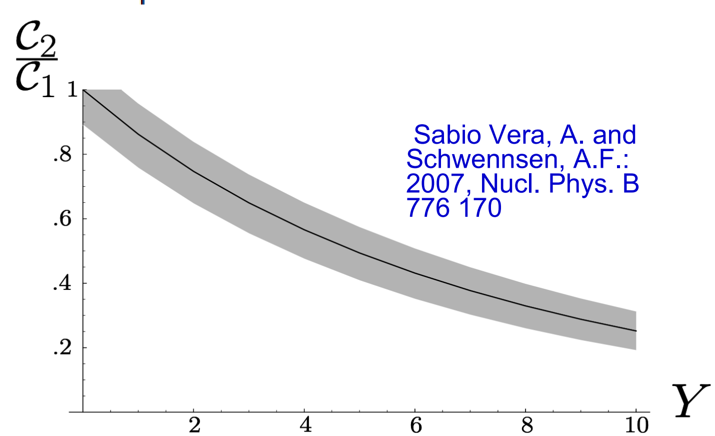


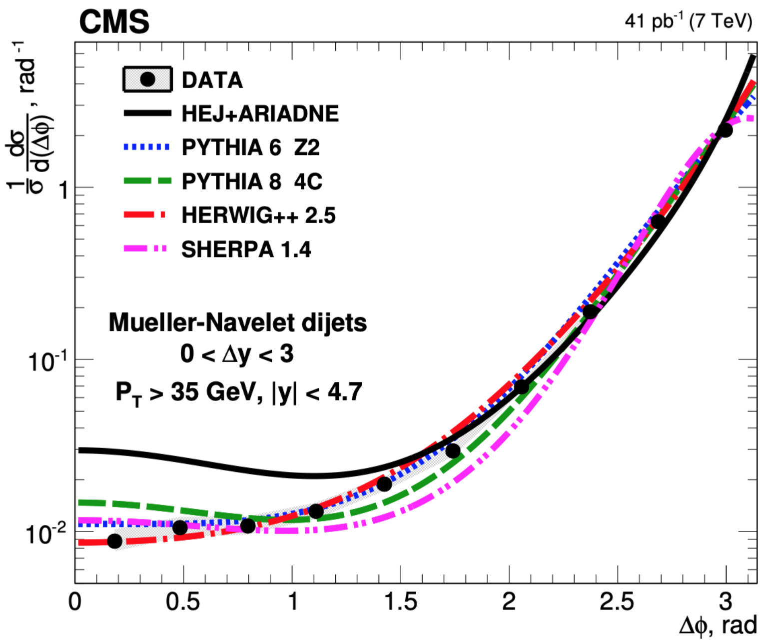
- The Fourier coefficients C_n are equal to the average cosines of the decorrelation angle

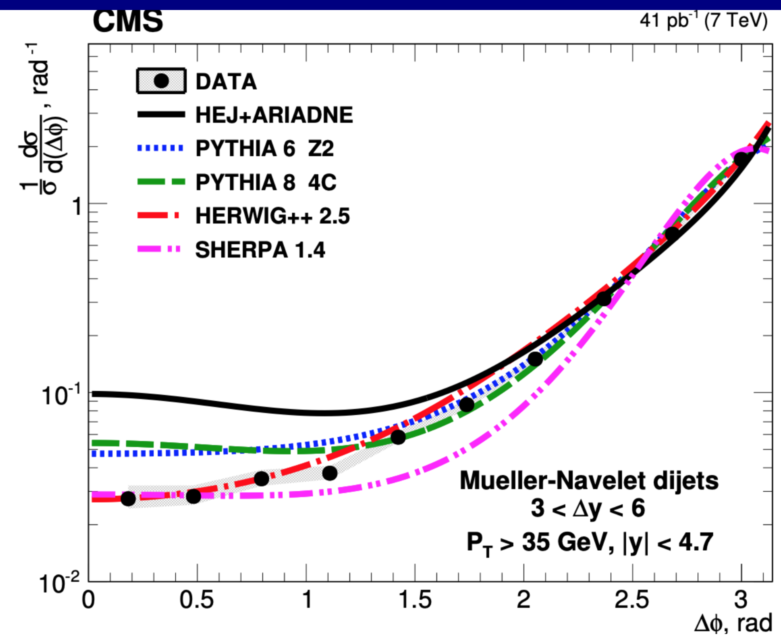
$$C_n(\Delta y, p_{\mathrm{Tmin}}) = \langle \cos(n(\pi - \Delta\phi)) \rangle$$

