Correlations in multijet events in CMS at 13TeV

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on behalf of the CMS collaboration.

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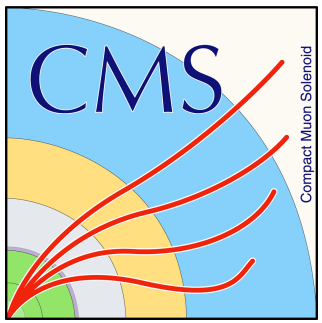
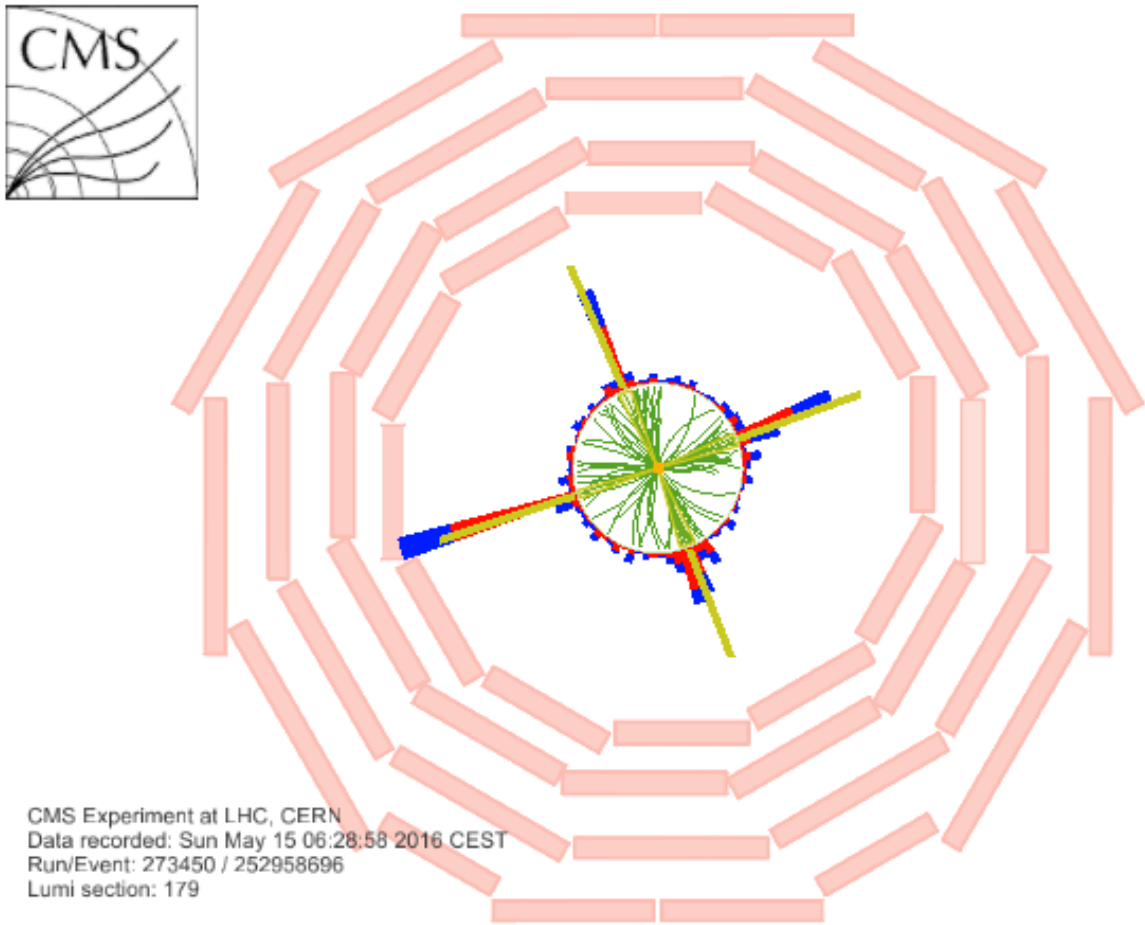


Multijets correlations

- Testing ground for perturbative quantum chromodynamics (pQCD).
- Insight to resummation by means of Parton Showers.
- Interplay between Parton Showers and Matrix Elements.



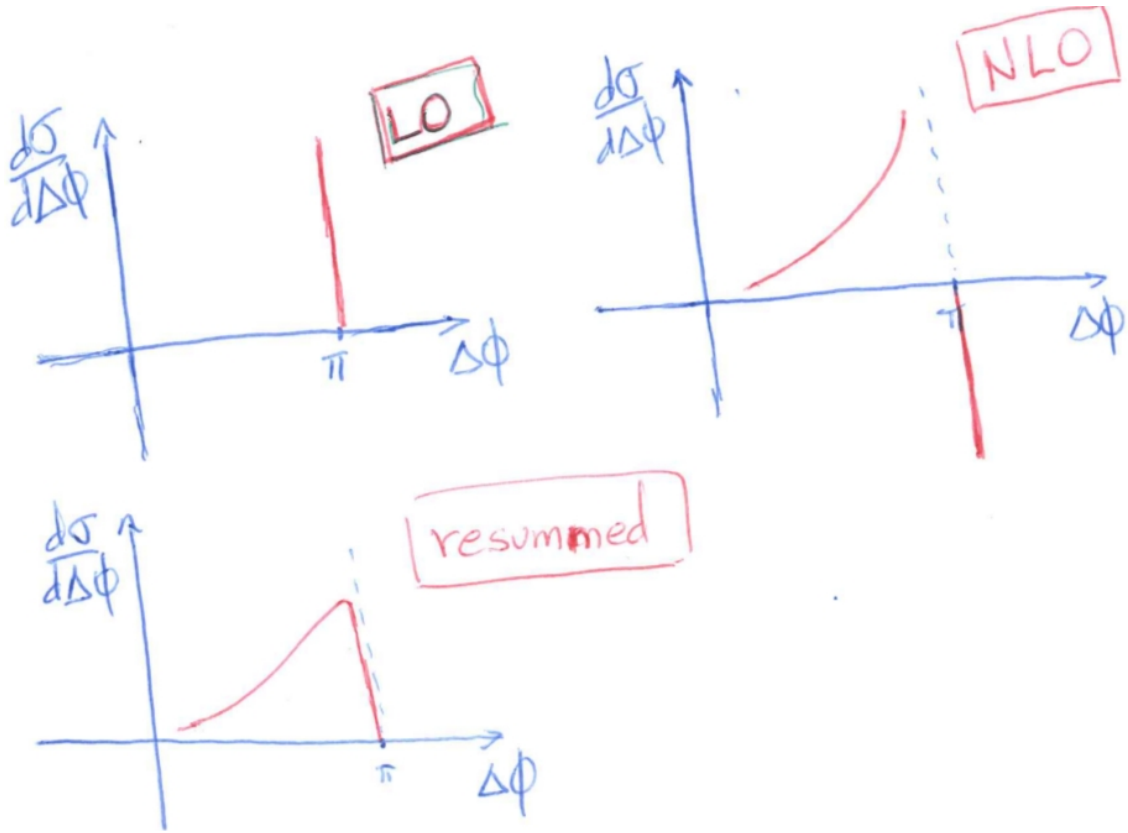
Why to bother?

