Forward Jets, Forward-central Jets, Etc... in CMS

27th May 2014

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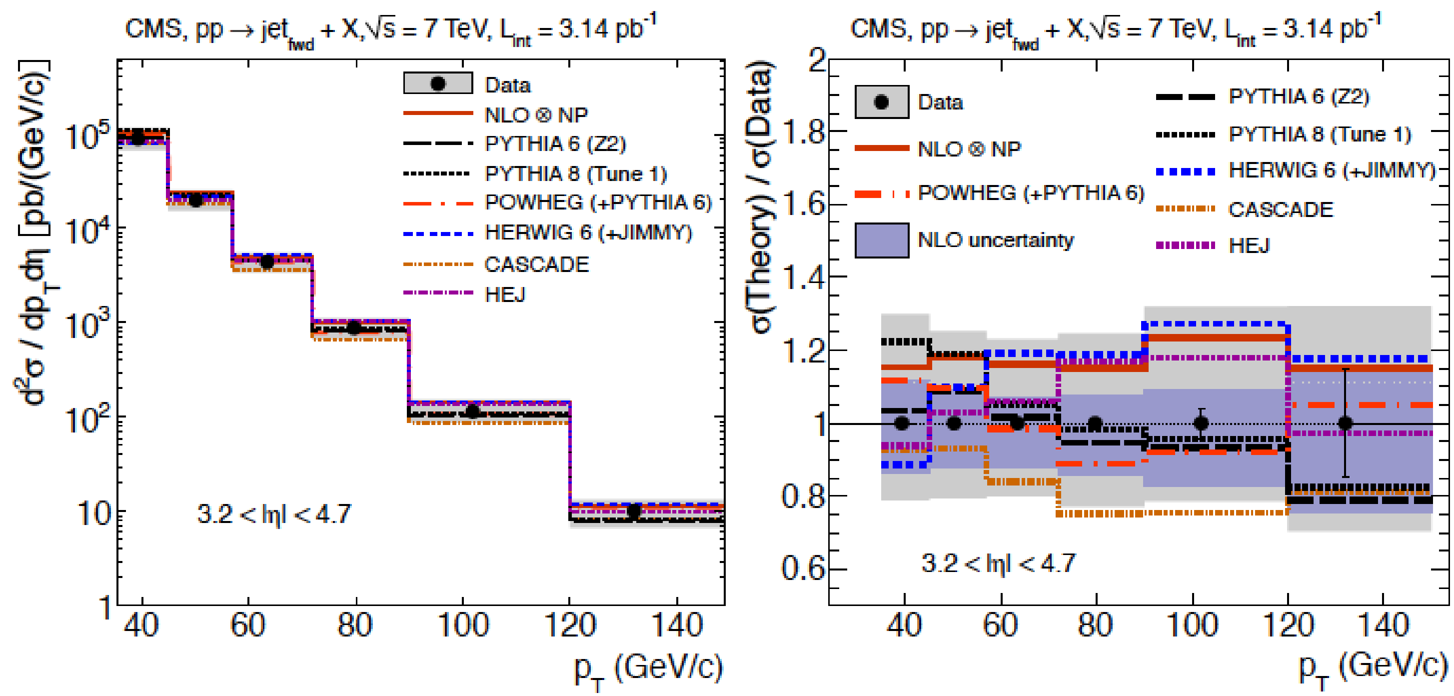
OUTLINE

Inclusive forward jets
Inclusive forward + central jets
Di-jet k-factor
Azimuthal decorrlations
Forward Central Jet correlations

Majority of slides based on cut and paste from:
AK – DIS2013
Grigory Safranov – DIS2014
Pedro Cipriano – DIS2014

Events with at least one jet with $3.5<|\eta|<4.7$ and $p_{t,jet}>35$ GeV



- **All predictions describe the data within the uncertainties.**
- **NLO prediction (NLOJET++) too high, but agrees with the data within the large theoretical and experimental uncertainties.**
- **NLO+PS (POWHEG+PYTHIA6) best.**

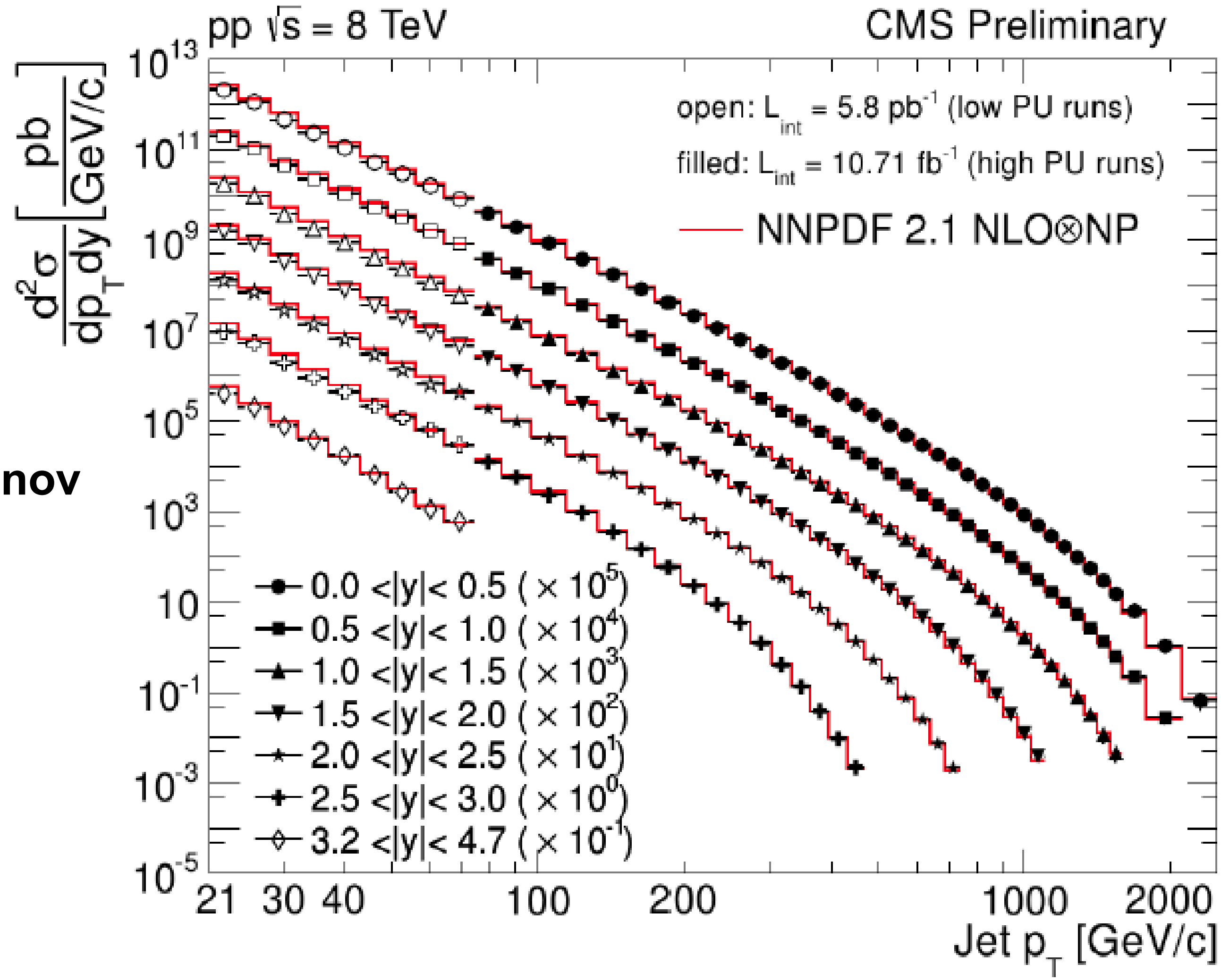
JHEP 1206 (2012) 036
arXiv:1202.0704

Forward Jet Measurement

Combined low-pileup runs (Summer 12) and full 2012 dataset

CMS-PAS-FSQ-12-031 [comb. CMS-PAS-SMP-12-012]

Grigory Safronov
DIS14



Data is well-described in wide range of p_T and rapidities by NLO⊗NP theory predictions

Closer look at forward jets

$3.2 < |\eta| < 4.7$
$21 < p_T < 80$

Experimental uncertainties:

JES:	< 45%
Unfolding:	3-6%
Luminosity:	4%

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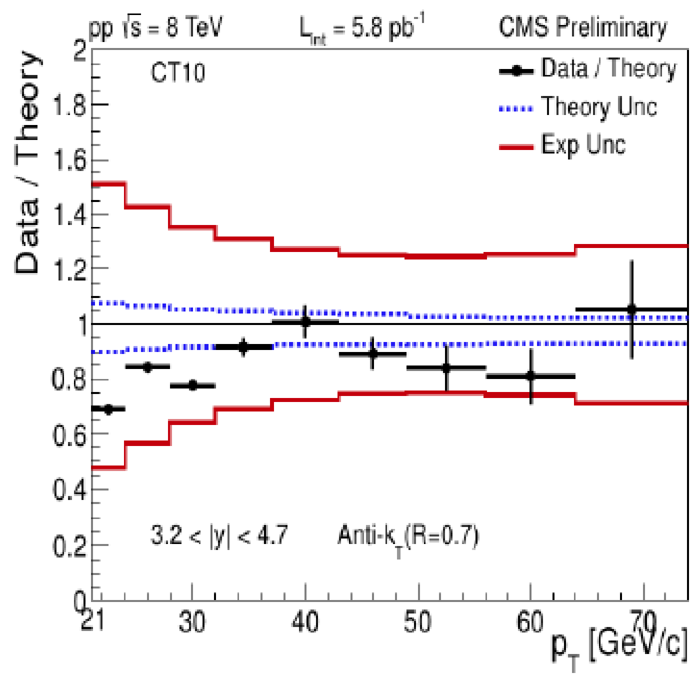
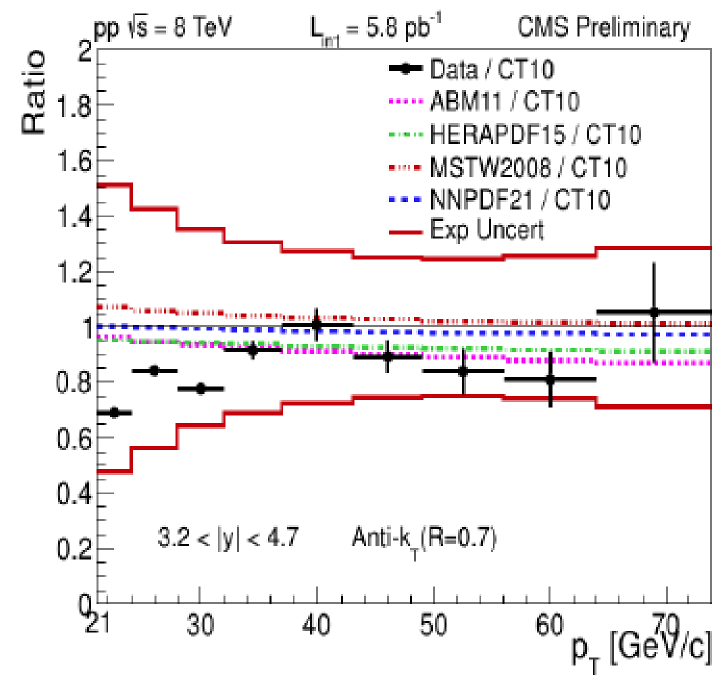
DIS14





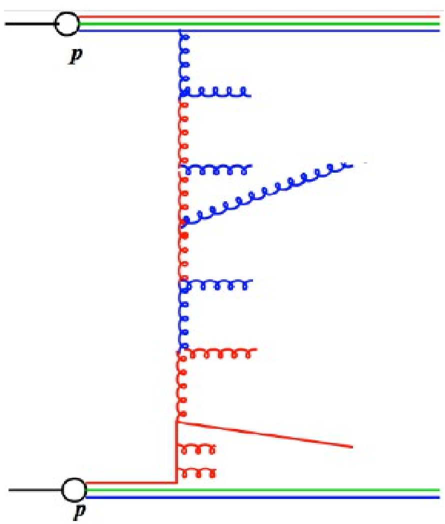
All predictions agree with data within the uncertainties