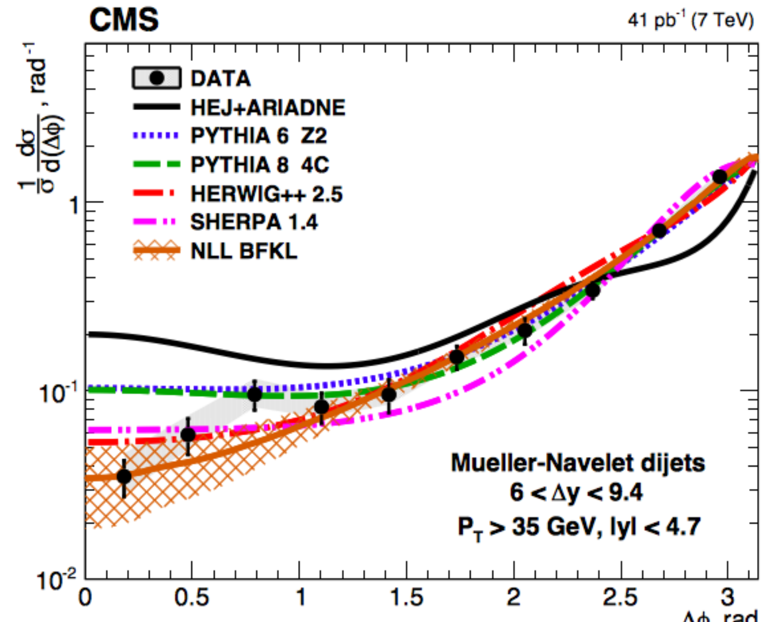
- **Decorrelation coefficients are the observables can be measured at the LHC experiments!**