- Fixed order calculations to get partonic cross sections

- They're only reliable when all the scales are of the same order

- Resummation looks for an improved perturbative expansion

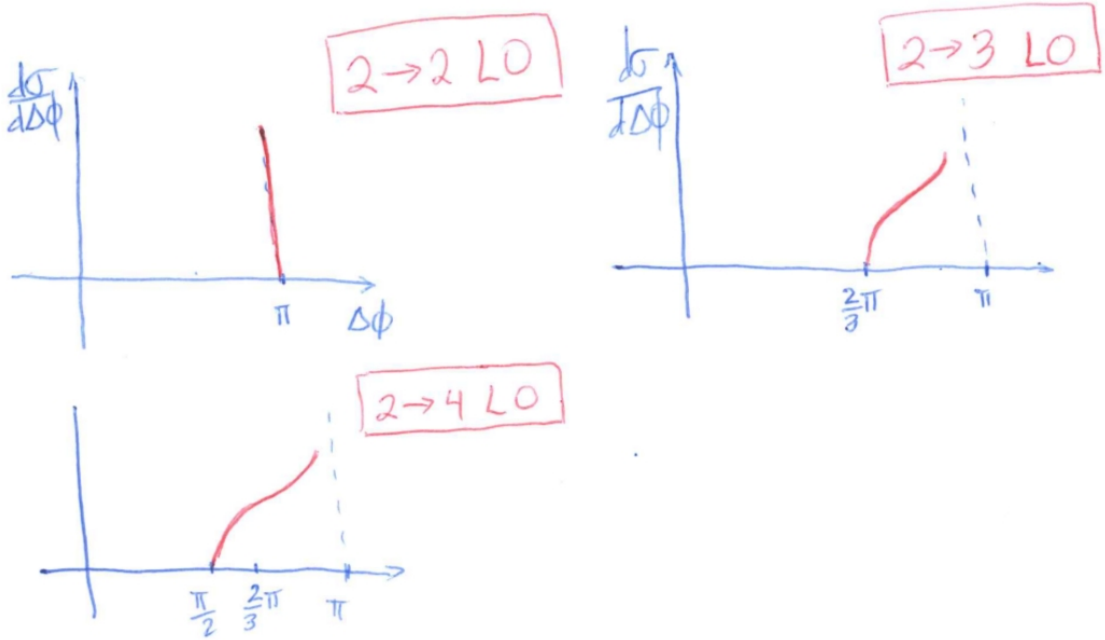
- It's done by Parton Showers in MC generators



Why to bother?

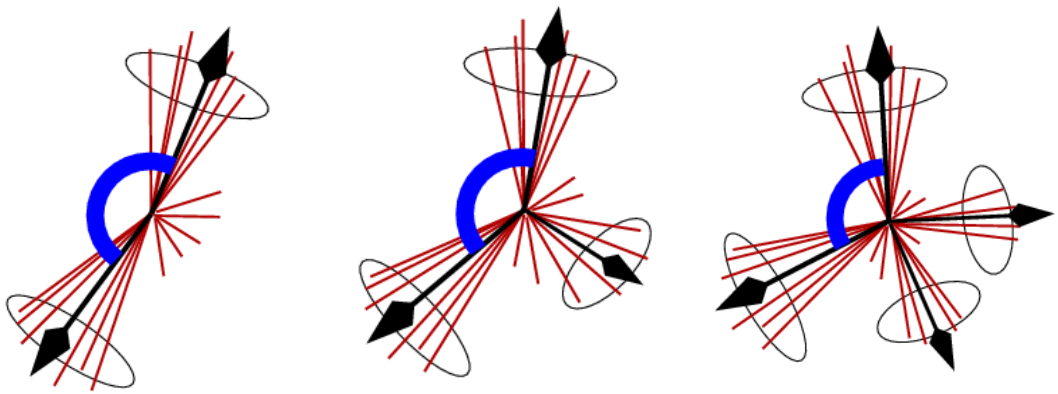
- High multiplicity partonic final state needed to get the tail

- Parton Showers and Matrix Elements interplay



Measurements of inclusive 2-jet, 3-jet and 4-jet azimuthal correlations in pp collisions at 13TeV

CMS PAS SMP-16-014



Inclusive 2-jet cross section

$$\frac{1}{d\sigma}\frac{d\sigma}{d\Delta\phi_{1,2}}$$

- Reconstruction with **anti-k_t4**

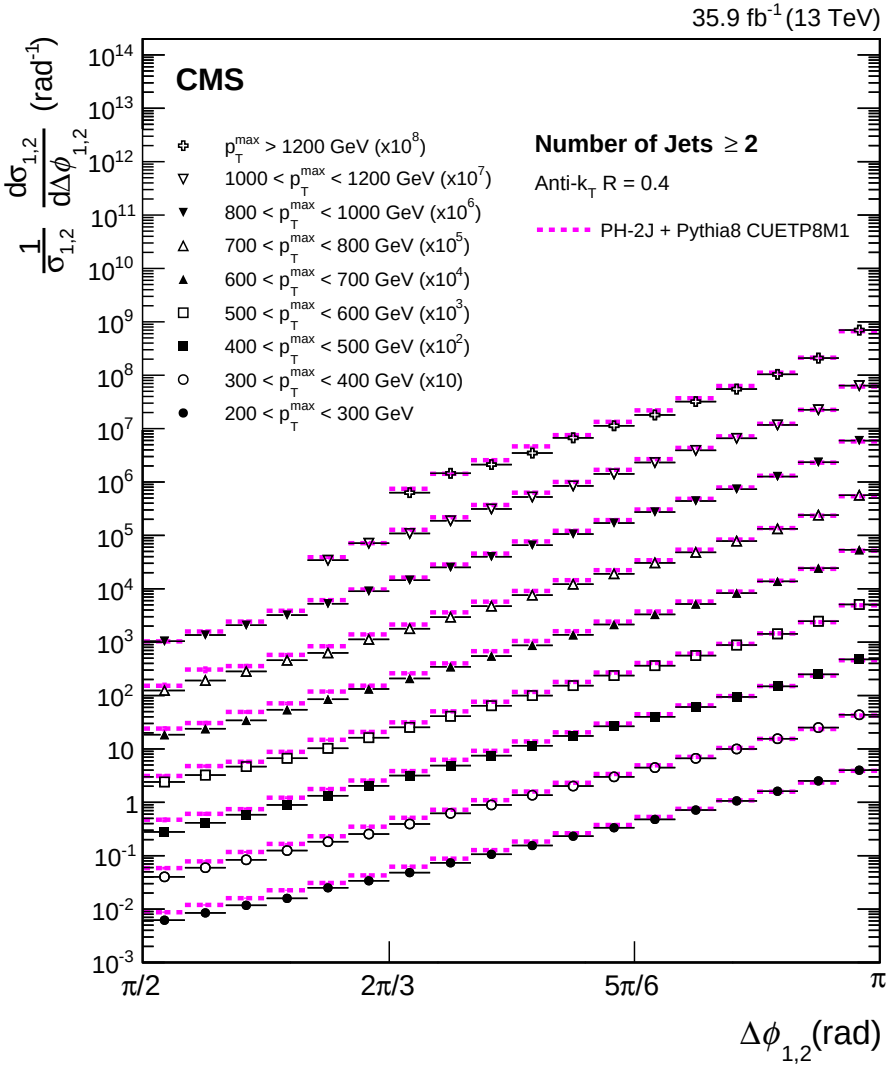
- Consider all jets up to $|y| < 5$ and $p_T > 100 GeV$

- Define n-jet event by requiring $|y_n| < 2.5$ for all n

- Region away from π is sensitive to hard radiation from Matrix Elements

- Region close to π is sensitive to resummed contributions from Parton Showers

- Overall description is achieved and understood over many orders of magnitud



Systematics

The main sources of systematics considered:

- Modelling of the true spectra
- $\Delta\phi$ resolution uncertainty
- Jet Energy Scale uncertainties
- Jet Energy Resolution uncertainties

Theory predictions

Matrix element generator	Simulated diagrams	PDF set	Tune
PYTHIA8.219	2→2 (LO)	NNPDF2.3LO	CUETP8M1
HERWIG++ 2.7.1	2→2 (LO)	CTEQ6L1	CUETHppS1
MADGRAPH5 2.3.3 + PYTHIA8.219	2→2, 2→3, 2→4 (LO)	NNPDF2.3LO	CUETP8M1
POWHEG + PYTHIA8.219	2→2, 2→3 (NLO)	NNPDF3.0nlo	CUETP8M1
HERWIG7	2→2 (NLO)	MMHT2014	UE-MMHT