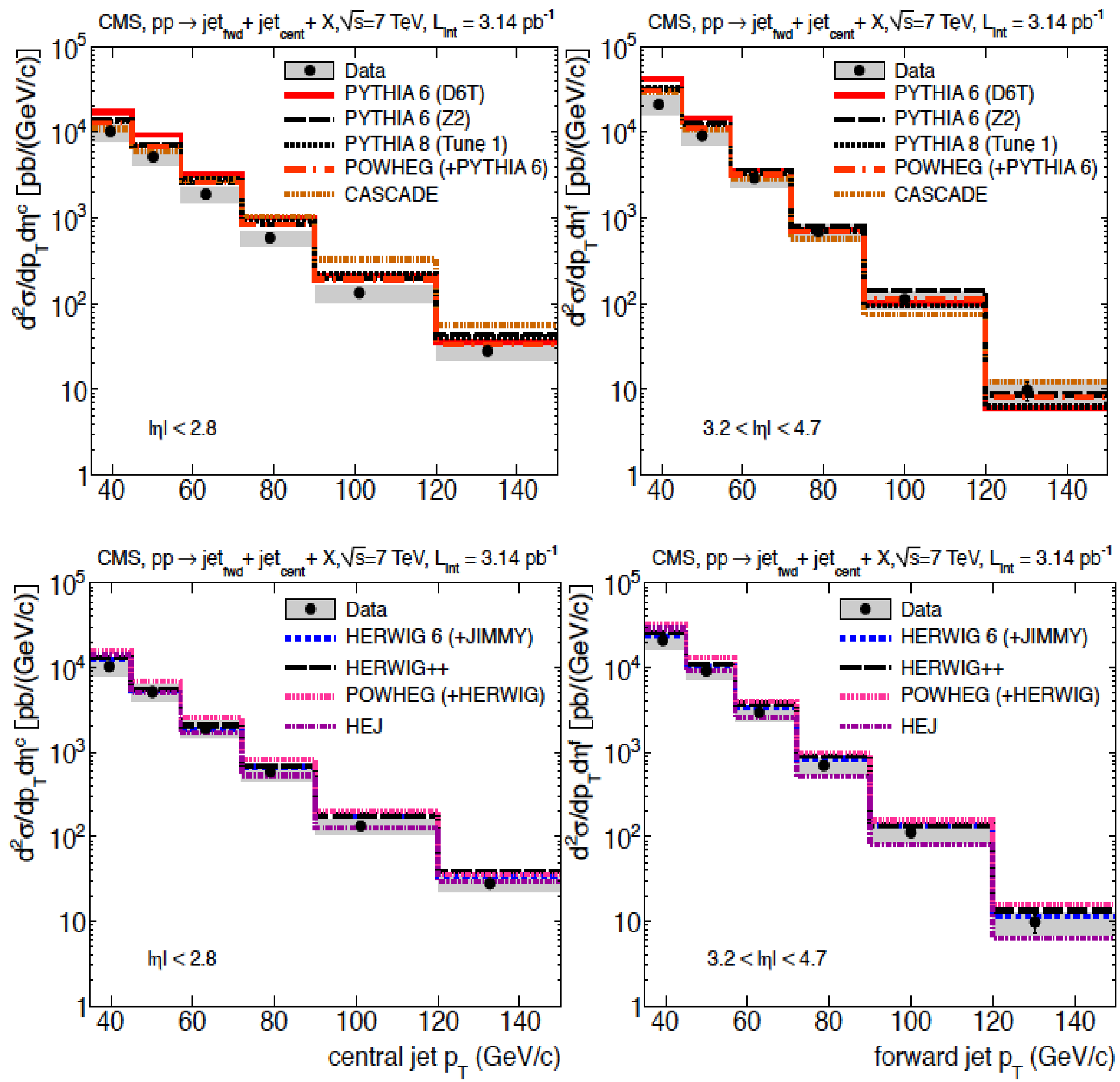
Conclusion: inclusive jet production is well-described by theory predictions over the wide range of p_T and rapidity

Forward+Central Jets

Events with at least one jet with
- **$3.5<|\eta|<4.7$**
- **$p_{t,jet}>35$ GeV**

and one central jet with
- **$|\eta|<2.8$**
- **$p_{t,jet}>35$ GeV**





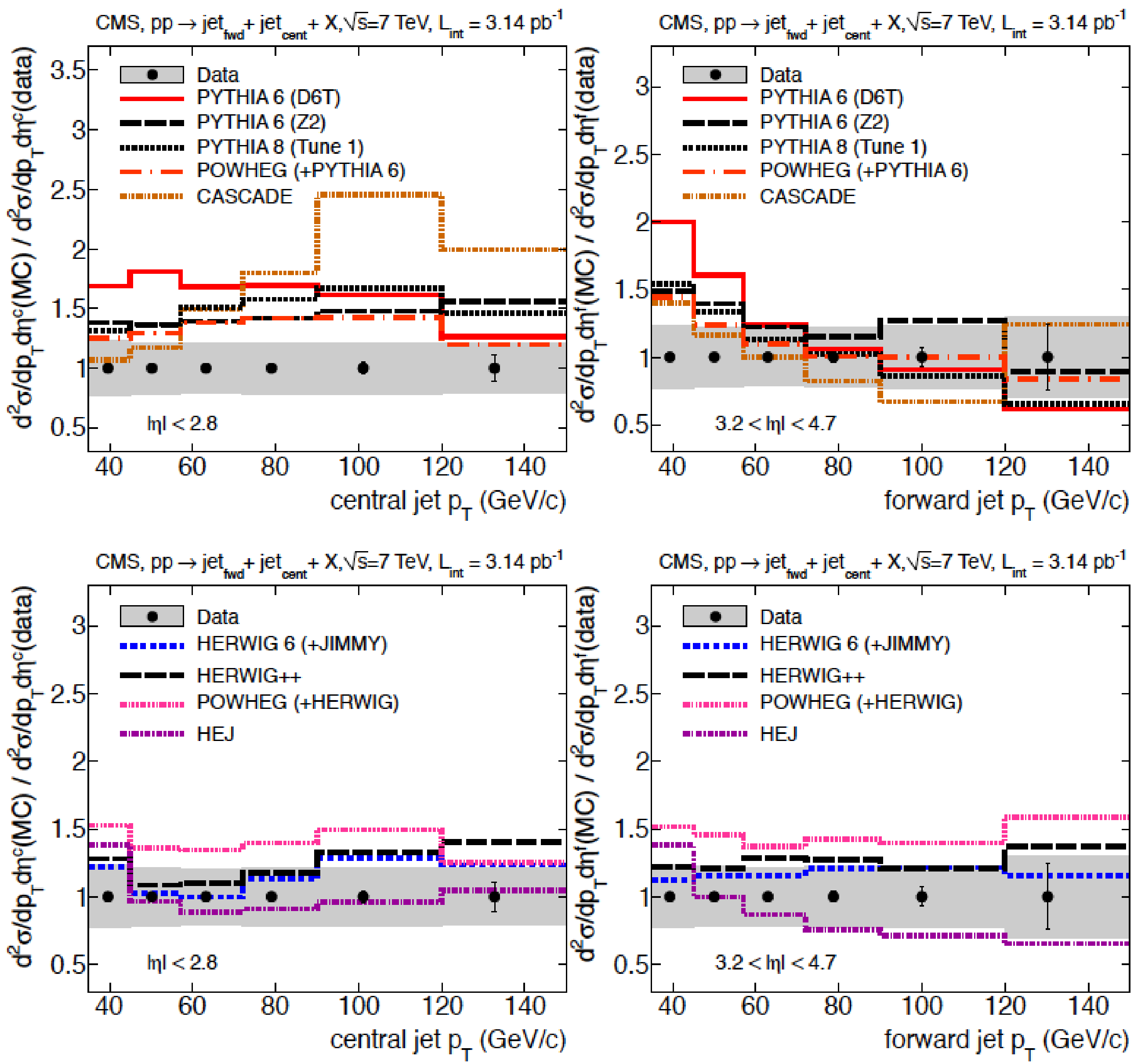
- **Forward jet cross-section somewhat steeper than central jet cross-section.**

- **Comparison to several generators. (ratios on next slide)**

JHEP 1206 (2012) 036
arXiv:1202.0704

Forward+Central Jets

- **Difference in MC description of data between the forward and the central jet.**
- **Largest shape difference for forward jet.**
- **Pythia6 and Pythia8, as well as CCFM based CASCADE problem with normalization of the central jet and shape of the forward jet.**
- **Herwig6, Herwig++, and the BFKL inspired MC HEJ describe the data best.**



JHEP 1206 (2012) 036
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Inclusive over Exclusive Di-jet Cross-section

Eur.Phys.J.C72(2012)2216
arXiv:1204.0696

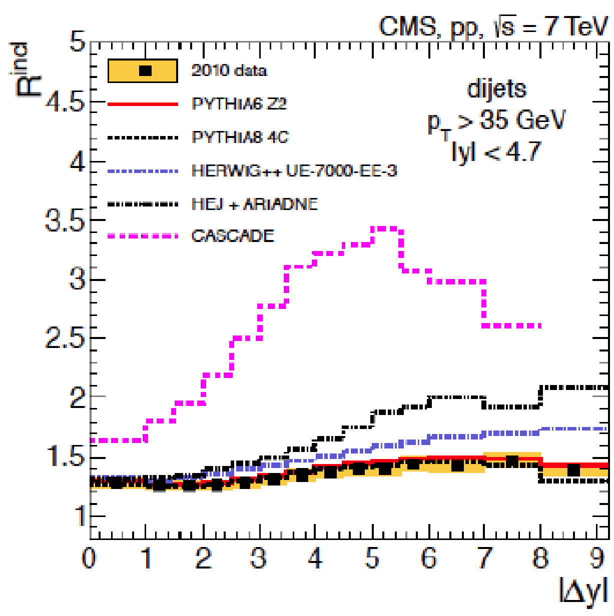
Jets reconstructed with the anti-kT algorithm (R=0.5)
$p_{t,jet}$>35 GeV and $|\eta_{jet}|$<4.7

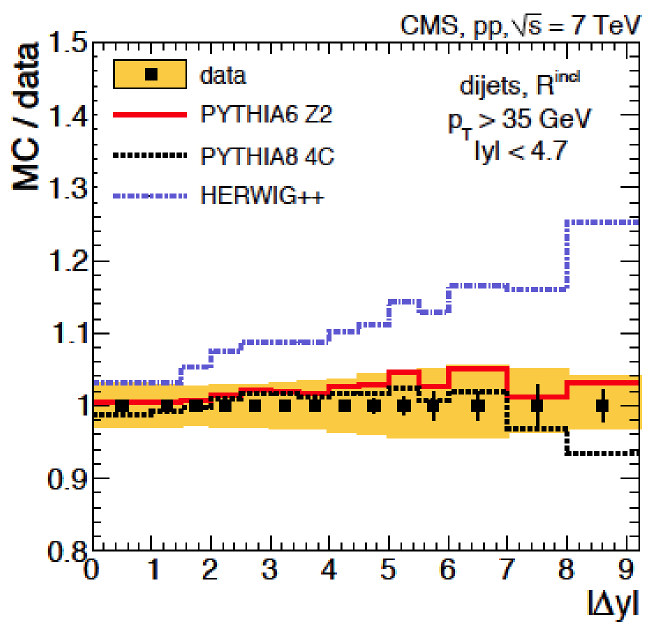
Observable: Rapidity difference between jets, Δy

Inclusive jets: **All jet pairs in the events considered**
Exclusive jets: **Events with exactly two jets above the threshold**
Mueller-Navelet jets: **Most forward and backward jet in the inclusive sample**

$$R = \frac{\sigma_{dijet}(\text{inclusive})}{\sigma_{dijet}(\text{exclusive})}$$

$$R = \frac{\sigma_{dijet}(\text{MN})}{\sigma_{dijet}(\text{exclusive})}$$





- Increasing Δy → Larger phase space for radiation
- Pythia6 (Z2) and Pythia8 (4C) agrees well with data
- Herwig++ (EE3) and HEJ+Ariadne too high at high Δy
- Small effect from MPI (not shown)
- Cascade off

MN over Exclusive Di-jet Cross-section

Eur.Phys.J.C72(2012)2216
arXiv:1204.0696

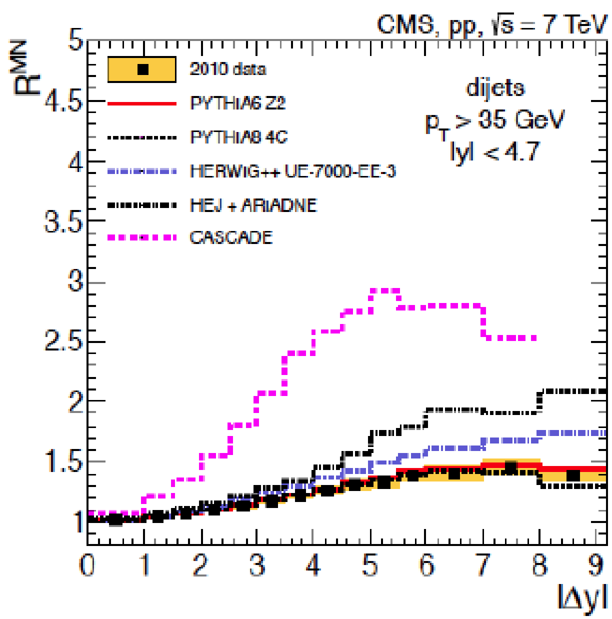
Jets reconstructed with the anti-kT algorithm (R=0.5)
$p_{t,jet}$>35 GeV and $|\eta_{jet}|$<4.7

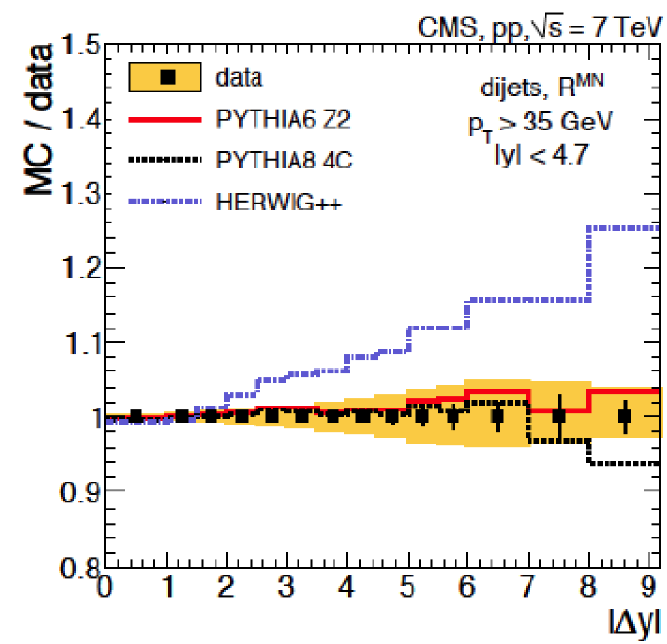
Observable: Rapidity difference between jets, Δy