Decorrelation of forward jets at 7 TeV

JHEP 08 (2016) 139



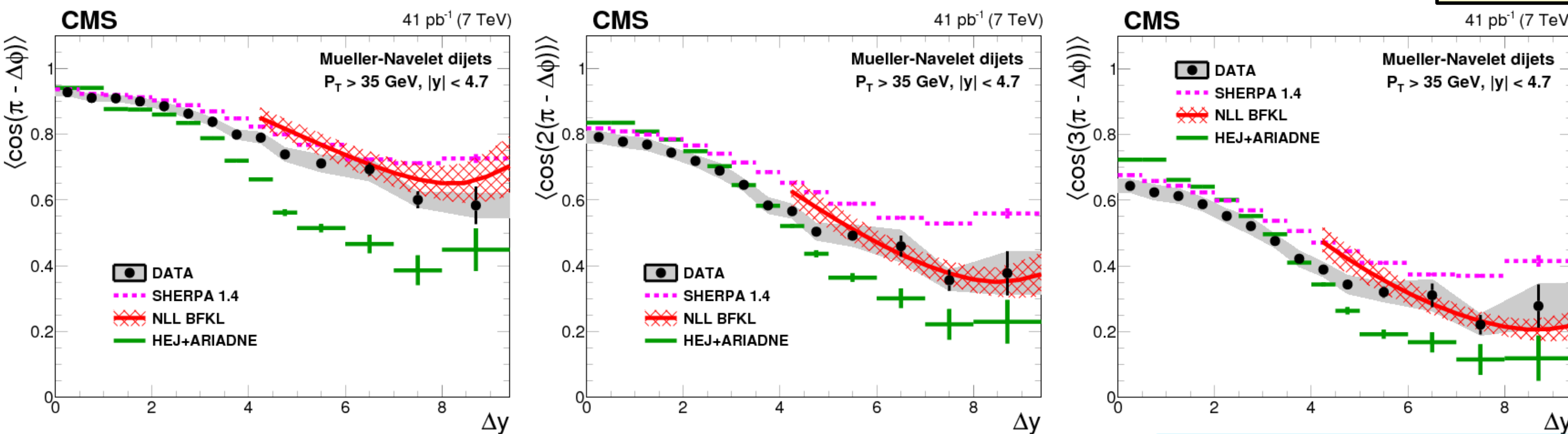


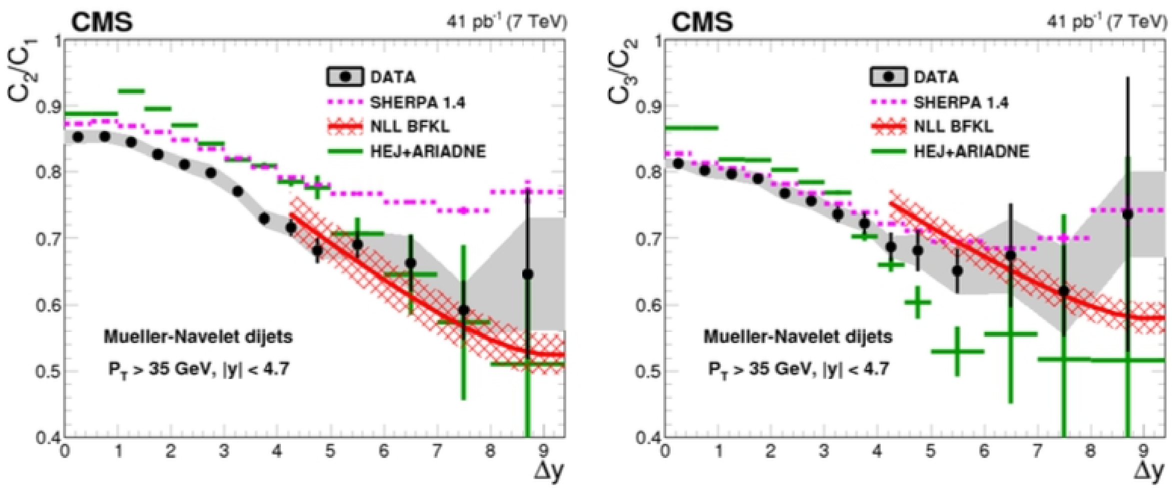


- Most forward and most backward jets with p_T > 35 GeV
- Results given for up to |Δy| = 9.4
- Compared to predictions
  - DGLAP-based LO MCs
  - HEJ: LL BFKL-based MC
  - NLL BFKL prediction
- Angular variables also studied as a function of Δy

Mueller-Navelet dijet azimuthal decorrelations

JHEP 08 (2016) 139





- MN dijets: pair of jets with the largest rapidity interval
- Decorrelation of Δϕ MN pair: sensitive to QCD dynamics
- Cross section vs. Δϕ expanded in terms of cos[n(π-Δϕ)]
  - expansion coefficients and their ratio depend on Δy
  - region of large Δy probes the BFKL evolution

- Good data-theory agreement: NLL BFKL analytical calculations at large Δy
- BFKL NLL calculations, parton level (small effects from hadronization) (JHEP 1305(2013) 096) sensitivity to MPI and angular ordering

$$\frac{1}{\sigma}\frac{d\sigma}{d(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1+2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}})\cdot cos(n(\pi-\Delta\phi))\right]$$

Dijets with large rapidity separation @ 2.76 TeV

NEW!

CMS PAS FSQ-13-004

- Scattering in the Bjorken limit ($s \sim Q^2 \gg m^2$, $x \sim 1$) is described by DGLAP evolution.
- Dijets with large rapidity separation (small-x, $s \to \infty \gg Q^2$ − fixed $\gg \Lambda^2_{QCD}$) are recognised as a sensitive probe for effects of BFKL evolution

- Dijet K-factor is a theoretical quantity:

  K-factor = cross-section / Born cross-section

  - Born cross-section:
    - no real and virtual corrections
    - In experimental point of view, virtual corrections cannot forbidden by kinematical condtions, so not measurable
  - Exclusive dijet cross-sections contain virtual corrections.

- **Analysis :**
  - $\Delta y = |y_1 - y_2| < 9.4$
  - $p_T > p_{T,min} = 35$ GeV
  - low PU data
  - Anti-k_T jets with R = 0.5

Dijets with large rapidity separation @ 2.76 TeV

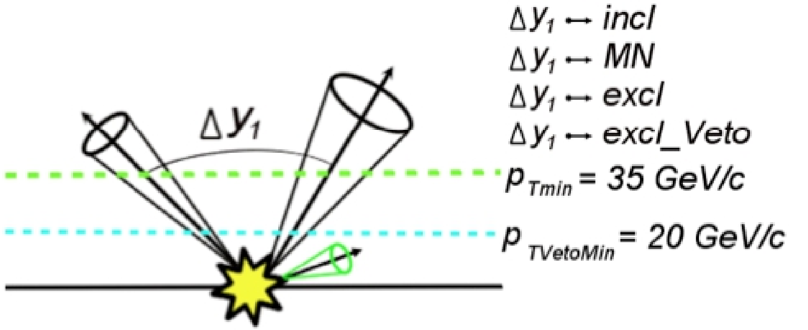
CMS PAS FSQ-13-004

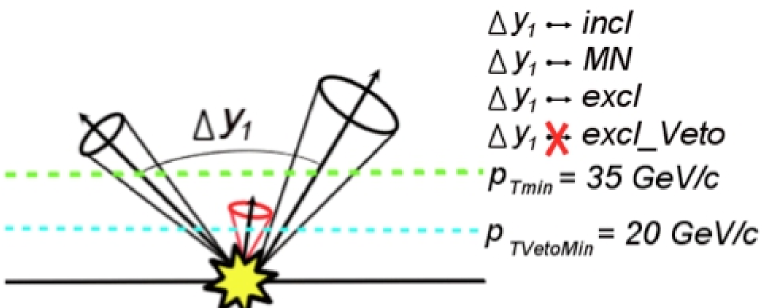
- **Definitions:**
  - σ_{incl} (inclusive x-section): all dijets with jets p_T > 35 GeV
  - σ_{excl} ("exclusive" x-section): exactly one dijet with jets p_T > 35 GeV in the event
  - σ_{MN} (Mueller-Navelet x-section): only the dijet with the most forward and most backward jets with p_T > 35 GeV
  - $\sigma_{excl\ veto}$ ("exclusive with veto" x-section): "exclusive" x-section, no extra jets above p_{Tveto} = 20GeV
  - **Lowering the veto threshold p_{Tveto} makes the R^{incl} and R^{MN} ratios closer to the theoretical K factor and increases the sensitivity to BFKL evolution effects.**