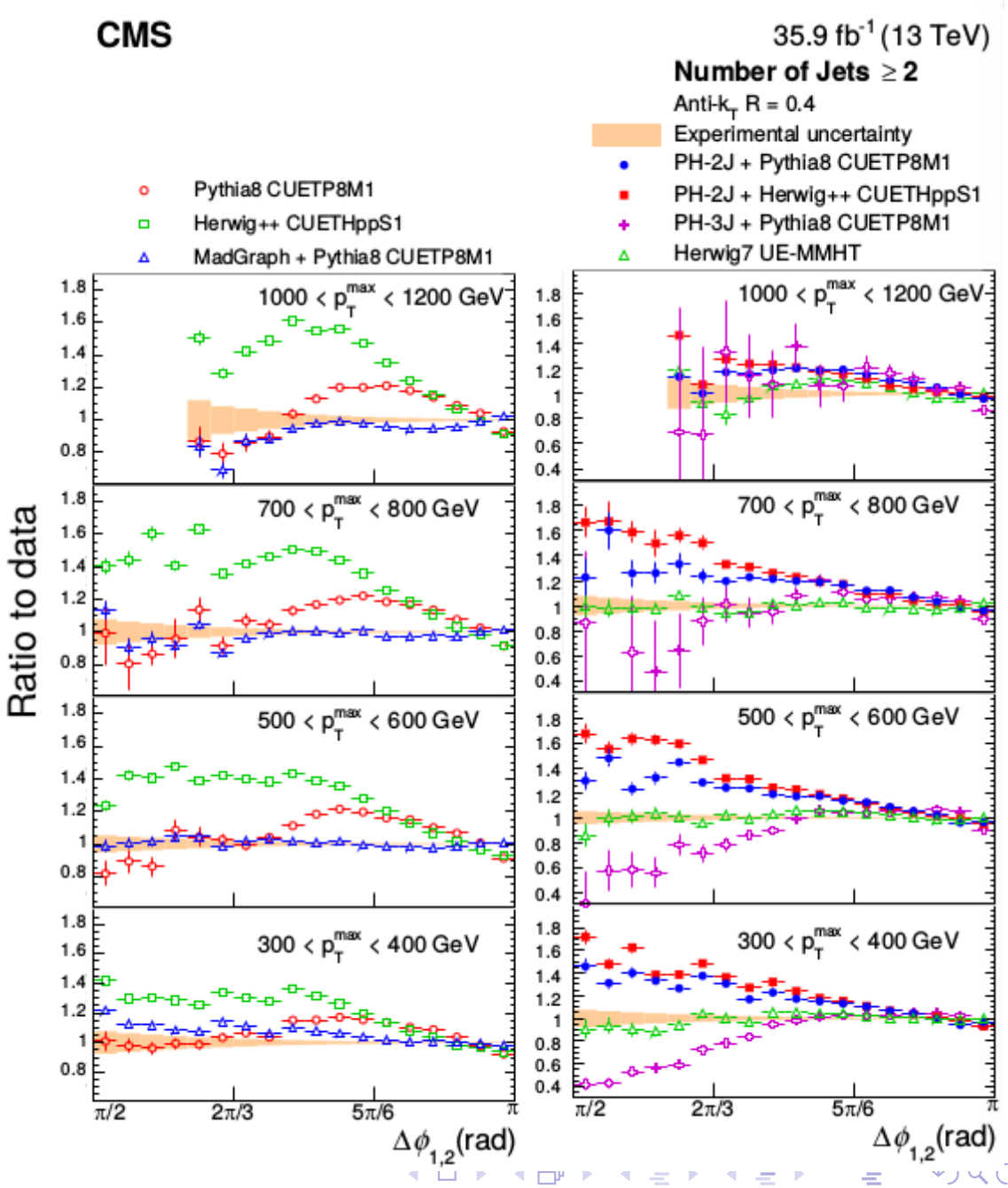
Inclusive 2-jet cross section

- MadGraph performs the best among the LO predictions

- Powheg 2J and 3J fail to describe the data

- Herwig7 (MC@NLO for matching to Parton Showers), formally NLO but effectively 2→3 LO, gives a good description

- MC@NLO method has advantages compared to the POWHEG method for this observable

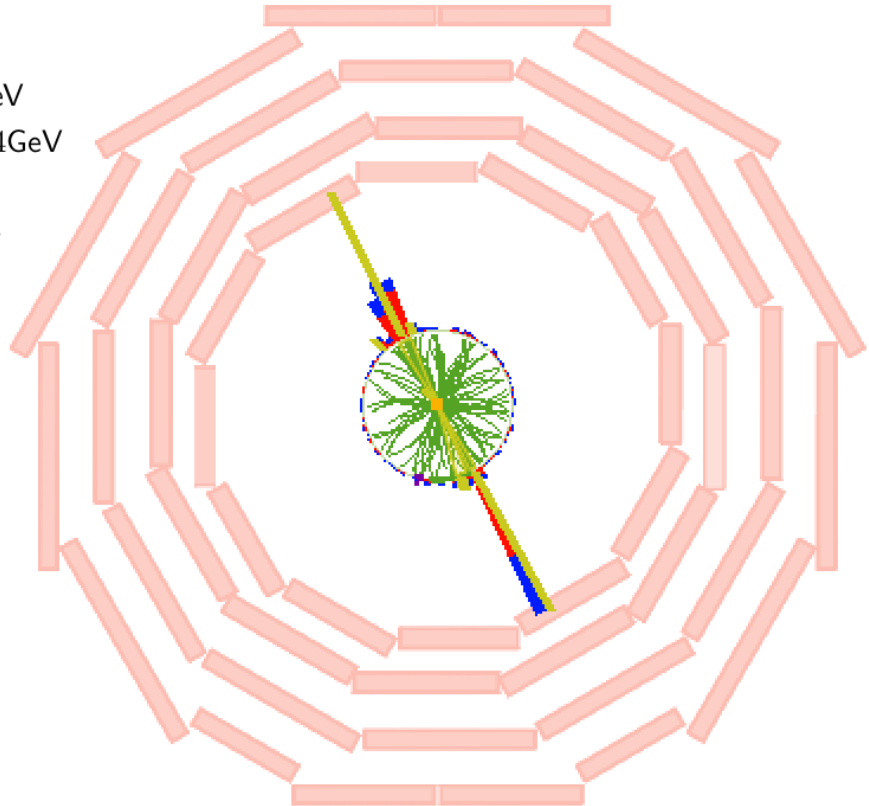


Azimuthal angular correlations in back-to-back jets topologies

CMS PAS SMP-17-009

CMS Experiment at LHC, CERN
Data recorded: Sun Aug 14 13:01:17 2016 CEST
Run/Event: 278820 / 21368498
Lumi section: 18

Leading $p_T = 696$GeV
Subleading $p_T = 694$GeV
Leading $y = 0.23$
Subleading $y = 0.57$
$\Delta\phi_{1,2} = 178.2°$



Previous measurement and motivation

$$\frac{1}{\sigma_{1,2}}\frac{\mathrm{d}\sigma_{1,2}}{\mathrm{d}\Delta\phi_{1,2}}$$

- What is new?