Inclusive jets: **All jet pairs in the events considered**
Exclusive jets: **Events with exactly two jets above the threshold**
Mueller-Navellet jets: **Most forward and backward jet in the inclusive sample**

$$R = \frac{\sigma_{dijet}(\text{inclusive})}{\sigma_{dijet}(\text{exclusive})}$$

$$R = \frac{\sigma_{dijet}(\text{MN})}{\sigma_{dijet}(\text{exclusive})}$$





- Low Δy: Ratio(MN/exclusive) per definition *smaller* than Ratio(inclusive/exclusive)
- High Δy: Ratio(MN/exclusive) per definition *same* than Ratio(inclusive/exclusive)
- MC data comparison: same conclusion as on previous slide

General conclusion: No visible effects beyond collinear factorization + LL parton-showers

Measurement

CMS-FSQ-12-002

- $\sqrt{s}$ = 7 TeV, Luminosity ≈ 5 pb^{-1}
- Inclusive single jet trigger, and dedicated forward+backward jet trigger.
- Calorimeter jets - anti-kt algorithm with R=0.5.
- Events with at least two jets with $p_{t,jet}$>35 GeV and $|\eta|$<4.7.
  The two jets with largest rapidity separation selected.
- Measurement corrected to stable particle level
- Observables:

  - Azimuthal angle between the two jets with largest rapidity separation: : $\Delta\varphi$

  - Fourier coefficients, C_n : $d\sigma/d(\Delta\varphi) \sim \sum C_n \cos(\pi - \Delta\varphi)$

    $C_1 = \langle\cos(\pi - \Delta\varphi)\rangle$

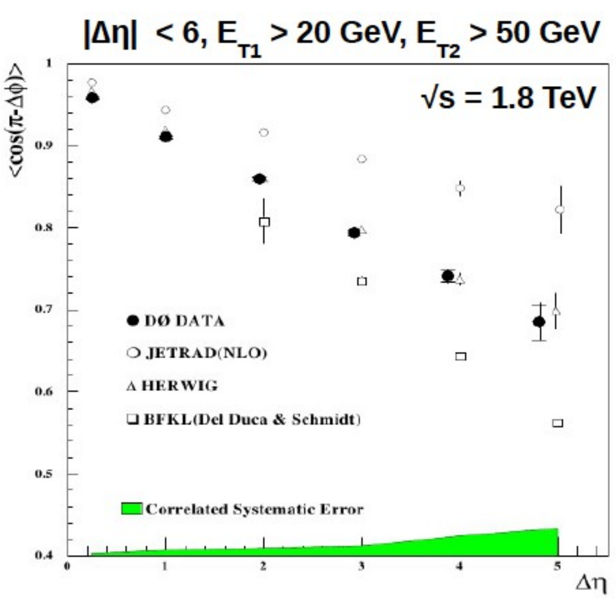
    $C_2 = \langle\cos(2*(\pi - \Delta\varphi))\rangle$

    $C_3 = \langle\cos(3*(\pi - \Delta\varphi))\rangle$

  - Ratios C_2/C_1 and C_3/C_2

  These quantities are measurement in 3 bins of rapidity separation between the jets: $0 < \Delta y < 3$
  $3 < \Delta y < 6$
  $6 < \Delta y < 9.4$

Previously measured up to Δy < 6.0.



Azimuthal decorrelations – $\Delta\phi$

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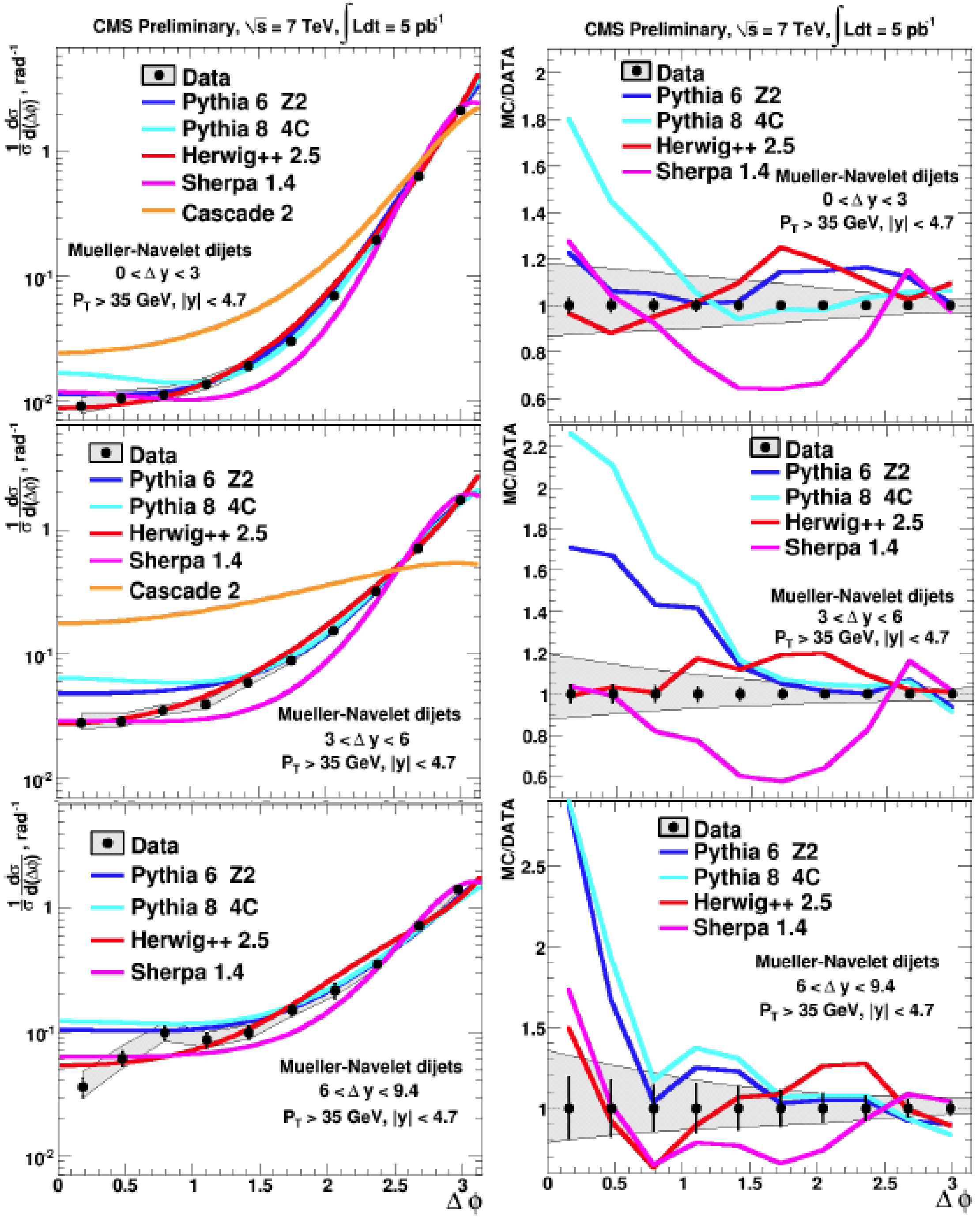
CMS-FSQ-12-002



Events with at least two hard jets with $|\eta|<4.7$ and $p_{t,jet}>35$ GeV

Measure azimuthal difference between the two jets with largest rapidity separation selected.

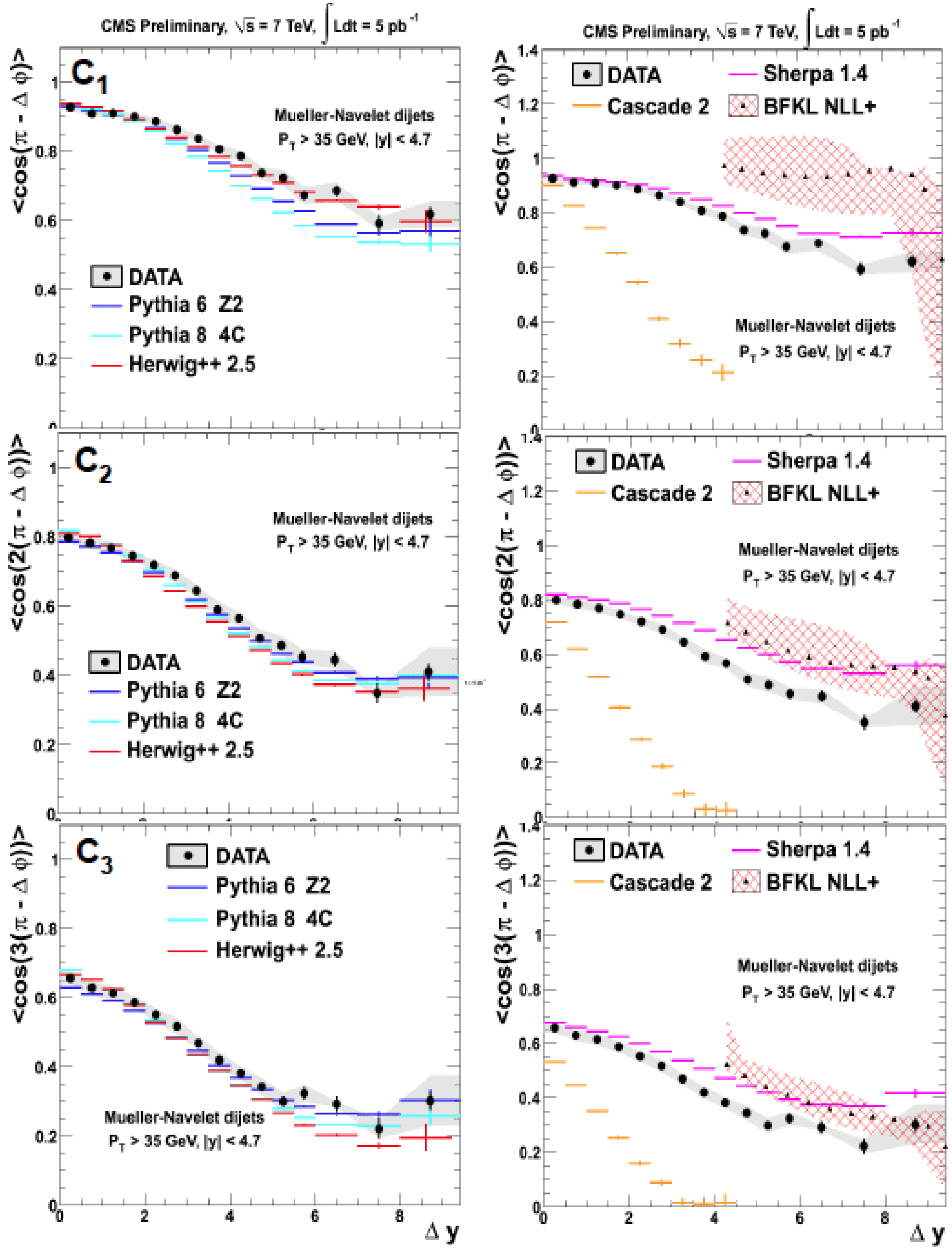
- **Larger azimuthal decorrelation with increasing Δy**
- **Herwig++ provides the best description of data**
- **Pythia6/8 too large decorrelation**

  → Overall description is opposite to what we see in the di-jet ratios

- **Sherpa with 4 final state partons – too much correlation**
- **CASCADE – k_t-factorization based (CCFM) – too strong decorrelations**