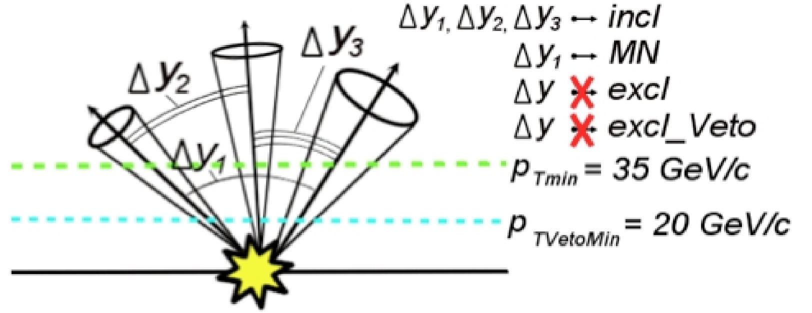
- **Observables : differential cross sections and ratios**

$$\mathrm{d}\sigma^{\mathrm{incl}}/\mathrm{d}\Delta y,\quad \mathrm{d}\sigma^{\mathrm{MN}}/\mathrm{d}\Delta y,$$

$$R^{\mathrm{incl}} = (\mathrm{d}\sigma^{\mathrm{incl}}/\mathrm{d}\Delta y)/(\mathrm{d}\sigma^{\mathrm{excl}}/\mathrm{d}\Delta y),$$
$$R^{\mathrm{MN}} = (\mathrm{d}\sigma^{\mathrm{MN}}/\mathrm{d}\Delta y)/(\mathrm{d}\sigma^{\mathrm{excl}}/\mathrm{d}\Delta y),$$
$$R^{\mathrm{incl}}_{\mathrm{veto}} = (\mathrm{d}\sigma^{\mathrm{incl}}/\mathrm{d}\Delta y)/(\mathrm{d}\sigma^{\mathrm{excl}}_{\mathrm{veto}}/\mathrm{d}\Delta y),$$
$$R^{\mathrm{MN}}_{\mathrm{veto}} = (\mathrm{d}\sigma^{\mathrm{MN}}/\mathrm{d}\Delta y)/(\mathrm{d}\sigma^{\mathrm{excl}}_{\mathrm{veto}}/\mathrm{d}\Delta y).$$