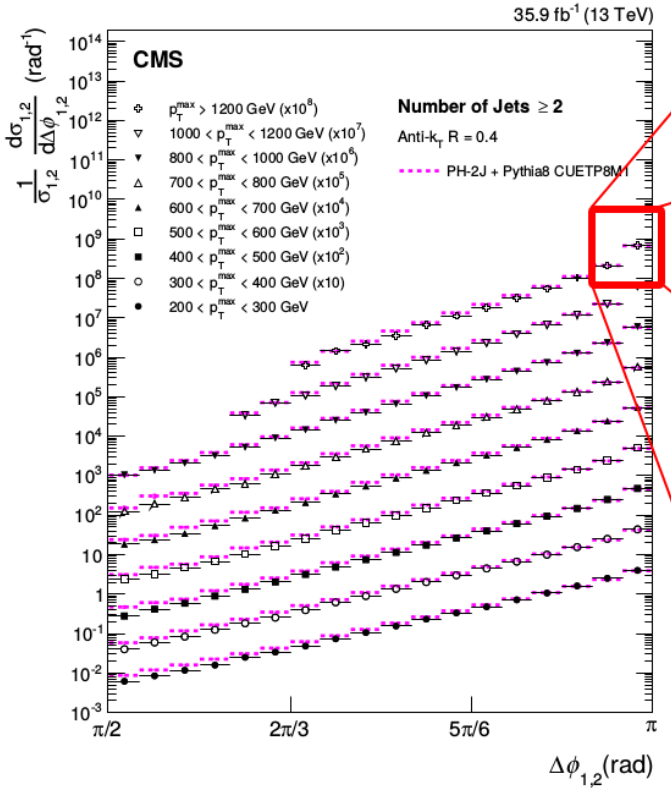
- In the back to back region, sensitive to effects beyond finite order in perturbative expansion

- Detailed investigation of the region ($\Delta\phi \sim 180°$)

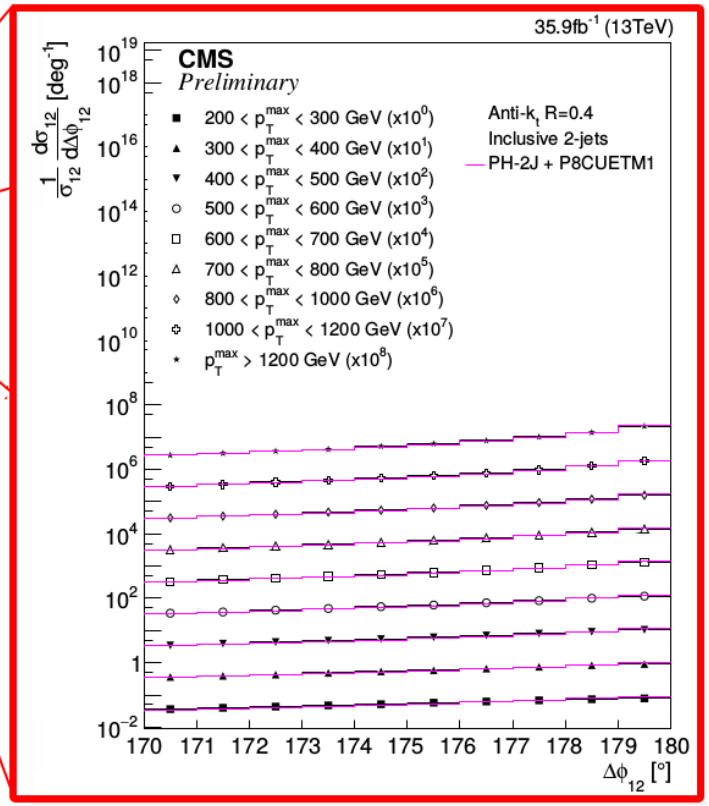
- Testing the resummed predictions coming from different Parton Shower models

- Soft radiation interference and factorization breaking?

CMS PAS SMP-16-014



CMS PAS SMP-17-009



- Fixed-order predictions diverge towards 180° → resummation needed

Motivation

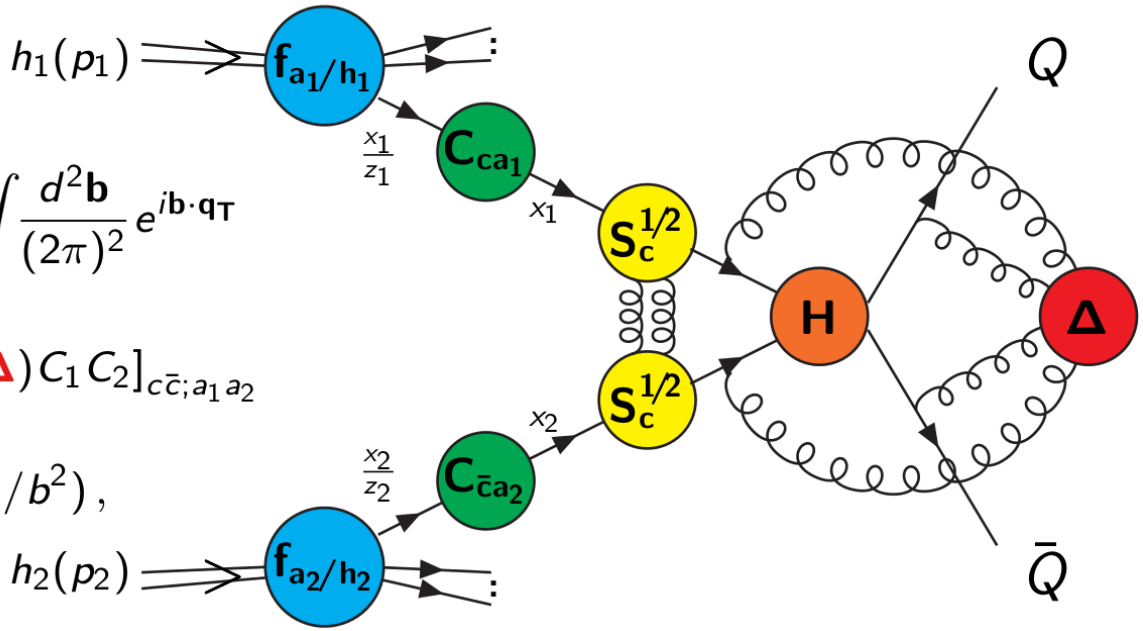
q_T Resummation for heavy-quark hadroproduction

[Catani,Grazzini,Torre('14)]

$$\frac{d\sigma^{(res)}}{d^2\mathbf{q_T} dM^2 dy d\Omega} = \frac{M^2}{s} \sum_{c=q,\bar{q},g} \left[d\sigma^{(0)}_{c\bar{c}} \right] \int \frac{d^2\mathbf{b}}{(2\pi)^2} e^{i\mathbf{b}\cdot\mathbf{q_T}}$$

$$\times\ S_c(M,b) \sum_{a_1,a_2} \int_{x_1}^1 \frac{dz_1}{z_1} \int_{x_2}^1 \frac{dz_2}{z_2} \left[(\mathbf{H}\Delta) C_1 C_2 \right]_{c\bar{c};a_1 a_2}$$