$C_N = < \cos (N (\pi - \Delta\varphi)) >$

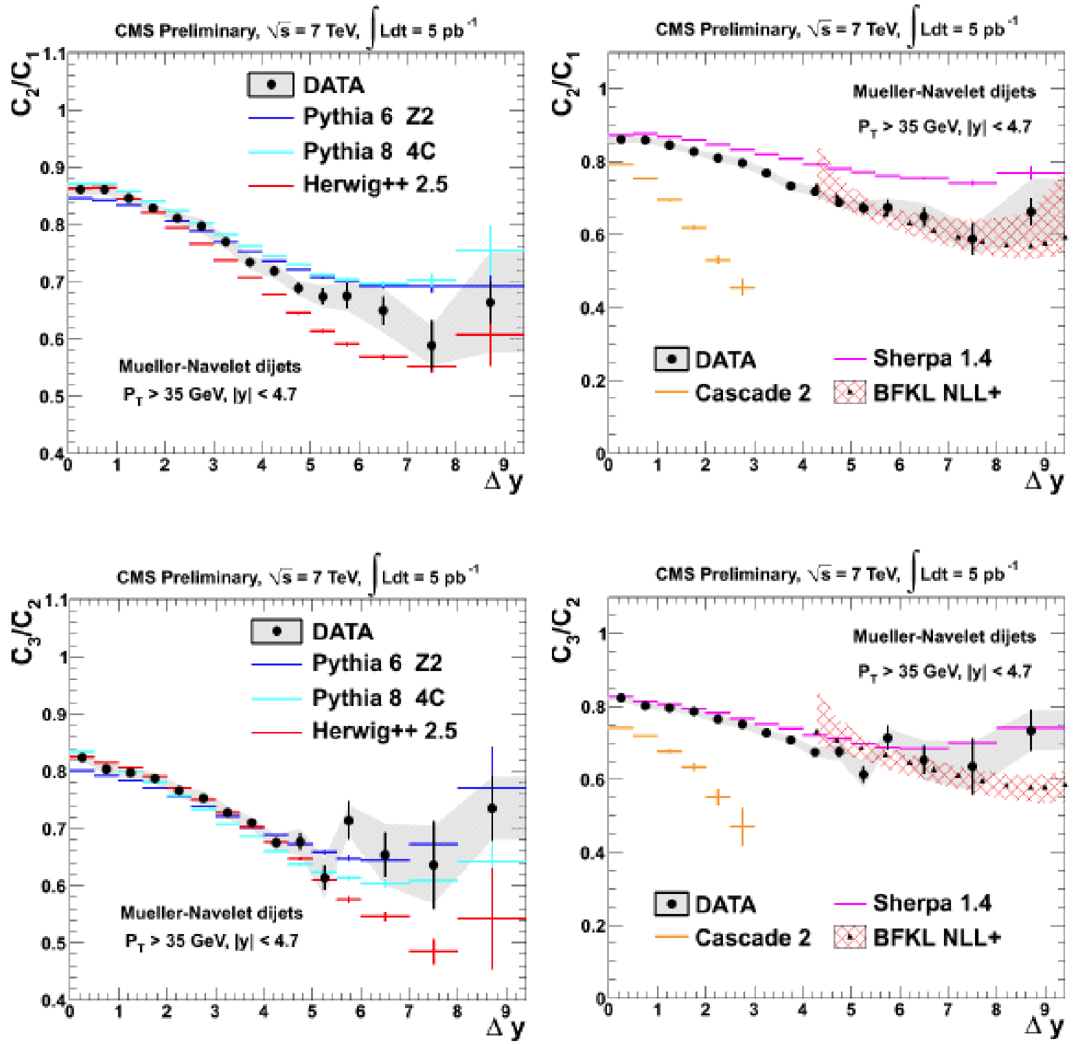
CMS-FSQ-12-002



- **Fourier coefficients, C_n, expected to be sensitive to properties of non-collinear dynamics**
  - **C_1 = <cos(π - Δφ)>**
  - **C_2 = <cos(2*(π - Δφ))>**
  - **C_3 = <cos(3*(π - Δφ))>**
- **Herwig++ and Pythia6/8 qualitatively describe $C_N = < \cos (N (\pi - \Delta\varphi)) >$**
- **Sherpa overestimates the data**
- **CCFM based CASCADE predicts too weak angular correlation**
- **BFKL NLL calculations**
  (arXiv:1302.7012 [Ducloue et al])
  - **only valid for Δy> 4**
  - **parton level predictions. However, small effect from hadronization compared to systematic uncertainty**
  - **Too strong angular correlation compared to data**

C_2/C_1 and C_3/C_2

CMS-FSQ-12-002



- DGLAP contributions are expected to partly cancel in the C_{n+1}/C_n – ratios.
- C_{n+1}/C_n described by LL DGLAP based generators towards low Δy
- Pythia8, Pythia6 Z2 overestimate C_2/C_1
- Herwig++ underestimate C_2/C_1
- Sherpa overestimates data
- CCFM based CASCADE predicts too small C_{n+1}/C_n
- At $\Delta y > 4$ theoretical BFKL NLL describe in particular C_2/C_1 within uncertainties

Forward-Central Decorrelations

Pedro Cipriano DIS14

Data

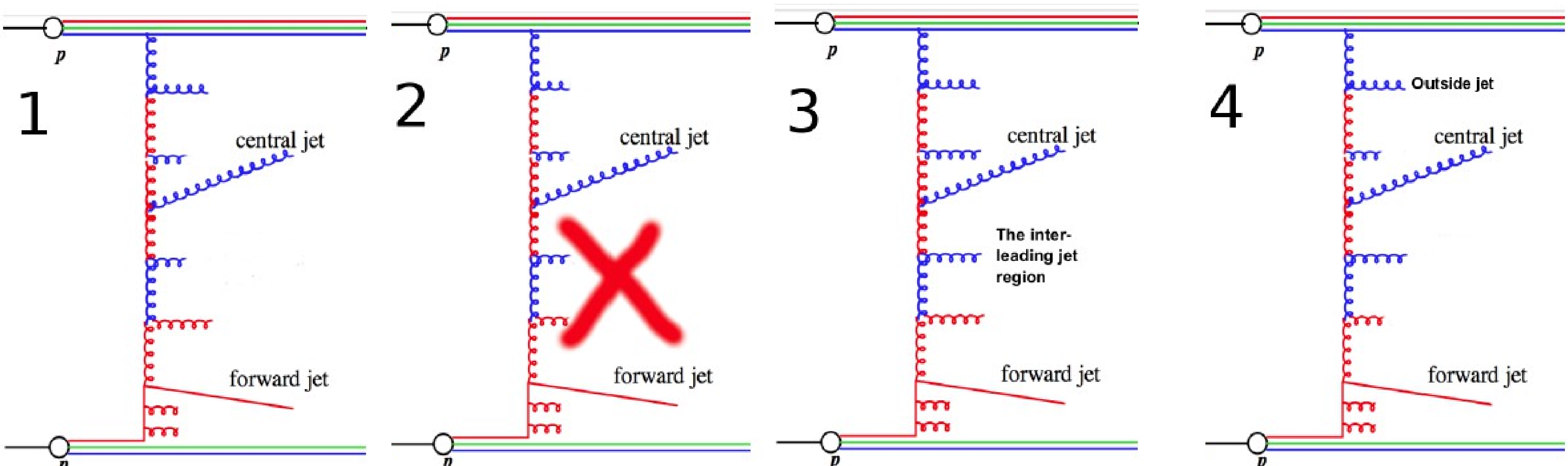
- 3.2 pb^{-1} from 2010 low pile-up *pp* collisions at $\sqrt{s} = 7$ TeV

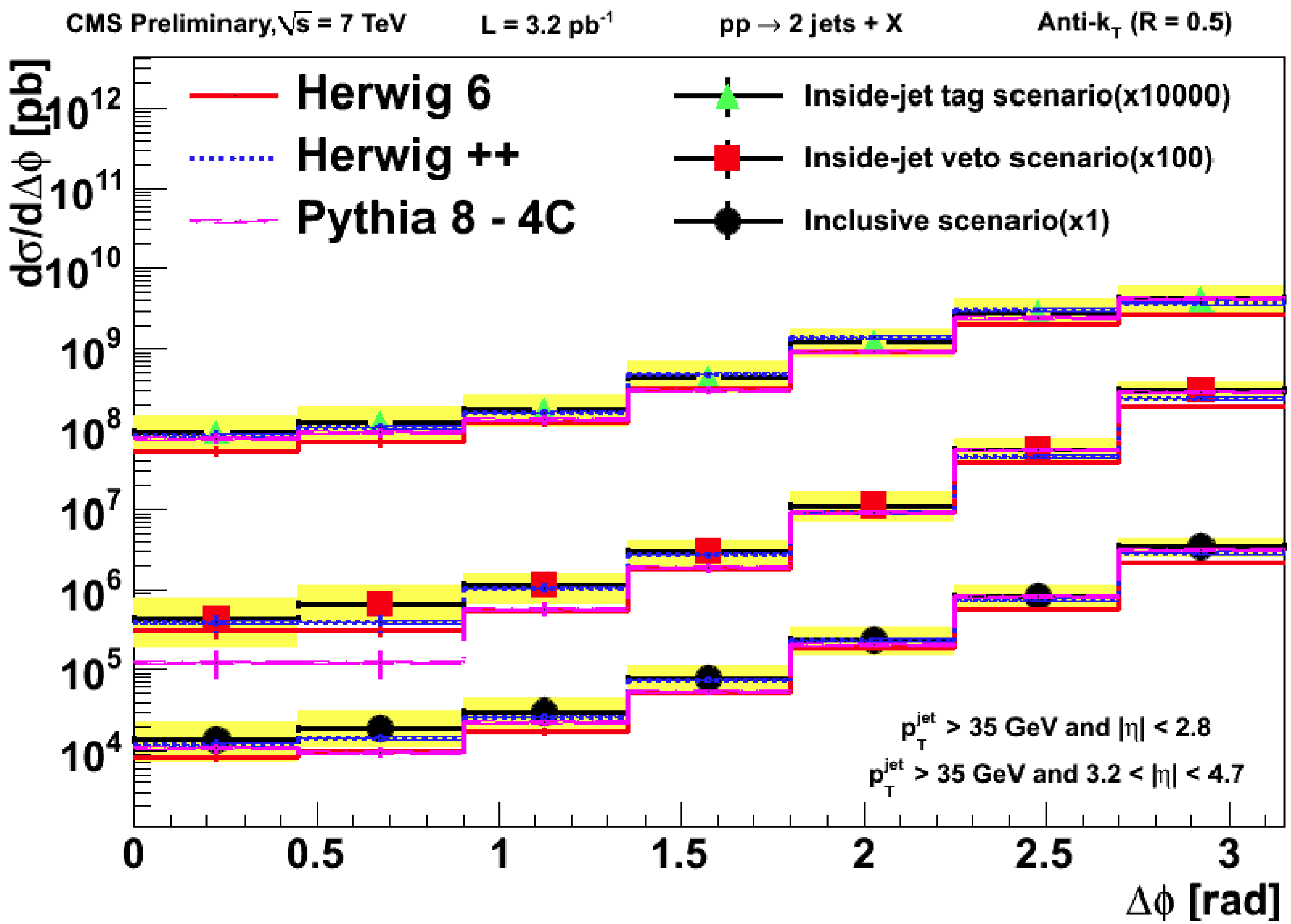
Physics selection

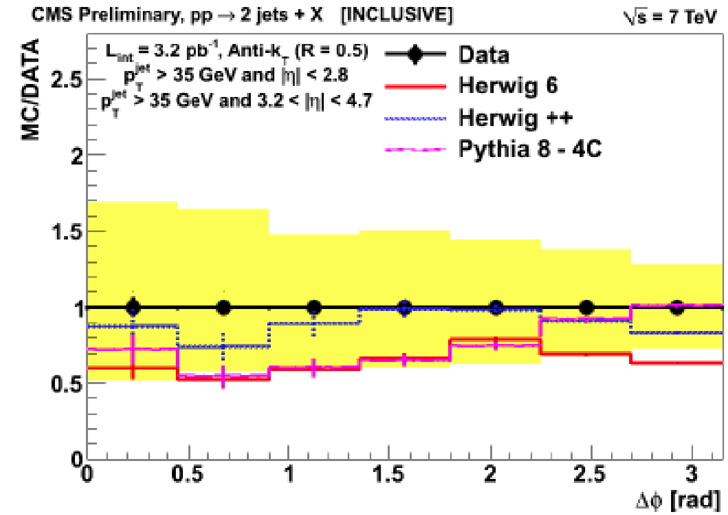
- Events with at least one forward ($3.2 < |\eta| < 4.7$) and at least one central ($|\eta| < 2.8$) jet with $p_T > 35$ GeV

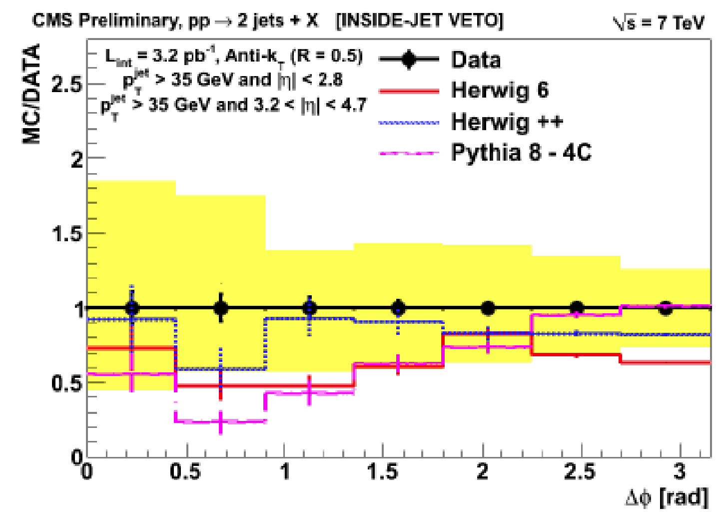
Different scenarios

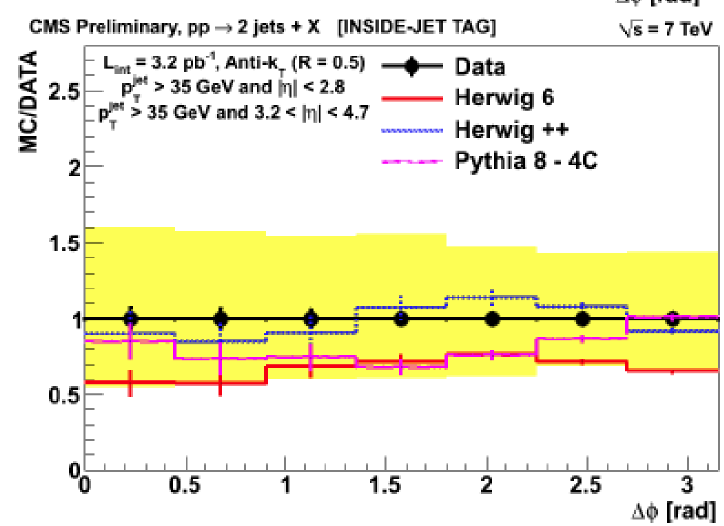
1. Inclusive scenario
2. Inside–jet veto scenario ($p_{T\ inside} < 20$ GeV)
3. Inside–jet tag scenario ($p_{T\ inside} > 20$ GeV)
4. Outside–jet tag scenario ($p_{T\ outside} > 20$ GeV)









