Measurement of four-jet production in pp collisions at 7 TeV, UE and DPS tunes

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on behalf of CMS collaboration

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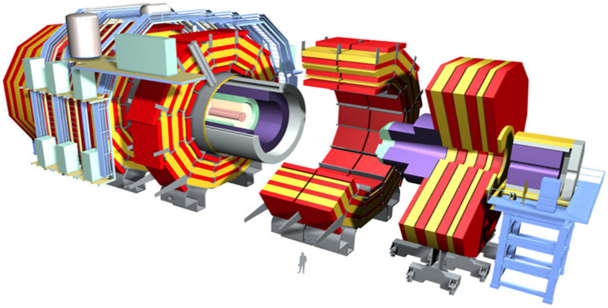
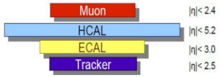
Introduction and outline



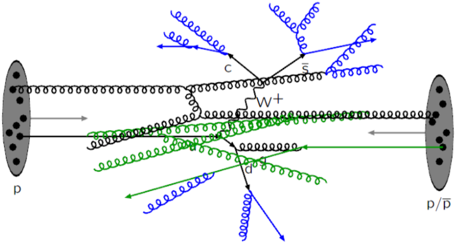
CMS detector:

- high tracking efficiency down to low p_T
- excellent jet energy resolution
- Particle Flow technique for jet reconstruction



- Physics motivation
- UE tunes: results and validation
- The four-jet channel:
  - Preliminary sensitivity studies
  - Event selection
- Results of four-jet channel
  - Jet kinematical spectra
  - Correlation observables
  - σ_{eff} extraction through a tuning method
- Compatibility studies among UE- and DPS-based tunes
- Summary and outlook

The underlying event at the LHC



Lecture by Torbjörn Sjöstrand, April 2005

A hard *pp*-collision at the LHC can be interpreted as a hard scattering between partons accompanied by the underlying event (UE) consisting of:

- Initial and final state radiation
- Multiple Parton Interactions (MPIs)
- Beam Remnants

In general the UE is a softer contribution but... some MPIs can be even hard!

Double Parton Scattering (DPS)

$$\sigma_{AB} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}} \rightarrow \sigma_{eff} \approx \text{15-20 mb}$$

Physics motivation (I)

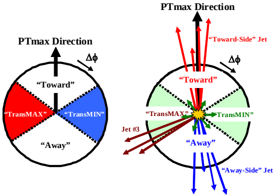
Large collection of Underlying Event data at several collision energies in a very complete way

$\rightarrow$ Charged particle multiplicity and p_T sum
as a function of the leading charged particle

$|\Delta\phi| = |\Delta\phi^{part} - \Delta\phi^{lead}|$ $\rightarrow$

if $|\Delta\phi| < \pi/3 \rightarrow$ TOWARD region
if $\pi/3 < |\Delta\phi| < 2\pi/3 \rightarrow$ TRANSVERSE region
if $|\Delta\phi| > 2\pi/3 \rightarrow$ AWAY region

- TRANS MIN: sensitive to MPI
- TRANS MAX: sensitive to MPI and PS
- TRANS DIF: sensitive to PS
- TRANS AVE: sensitive to MPI and PS

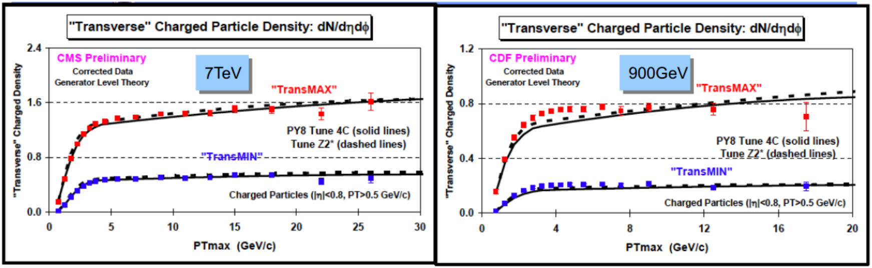


MIN and MAX regions are defined by the activity in each of the two transverse regions

Charged particles in $|\eta| < 0.8$ with $p_T > 0.5$ GeV are counted

Physics motivation (II)

→ Understanding of the Underlying Event data is crucial for every analysis using MC predictions



Comparison of charged particle multiplicity data in TRANS MIN and MAX with P6 Z2* and P8 4C predictions at 7000 and 900 GeV

→ The energy dependence of the UE data is not well described by the current tunes

- → Spectrum well followed by the predictions at 7 TeV
- → Not optimal description at 900 GeV

→ How to make reliable predictions for the new LHC runs at 13 TeV?