$$\times\ f_{a_1/h_1}(x_1/z_1, b_0^2/b^2) f_{a_2/h_2}(x_2/z_2, b_0^2/b^2)\,,$$

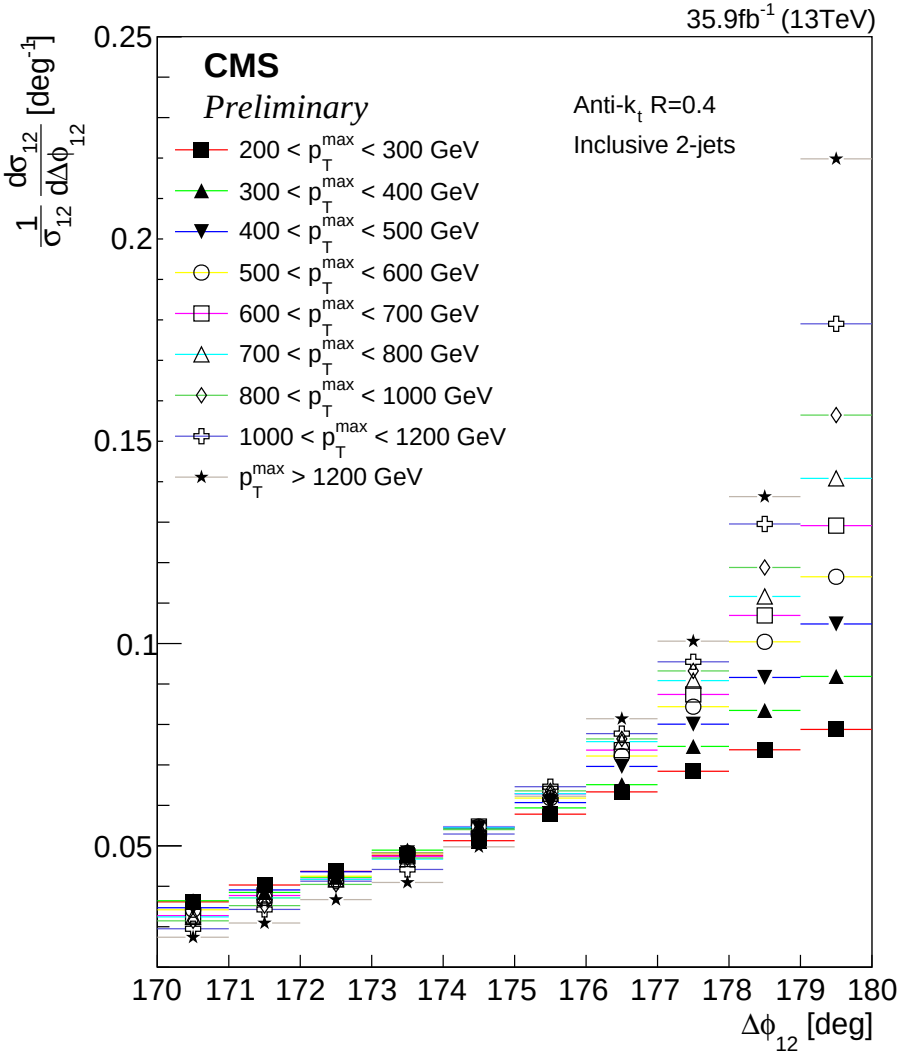


- △ is a non-universal process dependent factor.
- Final and initial state soft radiation interference.
- Color-connections lead to azimuthal correlations.

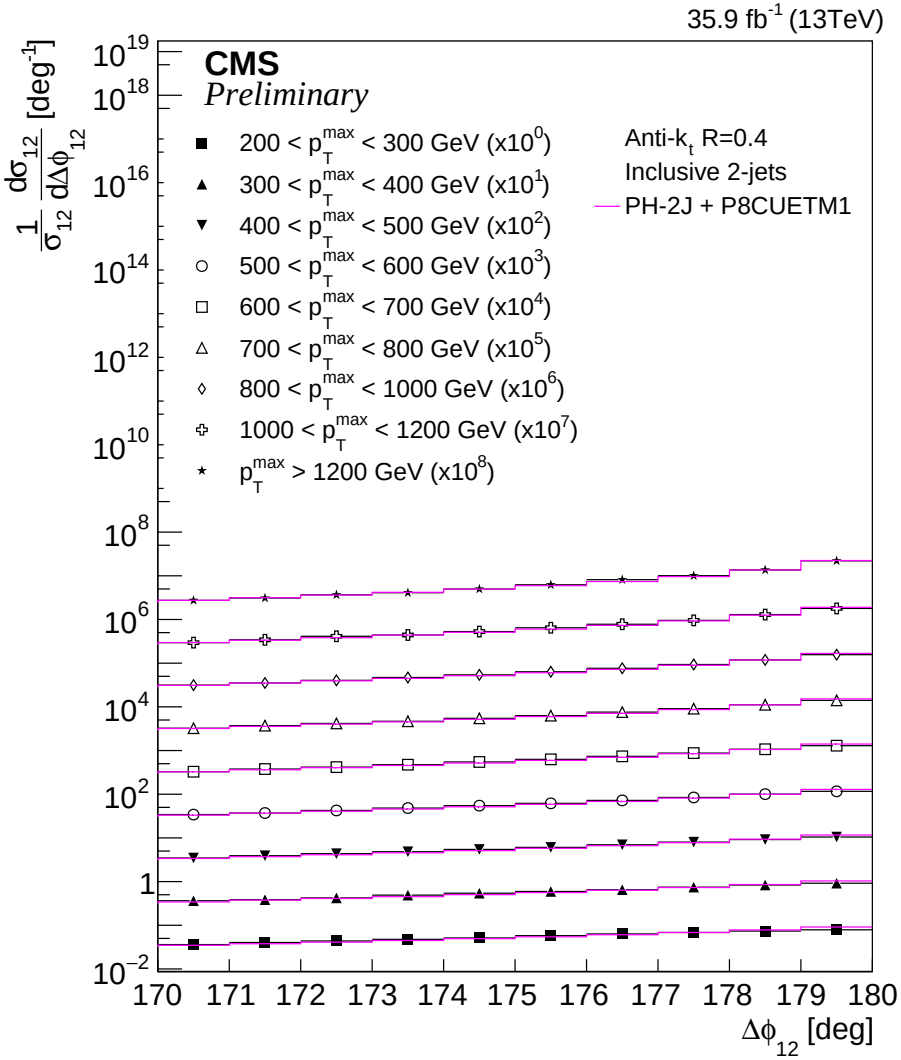
- How significant are these corrections?