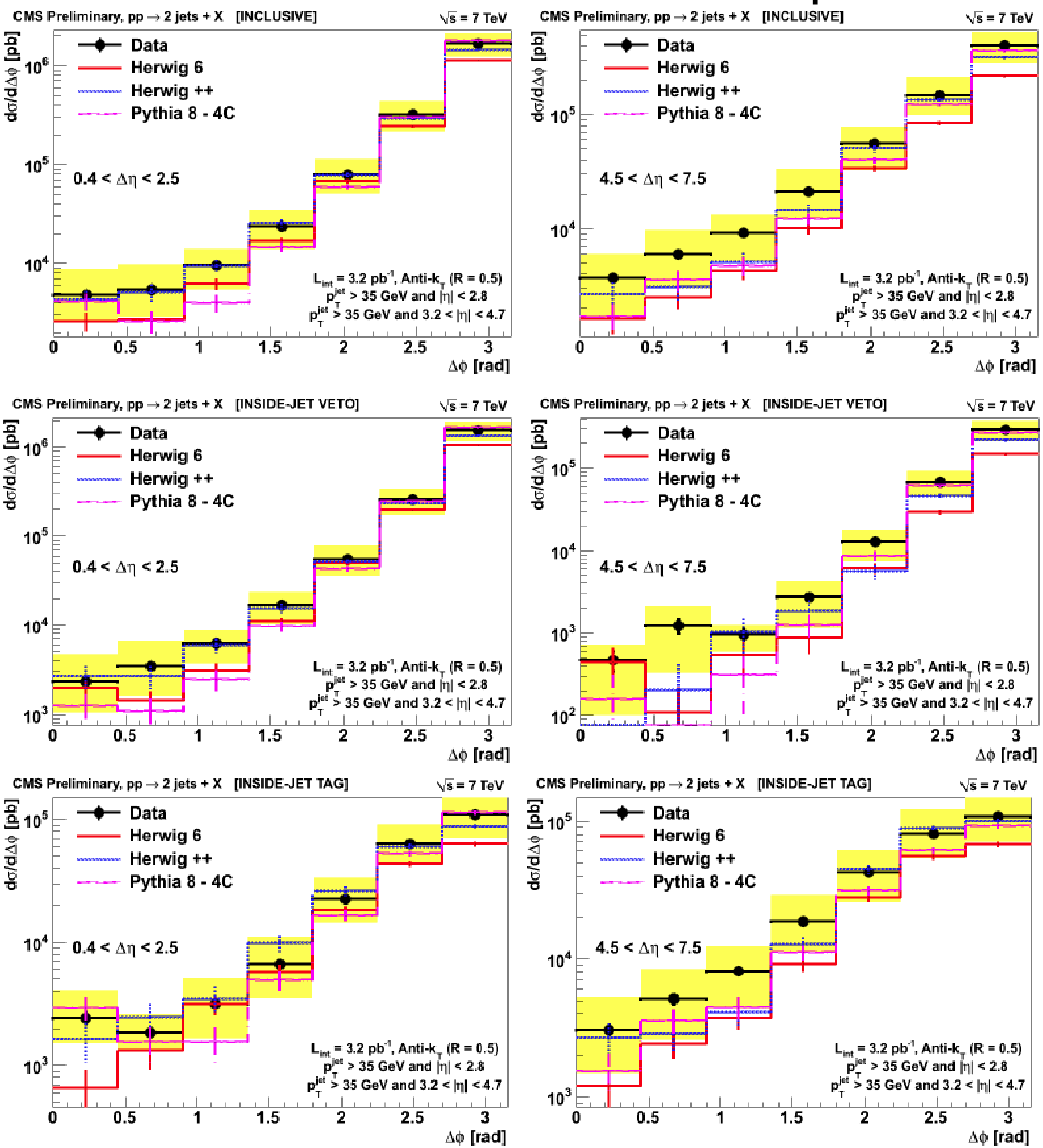


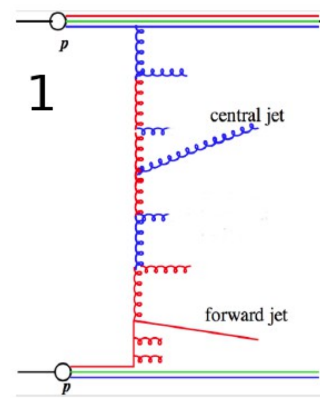
- **All tested MCs describe the data, considering the fairly large experimental uncertainty**

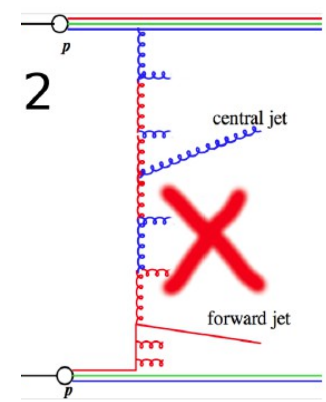
Δφ in for different of Δη

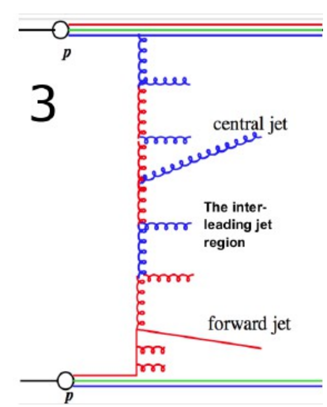
0.4 < Δη < 2.5

4.5 < Δη < 7.5



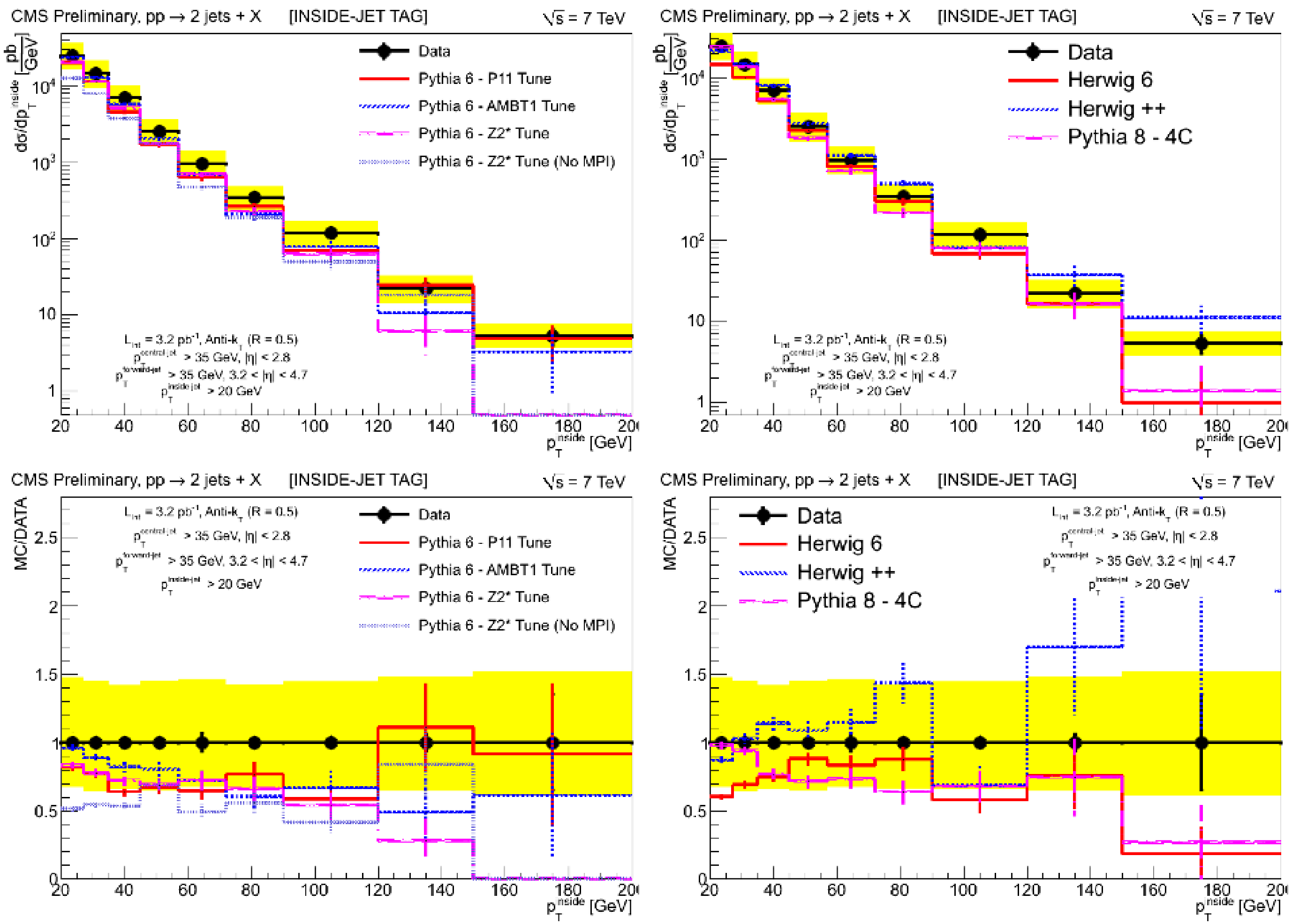


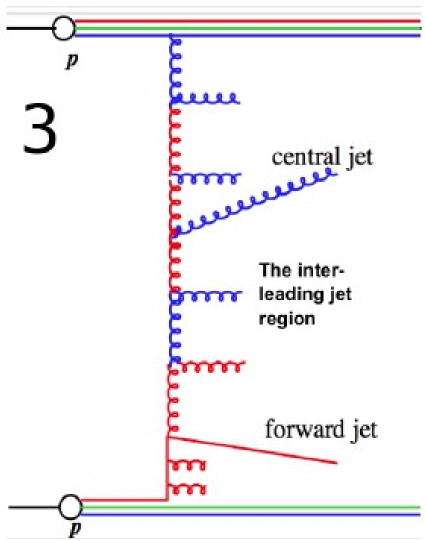




tc...

Inter leading jet pt

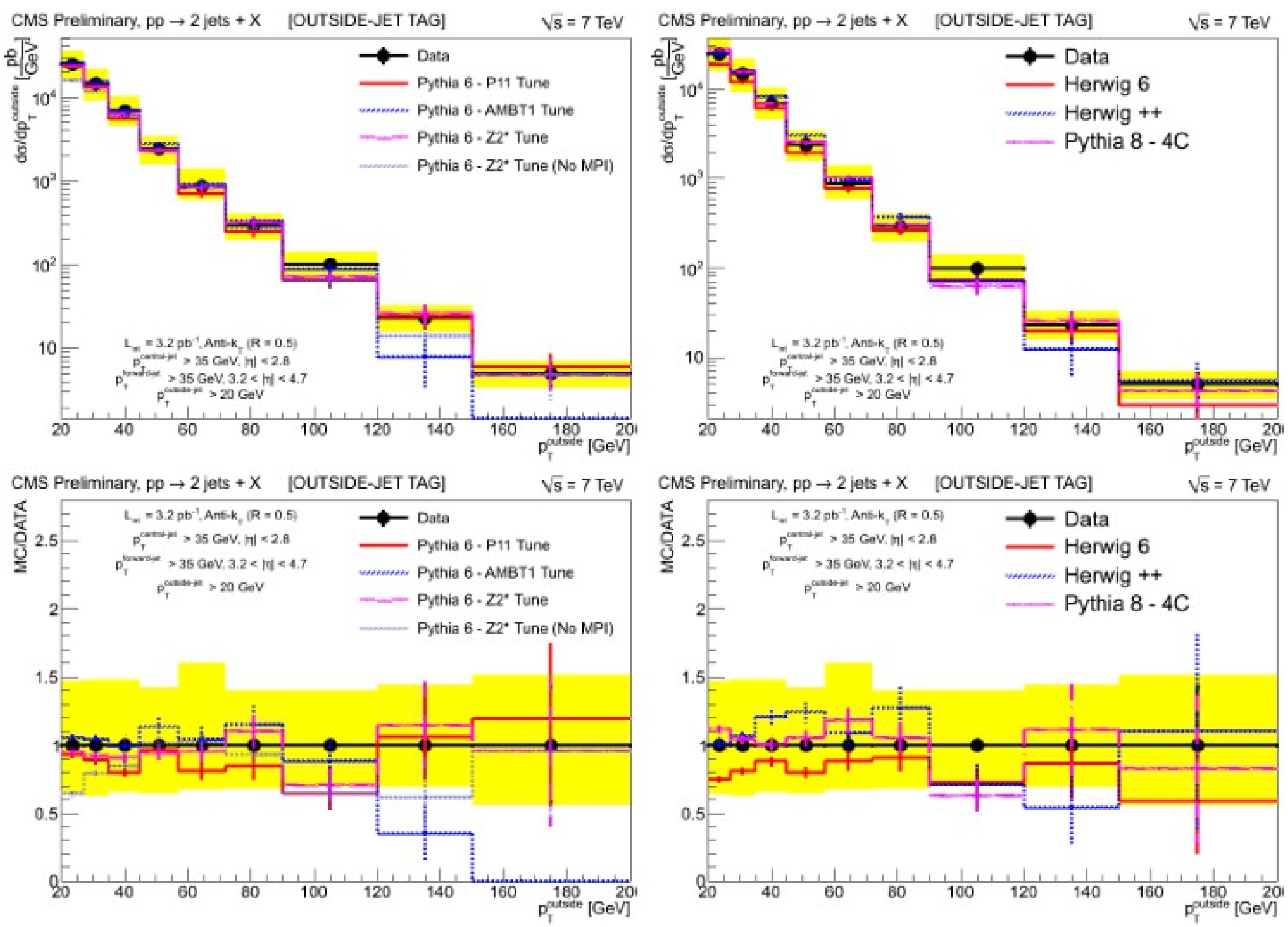




Outside jet pt

$$\Delta\eta^{out} = \min(|\eta_{outside-jet} - \eta_{central-jet}|, |\eta_{outside-jet} - \eta_{forward-jet}|)$$

Expected to give additional sensitivity to PS algorithms and color coherence effects.