Need for a better tune by looking at the energy dependence
CDF energy scans (300, 900, 1960 GeV) and CMS (7000 GeV) data

R.Field, The Tevatron Energy Scan: Findings & Surprises, (September 17,2013)
CMS Collaboration, Measurement of the UE Activity at the LHC at 7 TeV and Comparison with 0.9 TeV, CMS-PAS-FSQ-12-020

The software used for the tunes

RIVET (A. Buckley et al, doi:10.1016/j.cpc.2013.05.021)
PROFESSOR (A. Buckley et al. , Eur.Phys.J.C65(2010) 331357)

- Run predictions of several analyses for different choice of UE parameters
- Tune the MC response according to best data description

The parameters have been varied within these ranges:
→ Each MC sample uses a random choice of the parameters

PYTHIA 6:
CUETP6S1
(CMS Underlying Event Tune Pythia6 Set 1)

- Tune reference Z2* lep
  (CMS Coll. JHEP04(2013)072)
- PDF set: CTEQ6L1
  J. Pumplin et al., JHEP0207(2002)012

Parameter	Tuning Range
PARP(82): MPI cut-off	1.6-2.2
PARP(77): CR suppression	0.25-1.2
PARP(78): CR strength	0.2-0.6
PARP(90): MPI energy extrapolation	0.18-0.28
PARP(83): Matter fraction in core	0.1-1.0

PYTHIA 8:
CUETP8S1-CTEQ6L1,
CUEPT8S1-HERAPDF1.5LO

- Tune reference 4C
  R. Corke et al., JHEP03(2011)032
- PDF set: CTEQ6L1
  J. Pumplin et al., JHEP0207(2002)012
- Additional tune with HERAPDF1.5LO
  H1 and ZEUS Coll., H1prelim-13-141, ZEUS-prel-13-003

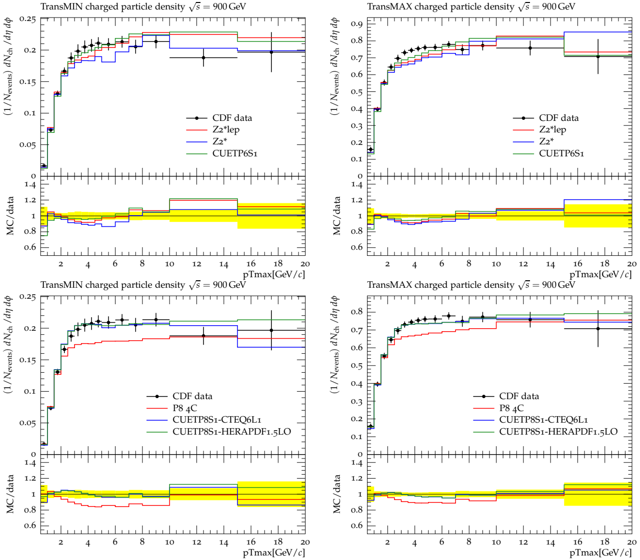
Parameter	Tuning Range
MultipleInteractions:pT0Ref	1.0-3.0
MultipleInteractions:ecmPow	0.0-0.4
MultipleInteractions:expPow	0.4-10.0
BeamRemnants:reconnectRange	0.0-9.0

By using the output from PYTHIA 8:

- it is possible to predict the σ_{eff} value in the tune, defined by the UE parameters
- Professor gives the eigentunes in order to get the uncertainties of the parameters

Tuning results at 900 GeV

Charged particle multiplicity, $\Sigma\ p_T$ in TransMIN, TransMAX at 900 GeV



Significant improvement in the description of TransMIN and TransMAX regions for the new tunes