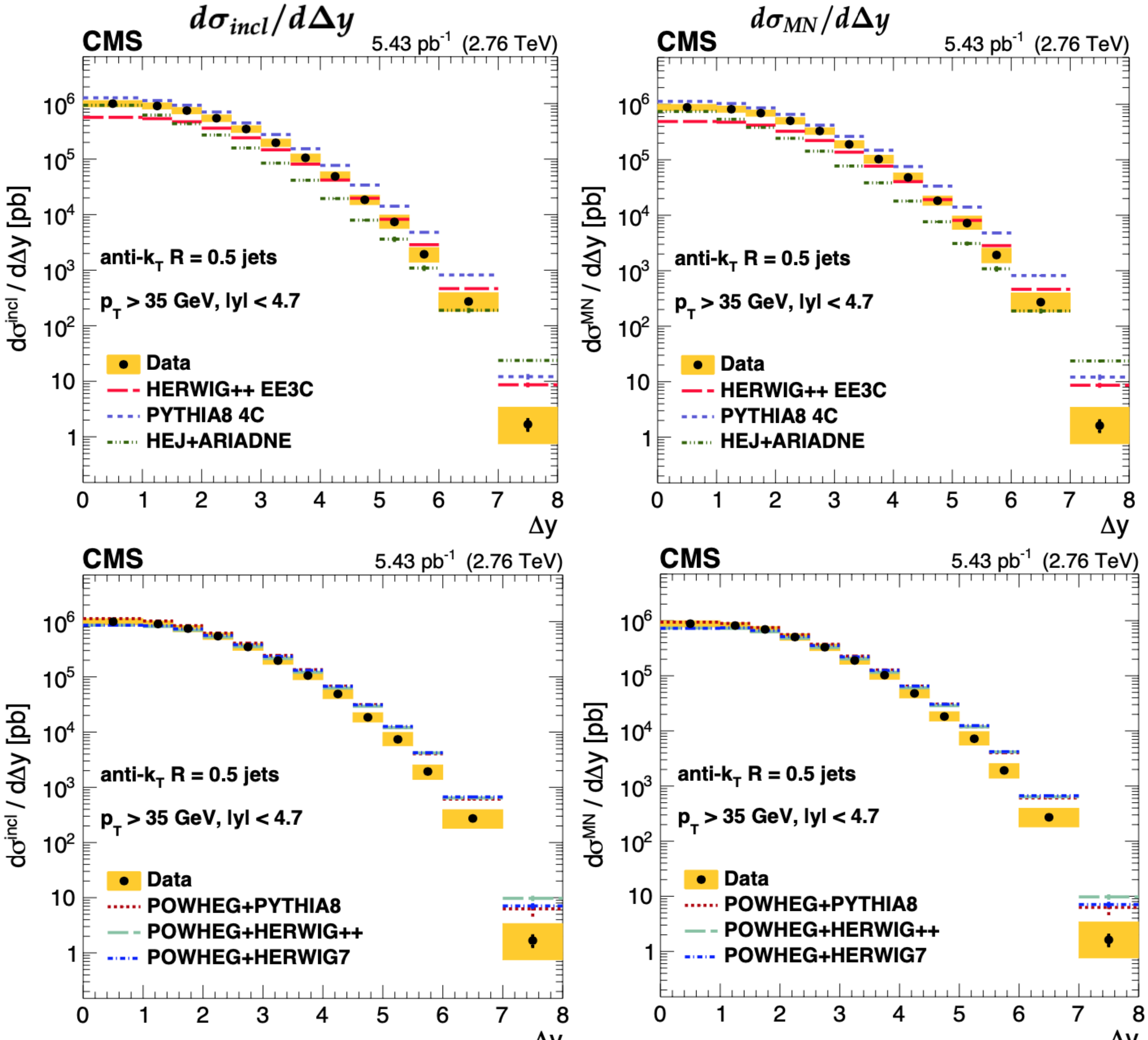




Differential cross sections

NEW!

CMS PAS FSQ-13-004

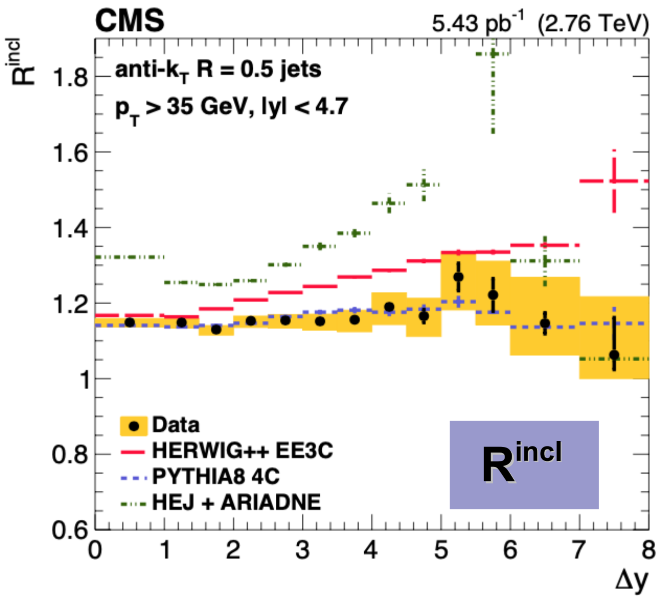


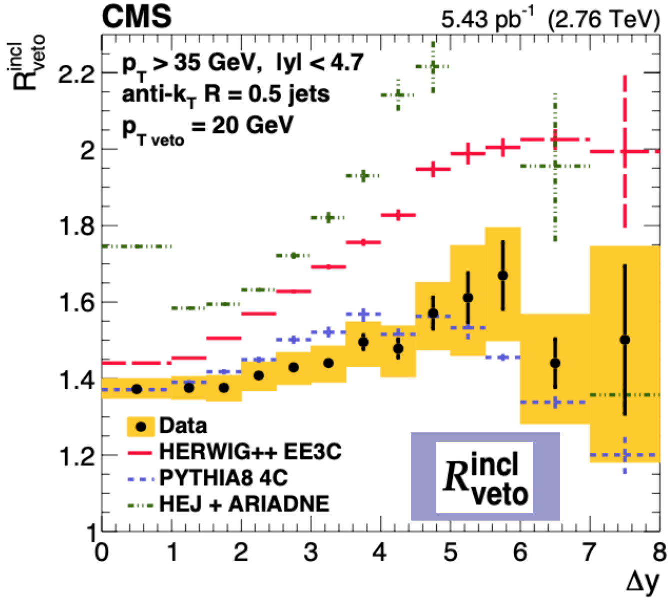
- LO+LLDGLAP-based PYTHIA8 overestimates data
- LL BFKL-based calculation of HEJ+ARIADNE systematically underestimate the data for Δy < 7
- MN dijets cross-sections Similar agreement as incl.cross-sections observed between data and predictions