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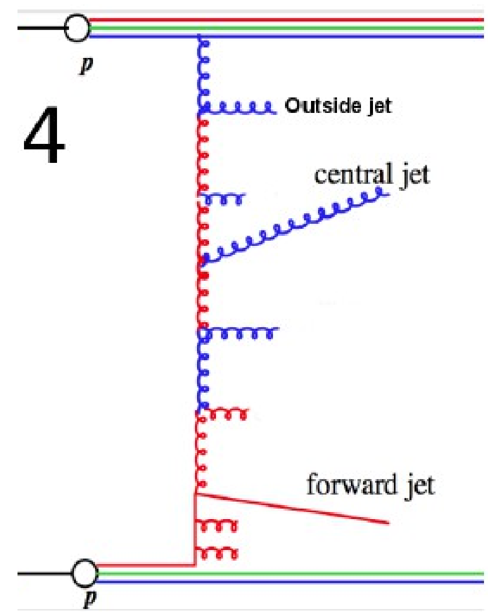
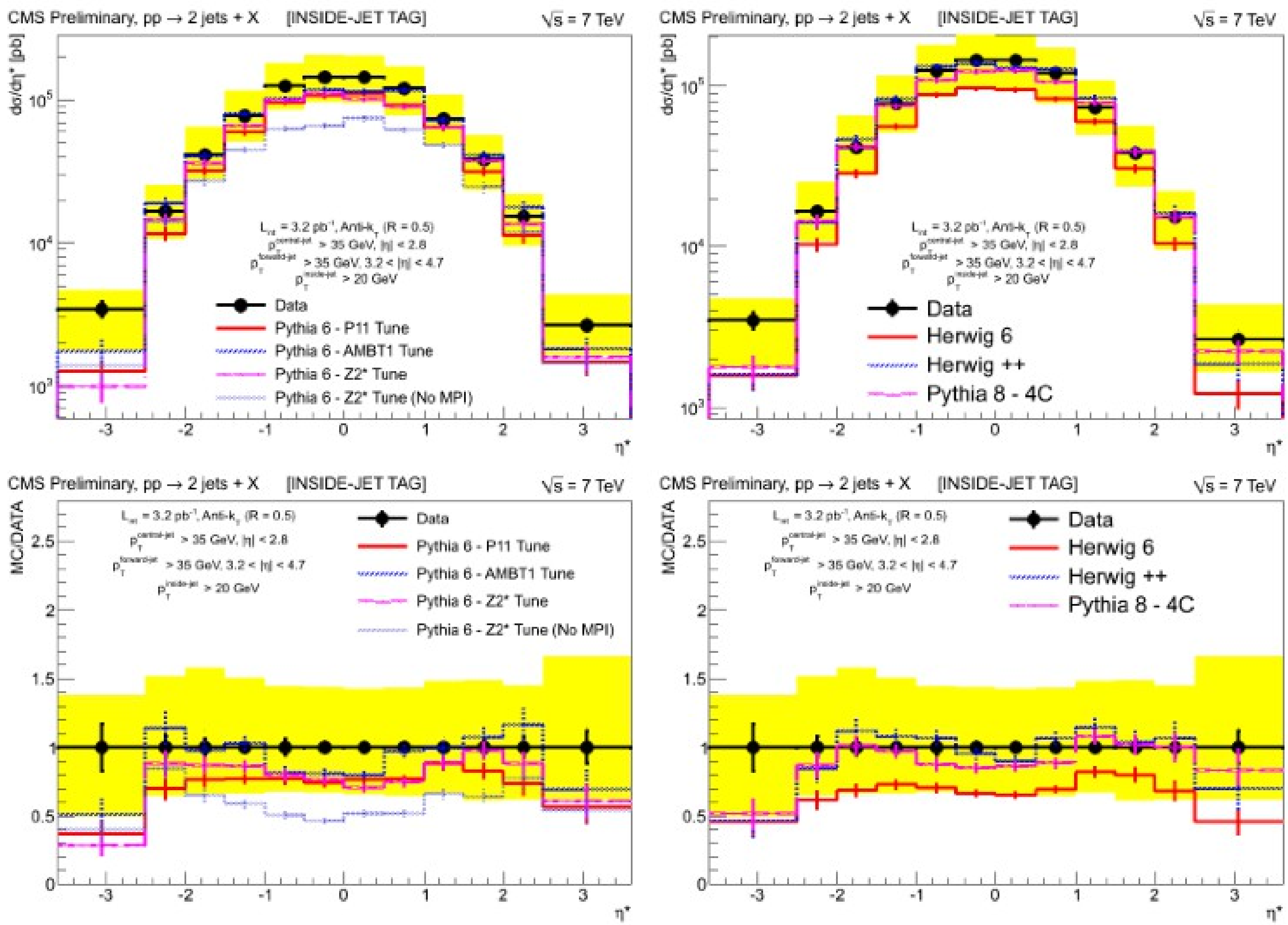
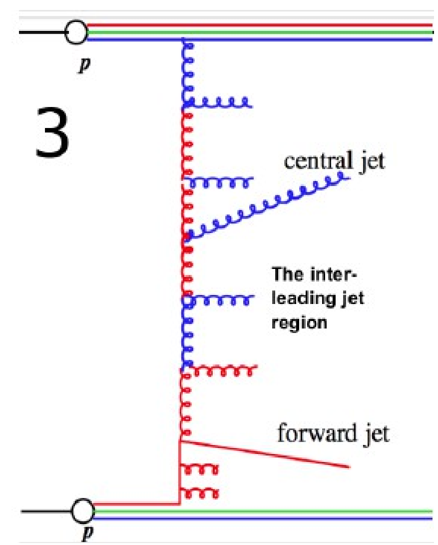


Forward-Central Decorrelations

$$\eta* = \eta_{inside-jet} - (\eta_{central-jet} + \eta_{forward-jet})/2$$

Expected to give additional sensitivity to PS algorithms and color coherence effects.





Forward-Central Decorrelations

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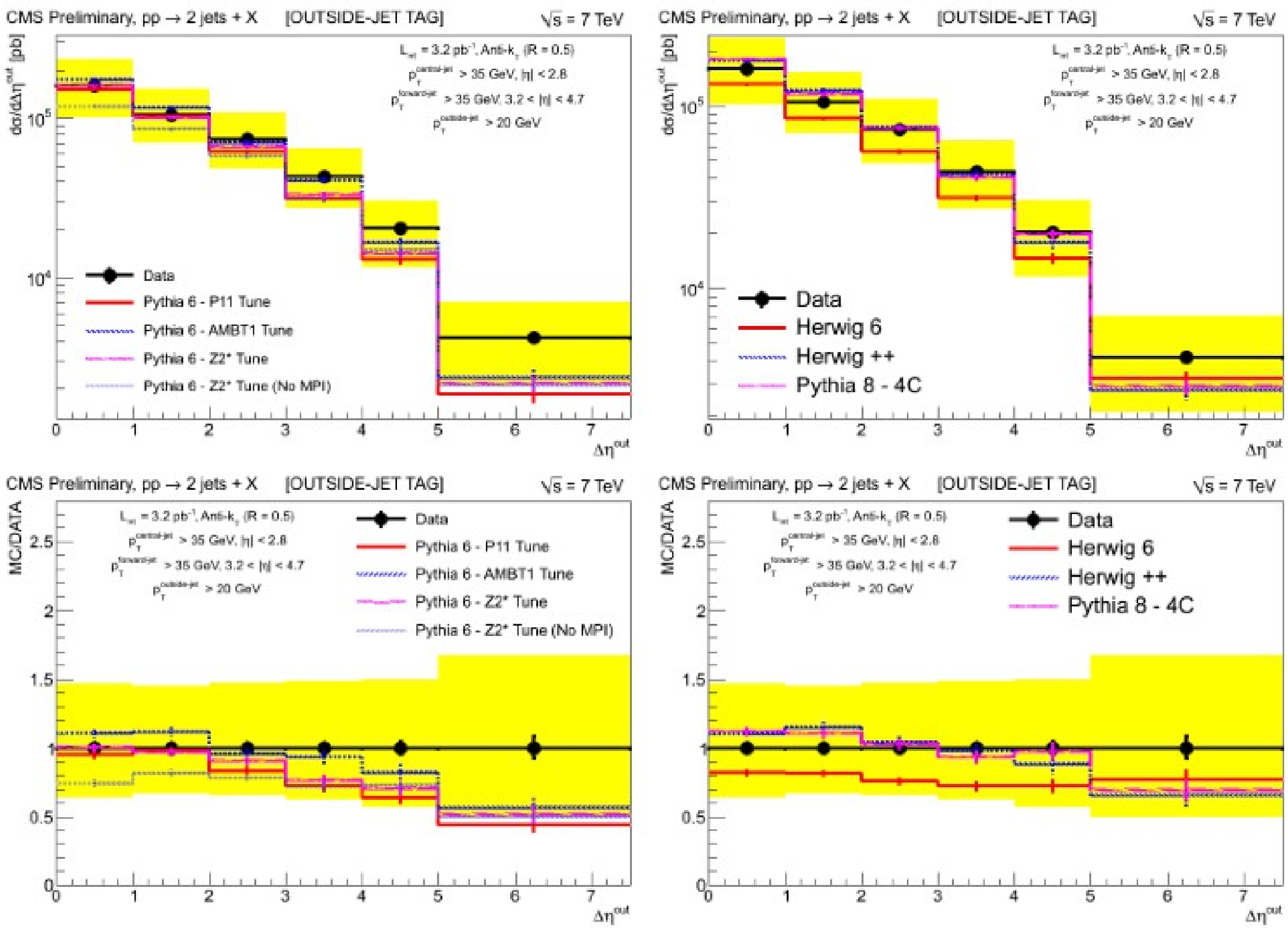
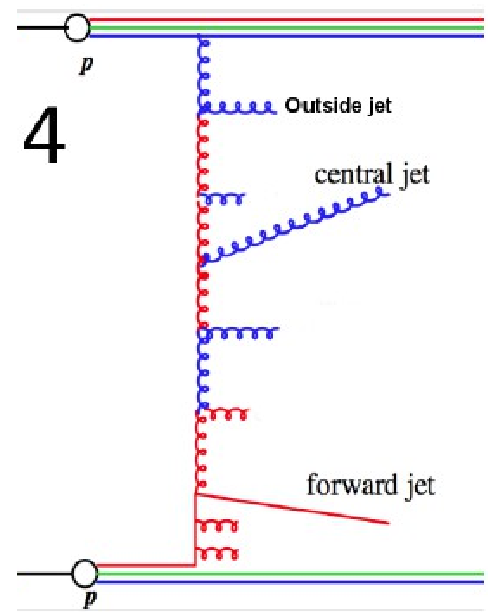




Summary and Conclusions

CMS results on forward and forward-central jets presented:

- **Inclusive Forward Jets**
  - **Large syst. uncert --> MCs describes data.**
- **Forward + Central Jets**
  - **Data does not prefer a certain model, but Herwig and HEJ best.**
- **Ratios of Dijet Production up to Δy < 9.4**
  - **Well described by Pythia6 and Pythia8. Herwig fails.**
- ***Azimuthal correlations of jets with large rapidity separation***
  - **Herwig best. Pythia too decorrelated.**
- **Forward-Central Jets. Large uncertainties in data --> MCs describes data.**

**→ Different DGLAP based generators describe the data differently.
DGLAP ~ OK, but not in a consistent way. No MC describes all data.**

→ No deviations beyond collinear-factorization+parton-shower in regions of phase-space where BFKL effects are expected to be enhanced.

→ Deviation between data and MC can not be interpreted as due to non-DGLAP dynamics

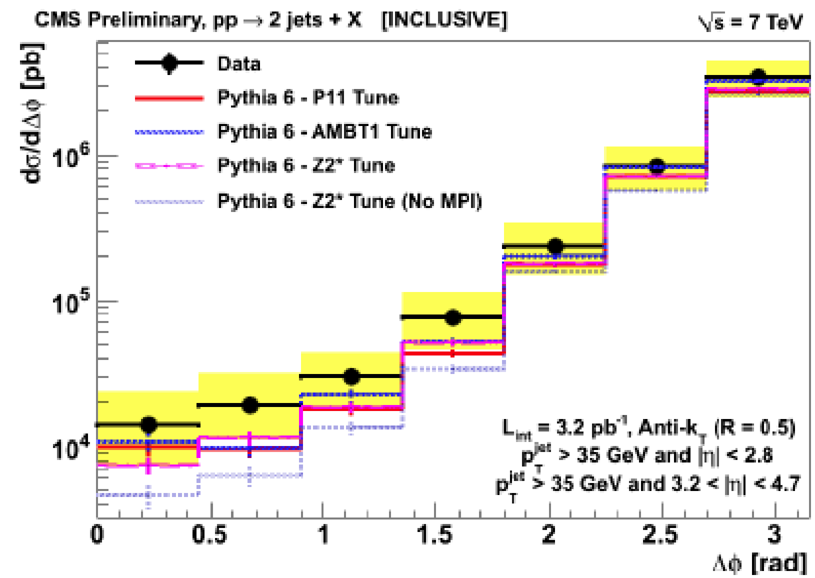
→ Failure of MC models is not only a matter of tuning

Back up

Results - $\Delta\phi$ inclusive scenario

Pedro Cipriano DIS14

- **Data fully corrected to hadron level**
- $\Delta\phi$ is a steeply growing distribution
- All MC models describe the distribution reasonably well, except for the lower $\Delta\phi$ region
- HERWIG++ has the best overall description
- PYTHIA 6 - Z2* without MPI deviates more from data than other PYTHIA 6 tunes