Both the rising part and the plateaux region are very well predicted by CUETP6S1, CUETP8S1-CTEQ6L1, CUETP8S1-HERAPDF1.5LO

Same behaviour for p_T sum

PYTHIA 6 (top)
PYTHIA 8 (bottom)

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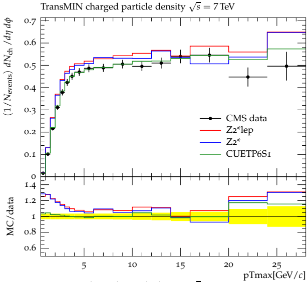
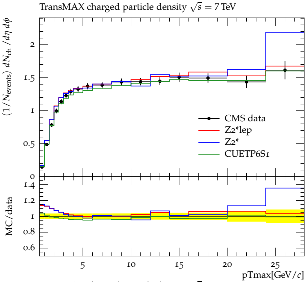
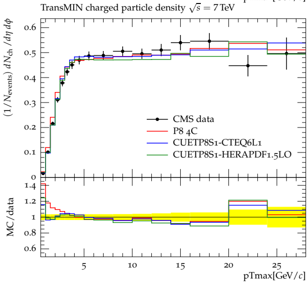
NEW!

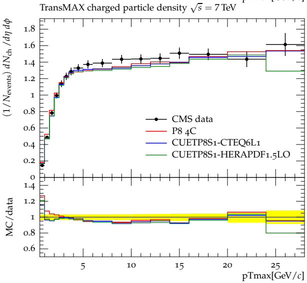
Tuning results at 7000 GeV

Charged particle multiplicity, $\Sigma\ p_T$ in TransMIN, TransMAX at 7 TeV









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Same behaviour for p_T sum

PYTHIA 6 (top)
PYTHIA 8 (bottom)

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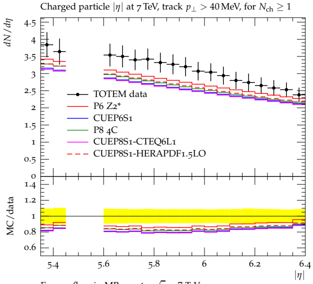
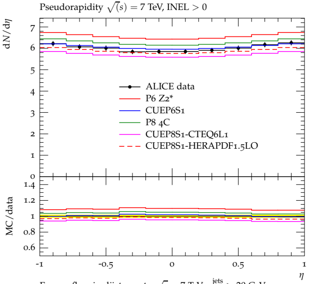
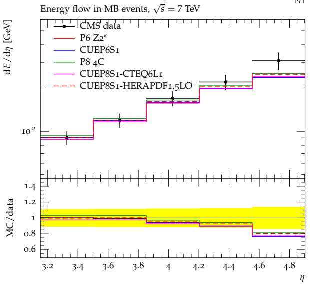
NEW!

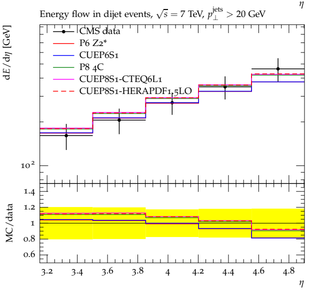
Validation plots

How well do the new tunes perform in different observables
(and compared to the old ones)?









Charged particle multiplicity at forward and central region

TOTEM Coll., Europhys.Lett.98(2012) 31002
ALICE Coll., Eur.Phys.J. C68 (2010)

Forward Energy Flow in MB and dijet events

CMS Coll., JHEP 1111 (2011) 148

Good data description from predictions of all new tunes except in the very fwd region

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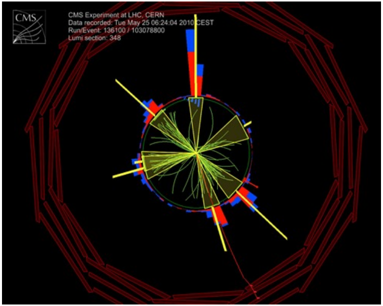
NEW!