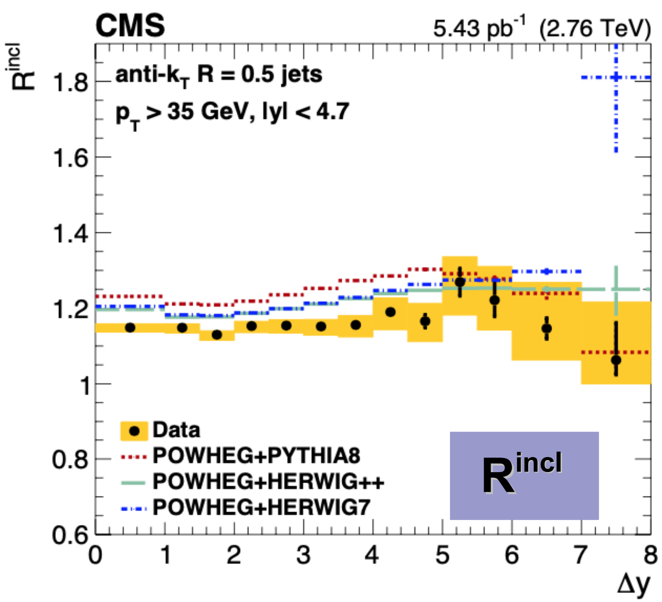
Ratios R^{incl} and R^{incl}_{veto}

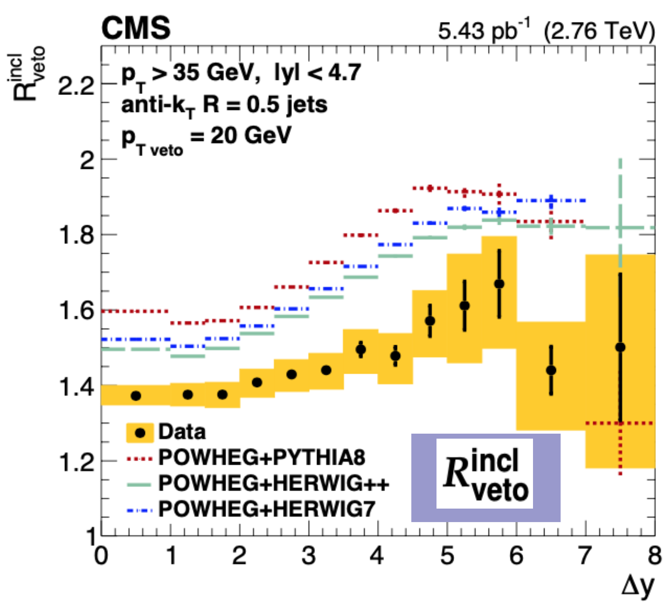
NEW!