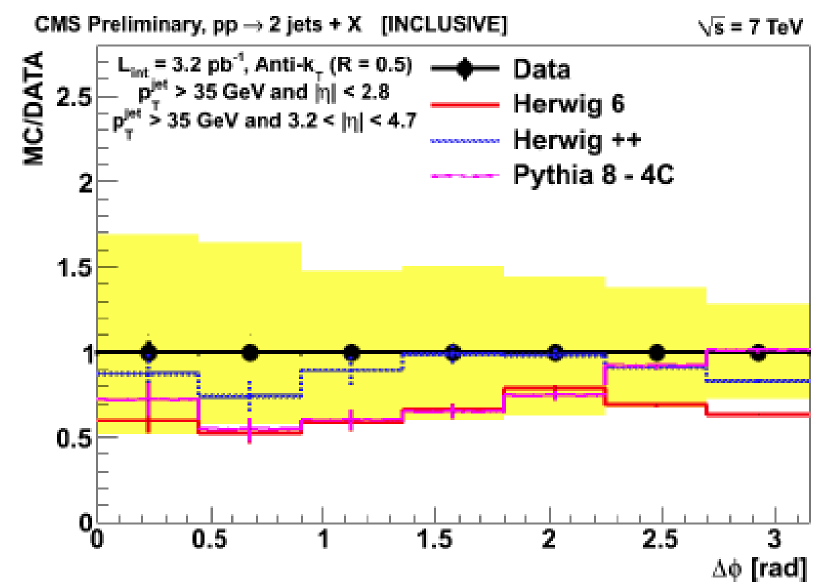


Figure: $\Delta\phi$ in inclusive scenario compared with different MCs

Forward-Central Decorrelations

Pedro Cipriano DIS14

Data

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Physics selection

- Events with at least one forward ($3.2 < |\eta| < 4.7$) and at least one central ($|\eta| < 2.8$) jet with $p_T > 35$ GeV

Different scenarios

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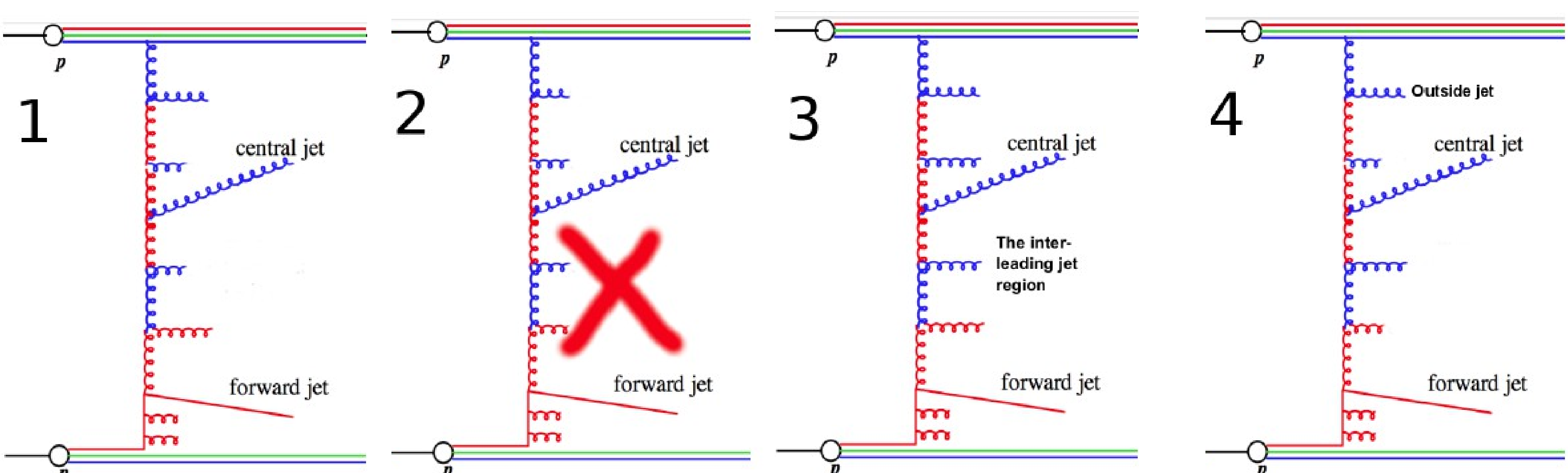

Forward-Central Decorrelations

Results - $\Delta\phi$ inclusive scenario in slices of $\Delta\eta$

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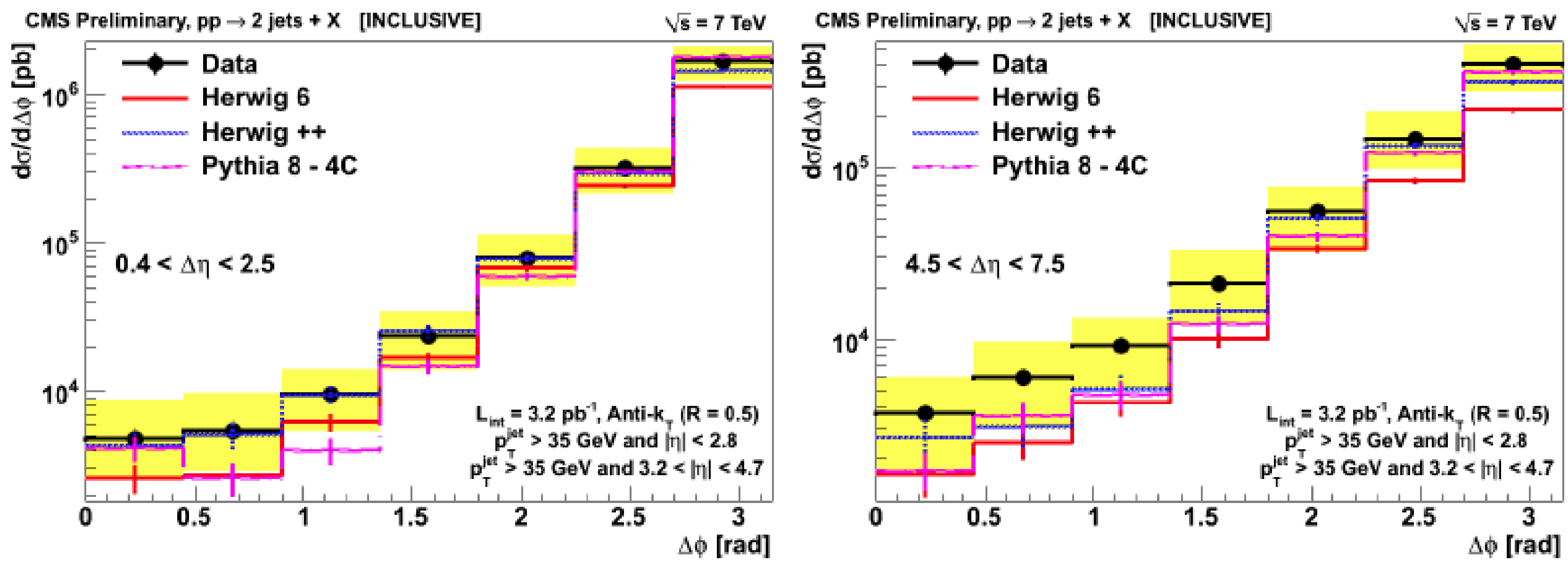

- At large $\Delta\eta$ there is more phase space for additional radiation
- At small $\Delta\eta$ the distribution is falling much more steeply than at large rapidity separation (from 2 to 2.5 orders of magnitude)
- In general the MC describe this effect, except for the lower $\Delta\phi$ region
- HERWIG++ provides the best overall description
- PYTHIA 6 - Z2* without MPI deviates event more from data than

Results - $\Delta\phi$ inside–jet veto scenario

- The correlation is stronger than in the inclusive scenario
- PYTHIA deviates more from data in the inclusive scenario while HERWIG describes it better for lower $\Delta\phi$
- The best description is provided by HERWIG++
- PYTHIA 6 - Z2* without MPI deviates from both data and other tunes for lower $\Delta\phi$, having too strong correlation

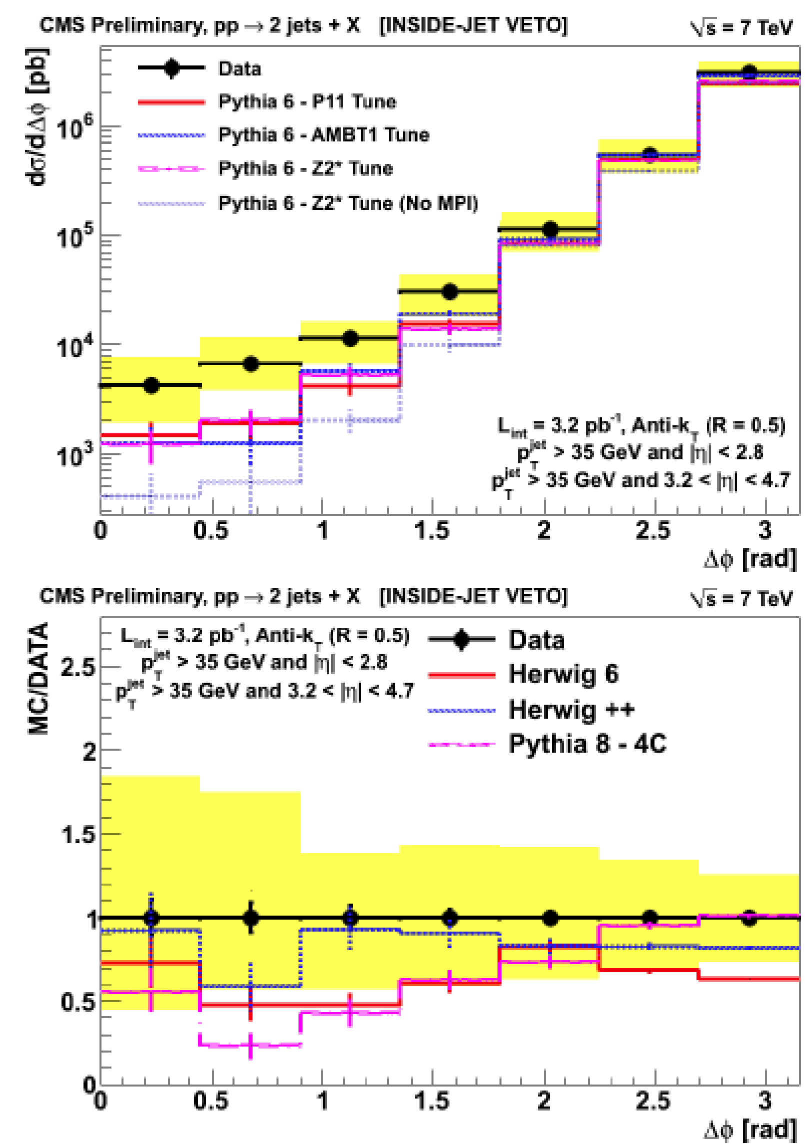

Figure: $\Delta\phi$ in inside–jet veto scenario compared with MC predictions

Forward-Central Decorrelations

Results - $\Delta\phi$ inside–jet veto scenario

- The correlation is stronger than in the inclusive scenario
- PYTHIA deviates more from data in the inclusive scenario while HERWIG describes it better for lower $\Delta\phi$
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Pedro Cipriano DIS14