Summary and Conclusions about UE tunes

- New UE tunes have been obtained by looking at the energy dependence of charged particle content in the separated TRANSVERSE regions
  - PYTHIA6: CUETP6S1
  - PYTHIA8: CUETP8S1-CTEQ6L1, CUETP8S1-HERAPDF
- Significant improvement for the new tunes in the description of all regions of the UE at a wide range of collision energy
- Good description of most of the validation measurements related to particle densities, UE data and energy flow
  - Improvement in the central region, still not optimal description in the forward region
- A look at the predicted DPS-related parameter, σ_{eff}, in the extracted UE tunes
  - Tune 4C $\sigma_{eff} = 30.3$ mb
  - CUETP8S1-CTEQ6L1 $\sigma_{eff} = 27.8^{+1.2}_{-1.3}$ mb
  - CUETP8S1-HERAPDF $\sigma_{eff} = 29.1^{+2.3}_{-2.0}$ mb
- It stays stable with respect to the old tune 4C, at a quite high value
- CMS result: $\sigma_{eff} = 20.7 \pm 0.8$ (stat) $\pm$ 6.6 (syst) mb (W+dijet @ 7 TeV)
- What is σ_{eff} value which would describe best DPS-sensitive data? $\rightarrow$ TUNING



Measurement of correlation observables in the 4-jet channel and DPS tuning

CMS-FSQ-12-013

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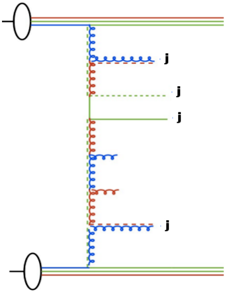
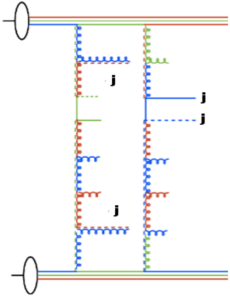
A four-jet final state may arise from one or two chains:

- the two additional jets may be produced via PS or a 2nd hard scattering



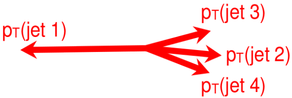


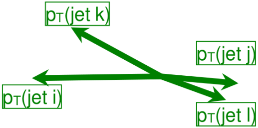
The different kinematical configuration can be used to discriminate the two processes through some observables:

$$\Delta\phi(j_i, j_k) = \phi_i - \phi_k$$

$$\Delta^{rel}_{soft} p_T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|}$$

$$\Delta S = \arccos\left(\frac{\vec{p}_T(j^i, j^k) \cdot \vec{p}_T(j^l, j^m)}{|\vec{p}_T(j^i, j^k)| \cdot |\vec{p}_T(j^l, j^m)|}\right)$$





! Selection of jet pairs at different scales helps the jet association !

Physics of a four-jet scenario (II)

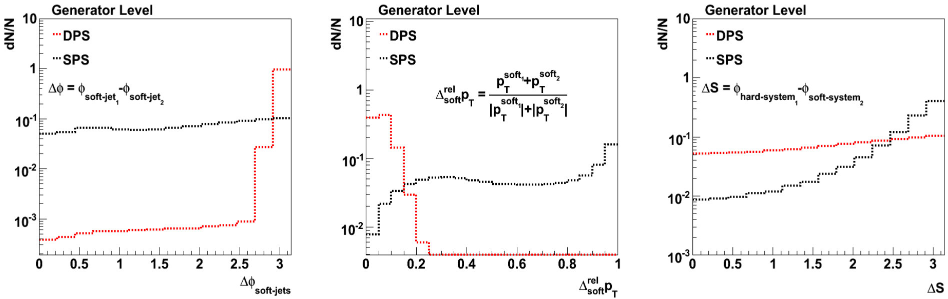
Which regions of the phase space are interesting for DPS detection?

Studies of SPS and DPS contributions performed with PYTHIA8 generator tune 4C:

Selection of a four-jet final state in $|\eta| < 4.7$ at two different p_T thresholds (20 and 50 GeV)

A SIMPLE scenario:

- SPS: MPI contribution switched off
- DPS: Two hard scatterings at the parton level forced to happen w/o parton shower



- Discriminating power: The two processes exhibit different shapes and specific regions of the phase space can be exploited to extract the DPS contribution

Event selection

Measurement of cross sections and normalized distributions of jet spectra and correlation observables

Data samples

- pp collisions @ 7 TeV
- Integrated luminosity: 36 pb^{-1}
- very low pile-up conditions
- single jet triggers