Dijet azimuthal correlations in inclusive 2-jets events

Linear scale

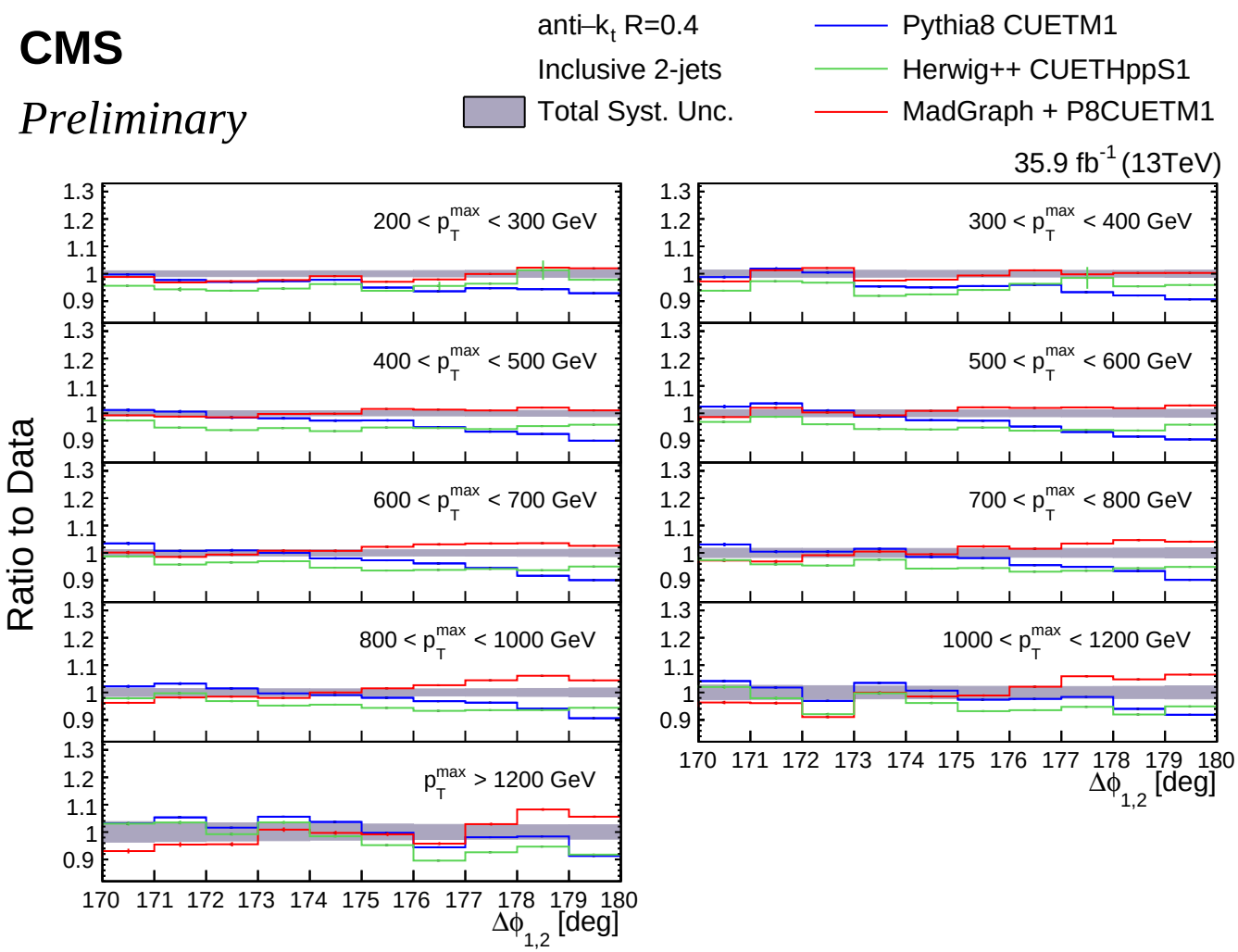


Log scale



- The normalized inclusive 2-jet cross section in linear scale (left) and in log scale, compared to predictions from Powheg-2J (right)
- As $\mathrm{p_T^{max}}$ increases the distributions become steeper.

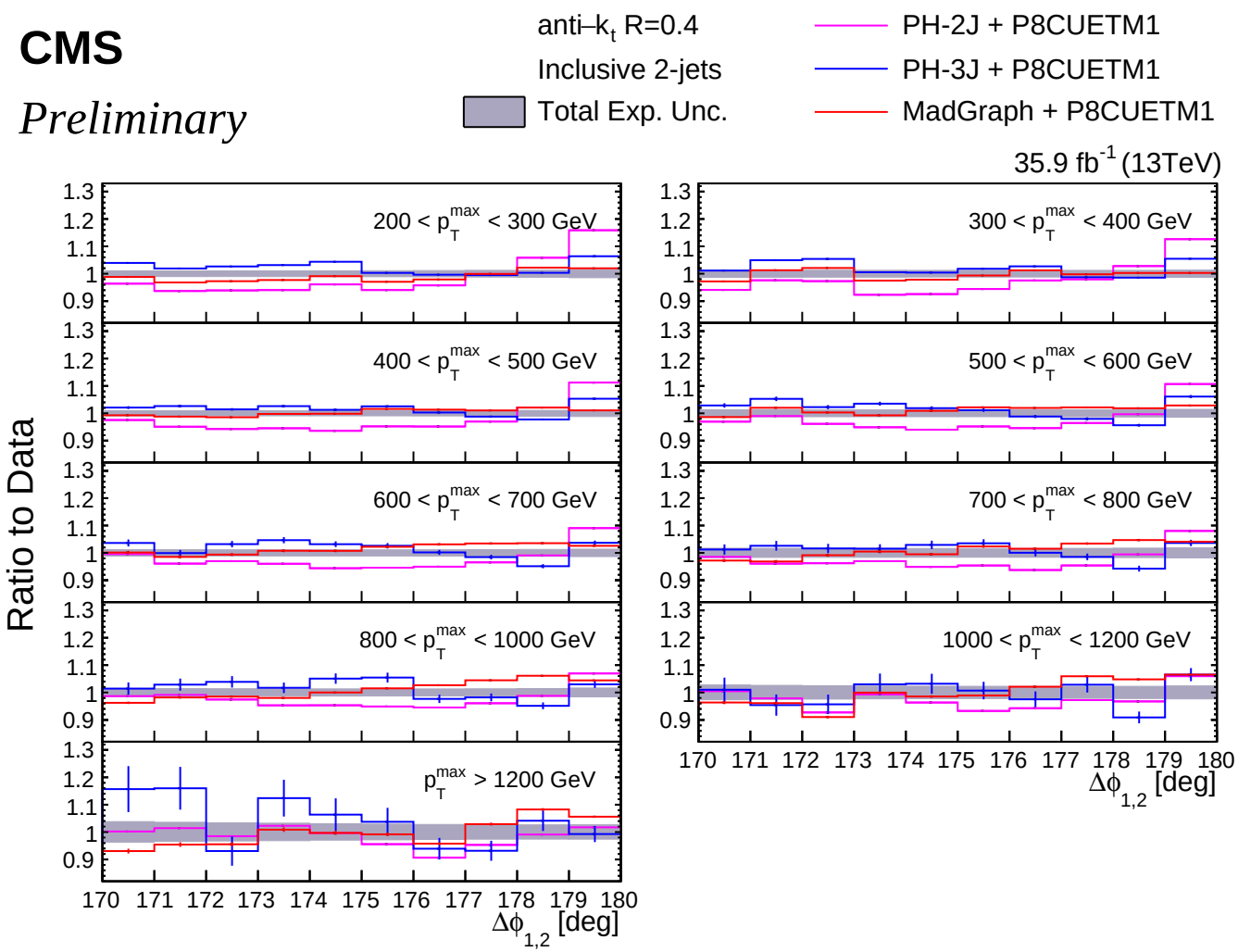
Dijet azimuthal correlations in inclusive 2-jets events



- MadGraph best, fails towards high p_T^{max}
- P8 and Herwig++ similar
- Differences of up to 10%

- Pythia8 and Herwig++ resum in the same way (only evolution variable differs)

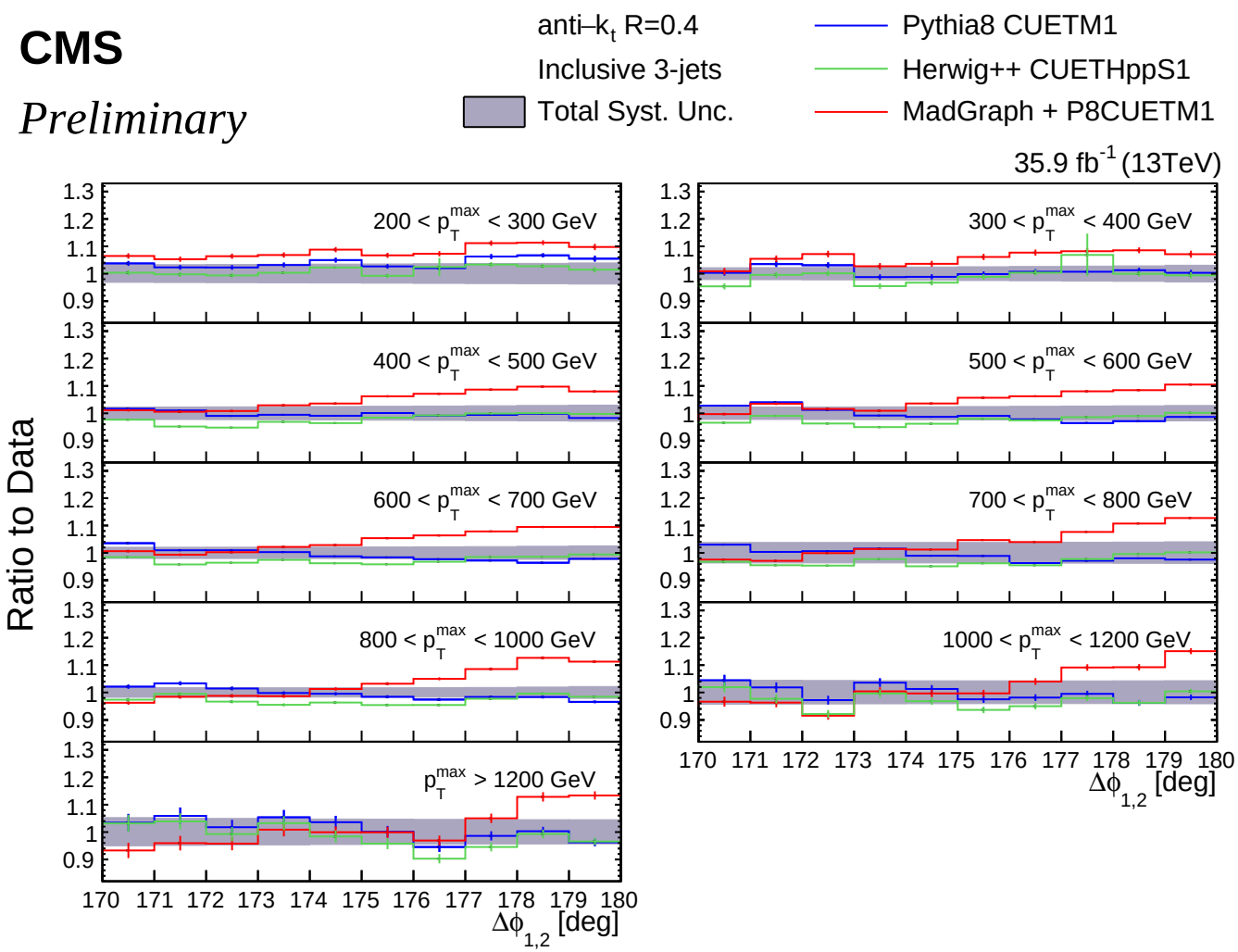
Dijet azimuthal correlations in inclusive 2-jets events