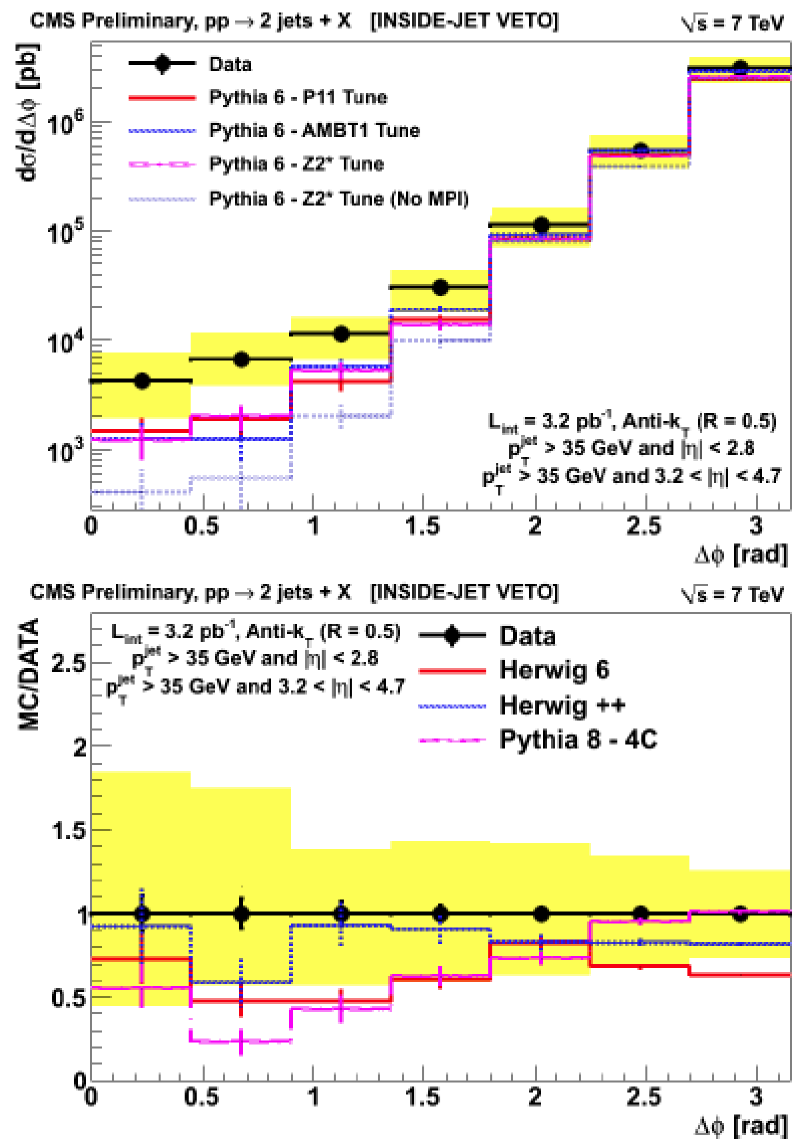

Figure: $\Delta\phi$ in inside–jet veto scenario compared with MC predictions

Results - $\Delta\phi$ inside–jet veto scenario in slices of $\Delta\eta$

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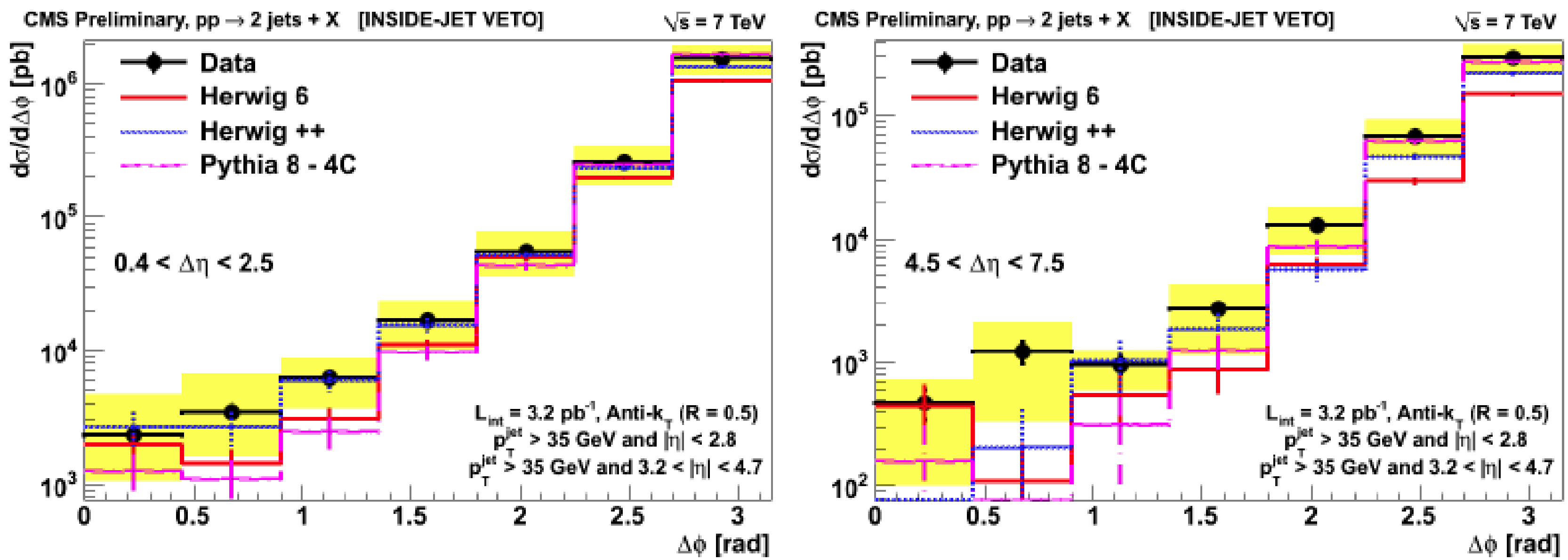

- In the inside–jet veto scenario, the slopes are steeper (3 orders of magnitude)
- The correlation shape has no significant variation with $\Delta\eta$
- HERWIG++ gives the best description
- For lower $\Delta\phi$ region PYTHIA 6 - Z2* without MPI is one order of magnitude away from the data

Results - $\Delta\phi$ inside–jet tag scenario

Pedro Cipriano DIS14

- The correlation is weaker than in the inclusive scenario
- Most predictions seem to yield a reasonable shape but fail slightly in the normalization
- The best description is provided by HERWIG++
- PYTHIA 6 - Z2* without MPI predicts a much lower cross-section than observed

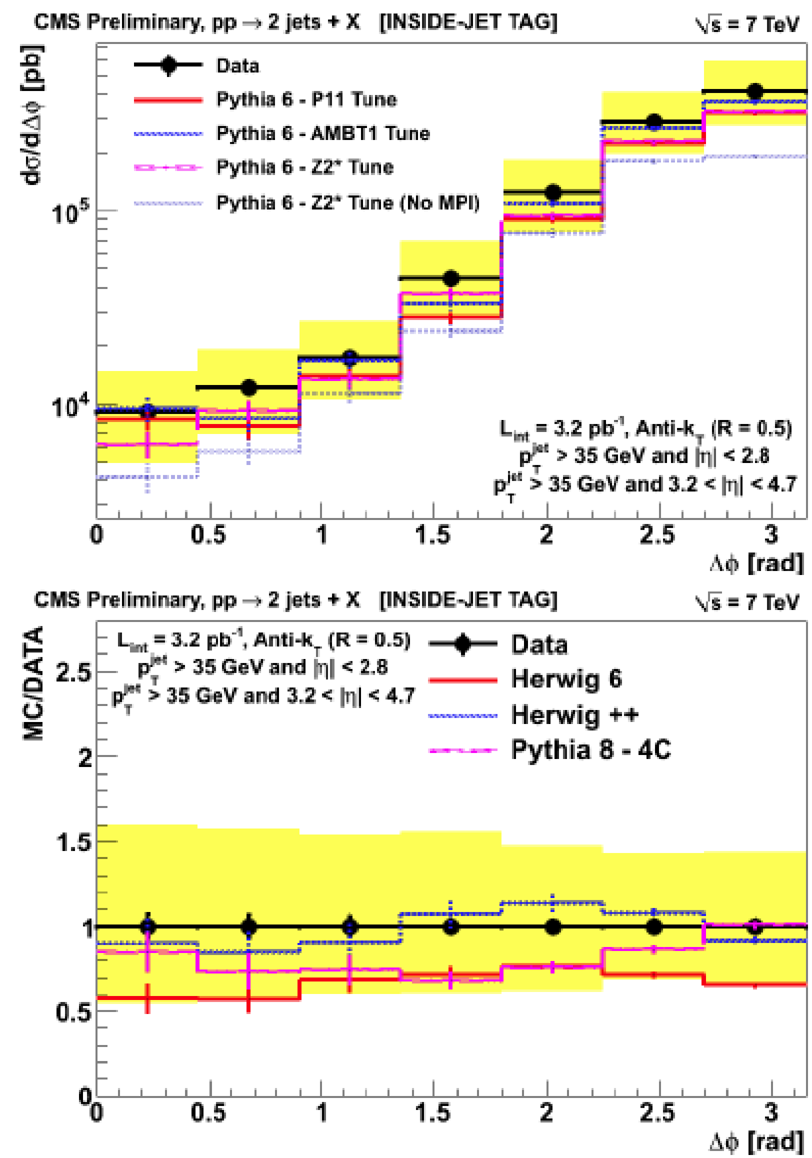

Figure: $\Delta\phi$ in inside–jet tag scenario compared with different MCs

Forward-Central Decorrelations

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Results - $\Delta\phi$ inside–jet tag scenario in slices of $\Delta\eta$

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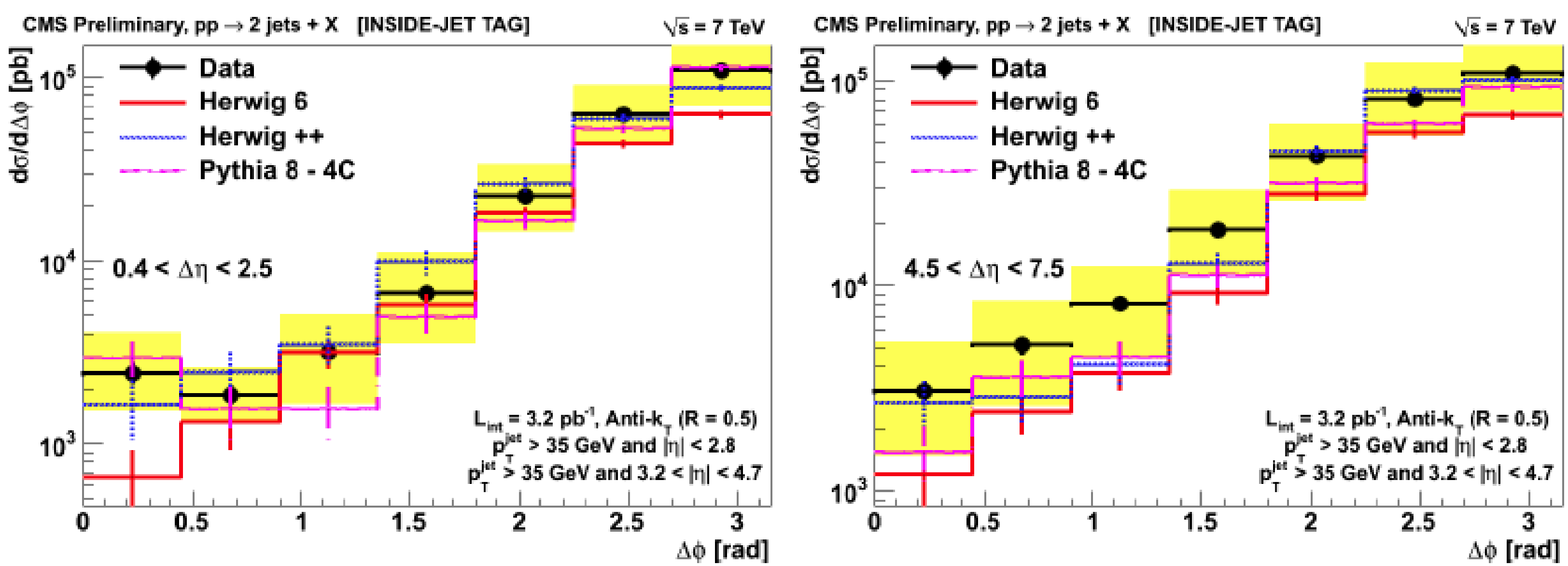

- The slope decreases as function of $\Delta\eta$ (2 to 1.5 orders of magnitude)
- The correlation is much weaker that in the inside–jet veto scenario
- HERWIG++ yields the best description
- PYTHIA 6 - Z2* without MPI fails both in slope and normalization

Results - Leading inter-leading jet p_T

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- The MC models describe the data reasonably well at low p_T
- PYTHIA 6 - Z2* without MPI shows a deficit for the lower p_T region
- PYTHIA 6 - P11 provides the best prediction

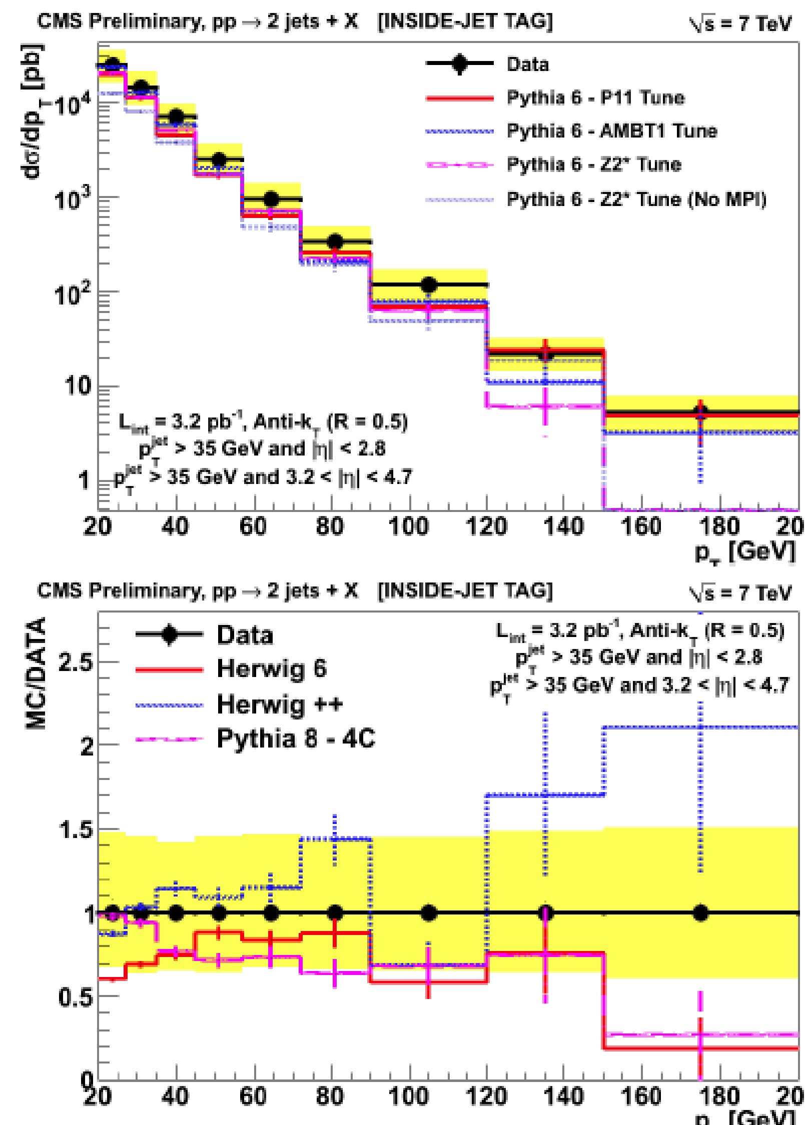

Figure: Leading inter-leading jet p_T compared with MC predictions