- Request for at least one good reconstructed primary vertex
- Particle Flow Jets clustered with the 0.5 anti-k_T algorithm
- Selection of exactly four jets in $|\eta| < 4.7$:
  - two jets with $p_T > 50$ GeV
  - two jets with $p_T > 20$ GeV
- Tight selection applied for the selected jets

The jets are associated in pairs:

- **hard-jet pair**: the two leading jets above 50 GeV
- **soft-jet pair**: the other two selected jets above 20 GeV

CMS-PAS-FSQ-12-013: arXiv 1312.6440 → Submitted to PRD

Cross section measurement and theory comparison

AIM: Comparison between data and different MC generators

- PYTHIA8 and HERWIG++: LO MC generators with extra jets from PS & MPI
- POWHEG: matrix element with a hard emission @ NLO (real & virtual)
- SHERPA, MADGRAPH: matrix element with N-jets (extra real emission)

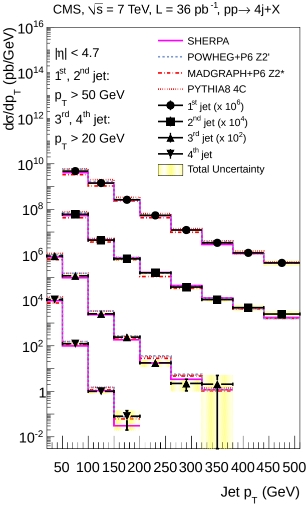
Sample	Cross section (nb)
PYTHIA8, tune 4C	423
POWHEG + PYTHIA6, tune Z2'	378
MADGRAPH + PYTHIA6, tune Z2*	234
SHERPA	293
HERWIG++, tune UE-EE-3	343
Data	327$\pm$ 5 (stat.) $\pm$ 45 (syst.)

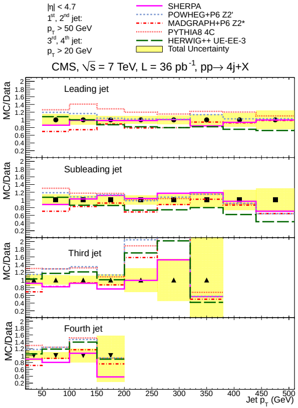
- PYTHIA8 and POWHEG+PYTHIA6 overshoot the cross section value
- MADGRAPH+PYTHIA6 underestimates the measurement
- SHERPA and HERWIG++ are in good agreement with the data

CMS-PAS-FSQ-12-013: arXiv 1312.6440 → Submitted to PRD

Jet spectra: differential p_T cross sections

A comparison between data and predictions from different generators is provided





- PYTHIA8 overestimates the low-p_T region
- POWHEG is closer to the data but it does not describe optimally the soft-jet spectra
- MADGRAPH underestimates the low-p_T region
- SHERPA offers an overall agreement for all the jet cross sections
- HERWIG++ is not able to reproduce the high-p_T region

Do the used tunes remain meaningful when a different matrix element is used?

Yes, checked with UE and inclusive jet cross section data

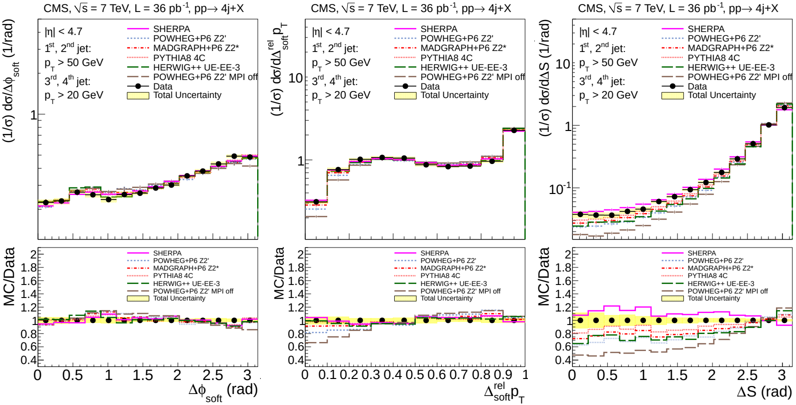
LEFT: Absolute differential cross section as a function of p_T