- MadGraph and Powheg 3J best
- Powheg 2J fails
- Biggest discrepancies in the last bin

- MadGraph and Powheg 3J, both go to up to 2→4 partons
- Powheg 2J is effectively 2→3 LO

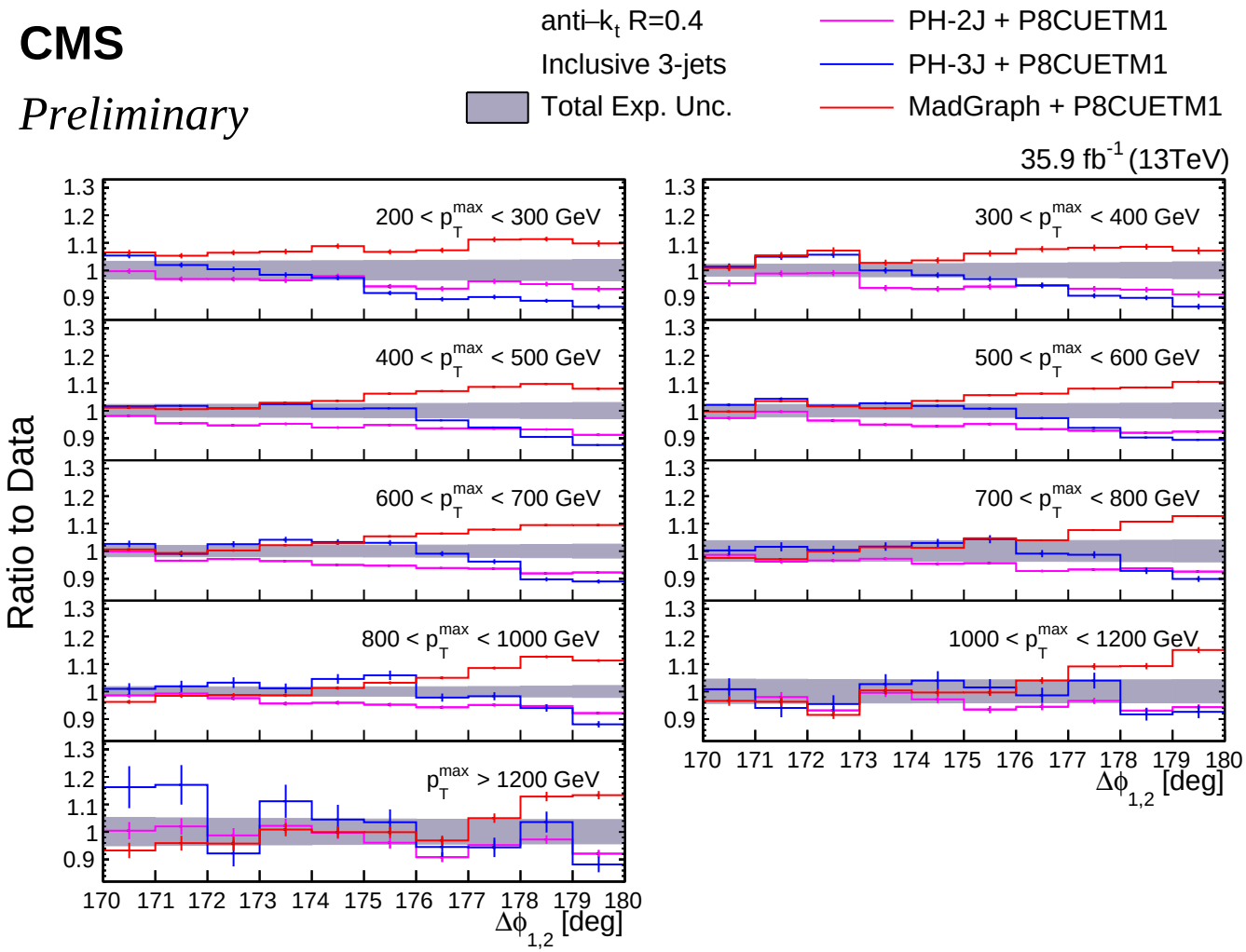
Dijet azimuthal correlations in inclusive 3-jets events



- Two scale process by requiring at least a third jet with $p_T > 30$GeV
- MadGraph fails in up to 15%

- P8 and Herwig++ describe

Dijet azimuthal correlations in inclusive 3-jets events



- MadGraph, Powheg 2J and Powheg 3J fail
- Powheg 2J and Powheg 3J similar

- Decorrelations in the 3-jets inclusive case are well described by partons coming from Parton Showers exclusively, whereas a mixture of partons from Parton Showers and Matrix Elements are not able to

Summary and conclusions

- Angular correlations in inclusive multijet events were considered
- Systematic uncertainties from Jet Energy Scale, Jet Energy Resolution, model dependence and $\Delta\phi$ resolution

Multijet azimuthal angular correlations @$\sqrt{s} = 13$TeV

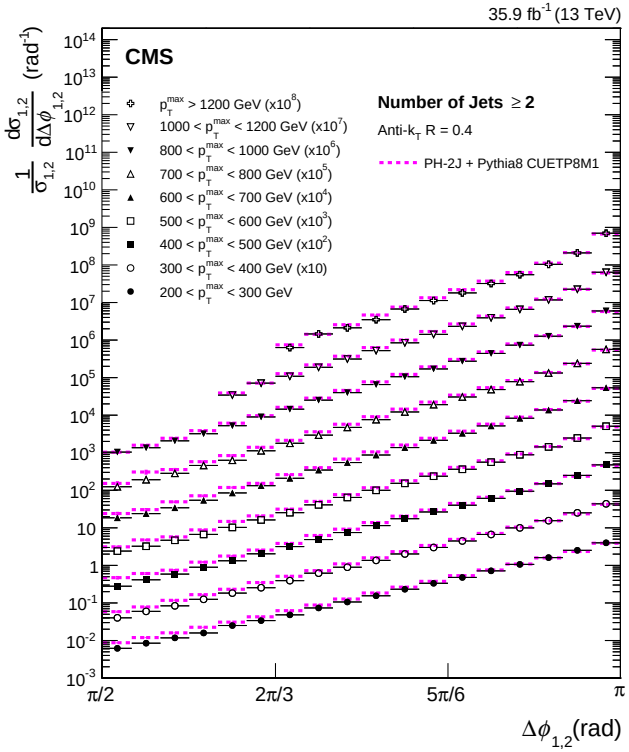
- Overall description of the data is achieved and understood
- Although, differences of up 40% are reached
- Observations emphasize the need to improve predictions for multijet production