CMS PAS FSQ-13-004







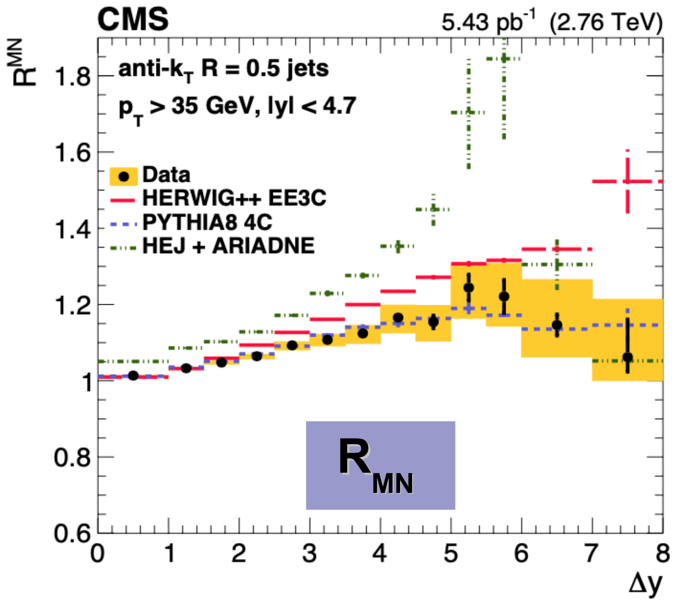


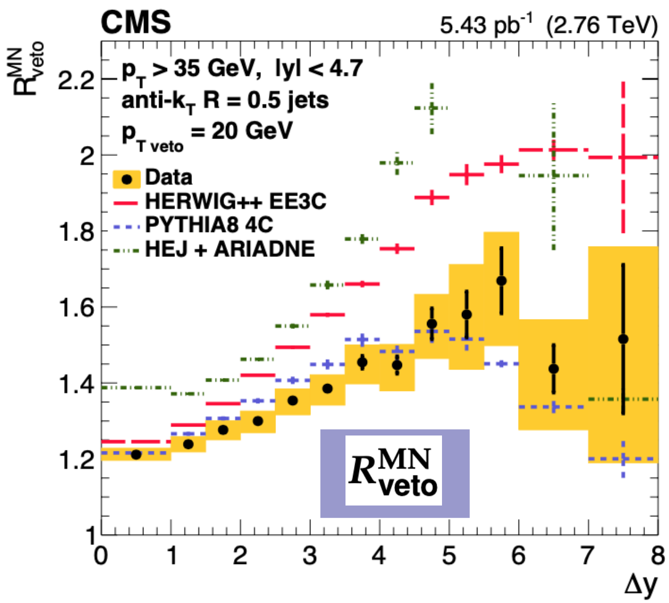
- Ratio R^{incl} of the cross sections for inclusive to "exclusive" dijet production.
  - PYTHIA8 is in agreement
  - Overestimation by HERWIG++ & HEJ+ARIADNE
  - Inclusion of POWHEG to LL DGLAP-based prediction of HERWIG degrades the quality of the description for $\Delta y < 2$ but improves it for large y intervals.

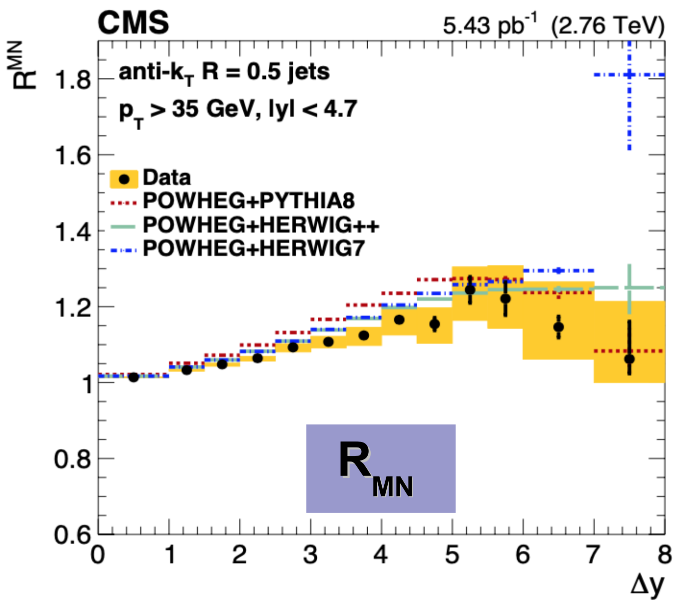
- Ratio R^{incl}_{veto} of the x-sections for incl. to "exclusive" with veto dijet production
  - Overestimation by HERWIG++ & HEJ+ARIADNE
  - **none of the models considered reproduces the data throughout.**