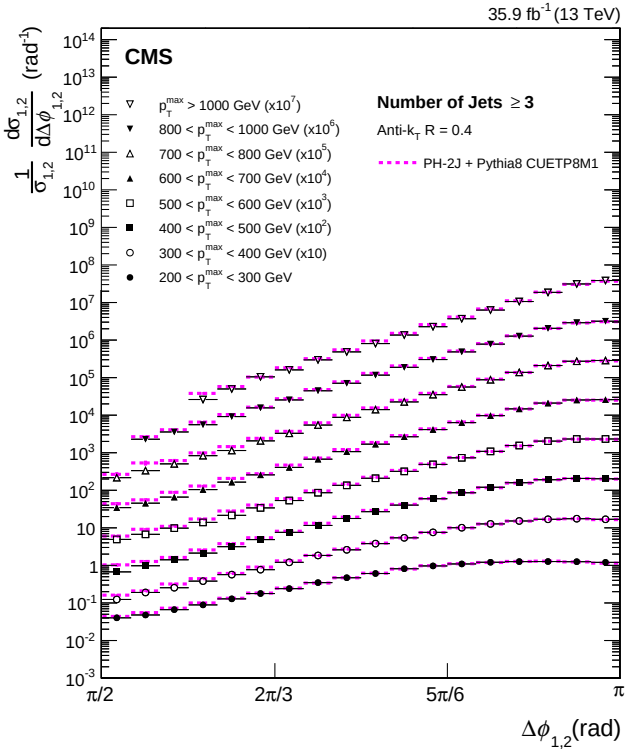
Azimuthal angular correlations in back-to-back jets topologies

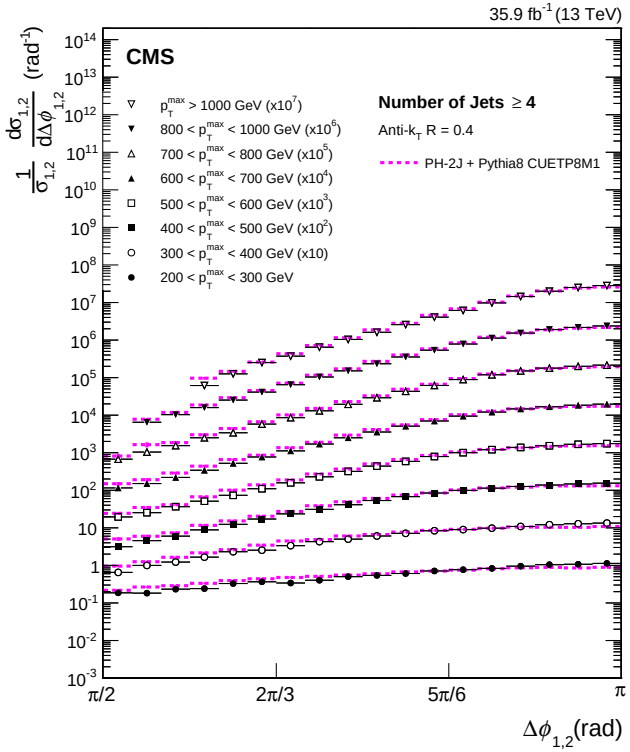
- Multi-leg final state MC Powheg 3J and Madgraph provide a good description of the data for 2-jet inclusive events
- They start to fail towards high p_T^{max}
- For 3-jet inclusive events, partons coming exclusively from Parton Showers describe the observed $\Delta\phi_{1,2}$, whereas the merged/matched results from Madgraph, Powheg2J and Powheg 3J don't
- In general, the predictions can not describe at the same time the 2-jet and 3-jet inclusive cross sections
- Further phenomenological and theoretical investigations (z.B TMDs, analytical resummation) are needed in order to understand the deviations

Thank you for your attention.

Inclusive 2-jet, 3-jet and 4-jet cross sections







- Three and four jet events distributions are smoother close to π since exclusive 2-jet are discarded
- The distributions are strongly peaked at π and become steeper with increasing p_T^{max}
- Best description among LO generators coming from Madgraph, and from Herwig7 among the NLO generators

Inclusive 3-jet $\Delta\phi_{2J}^{min}$

$$\frac{1}{d\sigma}\frac{d\sigma}{d\Delta\phi_{2J}^{min}}$$

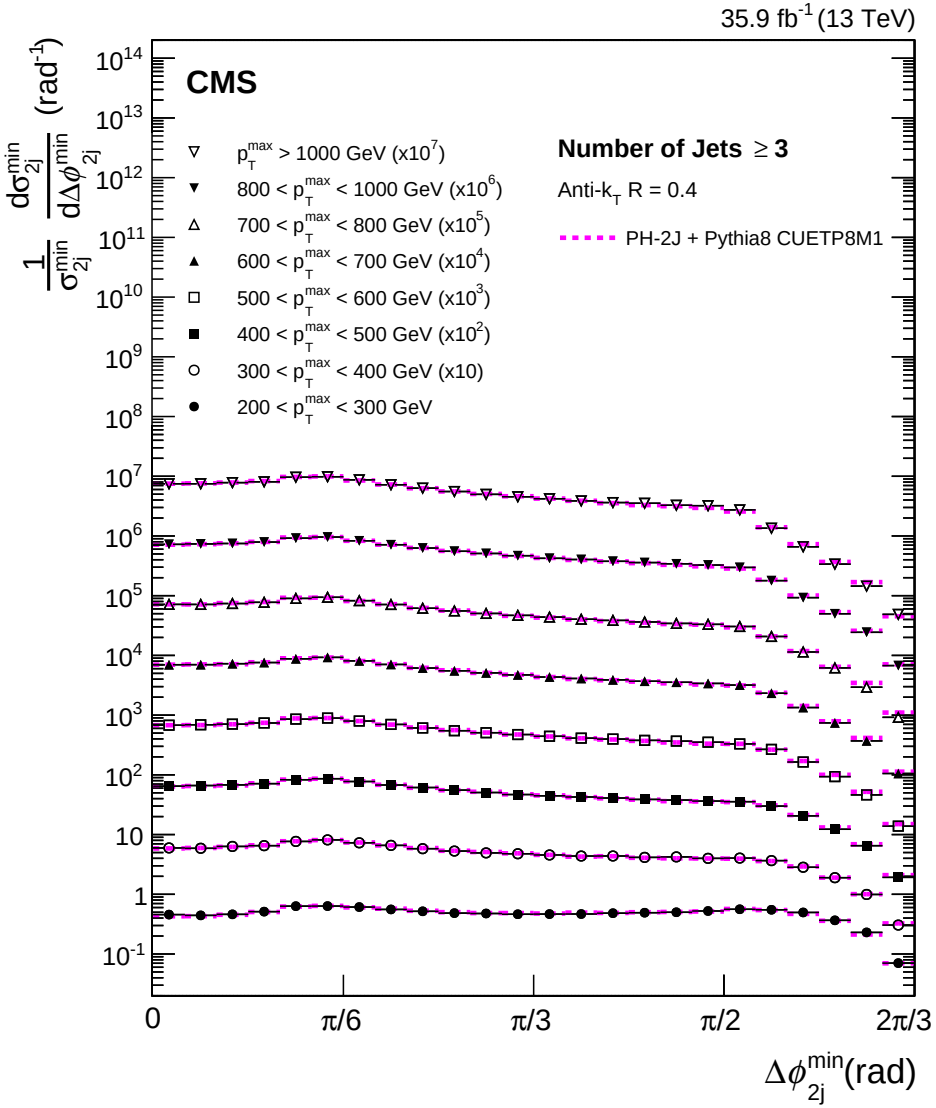
- Minimum $\Delta\phi$ between any two of the n-jets

- Infrared safe observable

- Sensitive to correlations among subleading jets

- Distributions are close to be flat and decrease slowly at the right end

- Flatter left end due to finite cone size



Inclusive 3-jet $\Delta\phi_{2J}^{min}$

- Pythia fails to describe

- Herwig++ performs well at high p_T^{max} (quantum correlations partially captured by angular ordering)

- Multileg generator Madgraph gives a good description