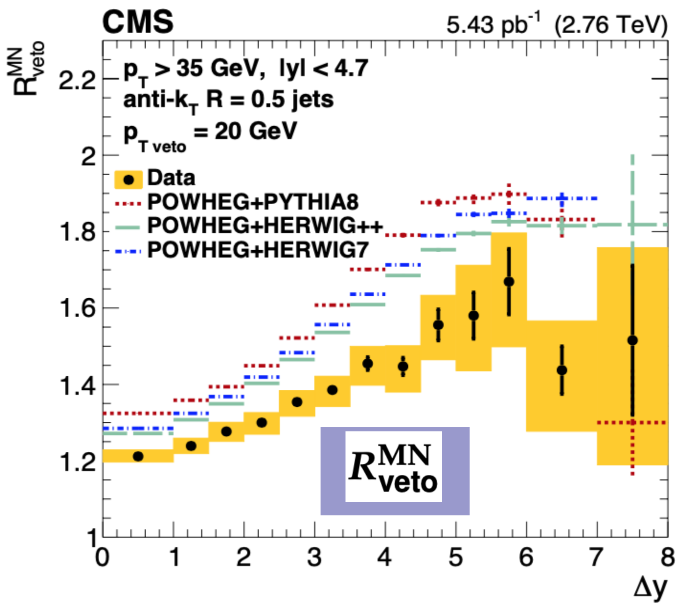
Ratios R^{MN} and R^{MN}_{veto}

CMS PAS FSQ-13-004





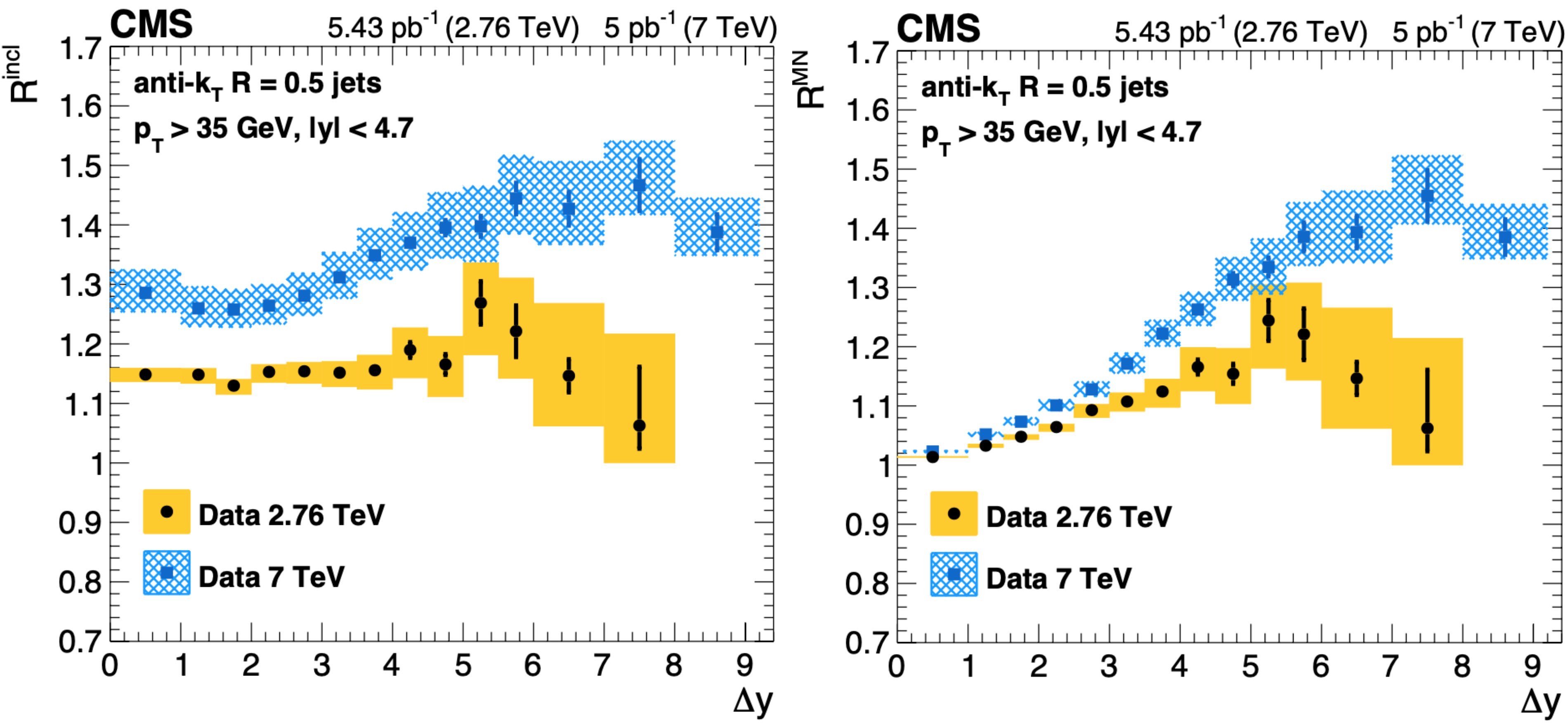




- Ratio R^{MN} of the cross sections for MN to "exclusive" dijet production.
- Ratio R^{MN}_{veto} of the x-sections for MN to "exclusive" with veto dijet production
- Similar results to $R^{incl.}$ vs. R^{incl}_{veto}

Comparison of Ratios for different √s

CMS PAS FSQ-13-004



- Ratios of cross-sections for inclusive (left) and MN (right) and "exclusive" dijet production, measured @ 2.76 & 7 TeV
- The ratios rise faster with Δy at higher energy, which may reflect both the increasing available phase space and BFKL dynamics
- At very large Δy, the ratios decrease because of the kinematic limitations on the production of events with more than two jets, each with p_T > 35 GeV

Summary

- Many interesting results from CMS,
  - wide range of jet measurements at various collision energies, improving our understanding of QCD

- Mueller-Navelet dijet decorrelations analytical NLL BFKL calculation agrees with data
  - Higher collision energies may be more decisive

- Dijet events with large rapidity separation between the jets @ 2.76 TeV
  - MN and inclusive dijet cross sections and their ratios are measured up to $\Delta y \leq 8.0$ between the jets.
  - None of the DGLAP based MC generators provide a reasonable description.
  - Calculations at the NLL, which are not yet available, are needed.

- New data are still to come to be used in precision QCD analyses and to improve the understanding of the BFKL evolution!

THANKS FOR YOUR ATTENTION!

BACKUP