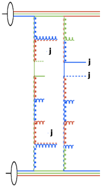
RIGHT: Ratios of predictions over data for the four jets

Correlation observables: normalized cross sections

Kinematical topology of the jets of the final state in the transverse plane:

$$\Delta\phi(j_i, j_k) = \phi_i - \phi_k \qquad \Delta^{rel}_{soft} p_T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|} \qquad \Delta S = \arccos\left(\frac{\vec{p}_T(j^i, j^k) \cdot \vec{p}_T(j^l, j^m)}{|\vec{p}_T(j^i, j^k)| \cdot |\vec{p}_T(j^l, j^m)|}\right)$$





Soft jets are expected to be produced also by a 2^{nd} scattering

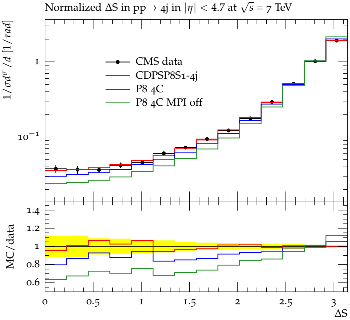
- No significant differences in $\Delta\phi$ and $\Delta^{rel}_{soft} p_T$ among generators
- POWHEG w/o MPI is far below for $\Delta^{rel}_{soft} p_T$ and ΔS
- SHERPA and PYTHIA8 perform best for ΔS
- ΔS and $\Delta^{rel}_{soft} p_T$ sensitive to MPI contribution: ROOM for DPS!

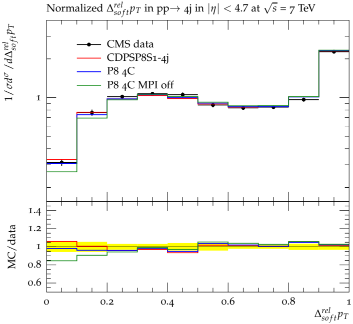
Tuning the four-jet distributions in the tuning range [0.8,2.5]

Parameter	New Tune	4C
MultipleInteractions:expPow	1.160	2.0
+Unc	1.2096	-
-Unc	1.1109	-
Goodness of fit	0.751	-

$$\sigma_{eff} = 21.3^{+1.2}_{-1.6} \text{ mb}$$

$\rightarrow \sigma_{eff}$ (Tune 4C) $\sim$ 30.2 mb





Improved agreement with the new tune

New set of parameters: CDPSP8S1-4j

LEFT: ΔS

RIGHT: $\Delta^{rel}_{soft} p_T$

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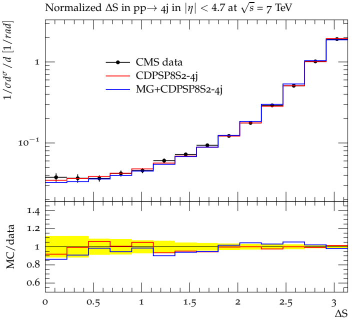
Effective cross section in the four-jets channel (II)

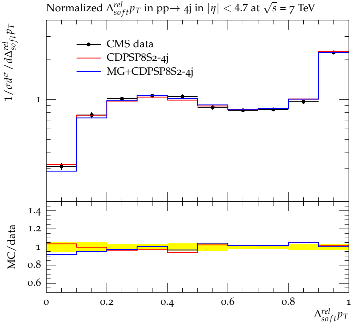
Tuning the four-jet distributions for the usual UE tuning range

Parameter	New Tune	4C
MultipleInteractions:expPow	0.6921	2.0
MultipleInteractions:ecmPow	0.345	0.19
MultipleInteractions:pT0ref	2.125	2.09
BeamRemnants:reconnectRange	6.526	1.5
Goodness of fit	0.42	-

$$\sigma_{eff} = 18.95^{+4.6}_{-2.97} \text{ mb}$$

$\rightarrow \sigma_{eff}$ (Tune 4C) $\sim$ 30.2 mb





Compatible results obtained with W-jet measurement

New set of parameters: CDPSP8S2-4j

LEFT: ΔS

RIGHT: $\Delta^{rel}_{soft} p_T$

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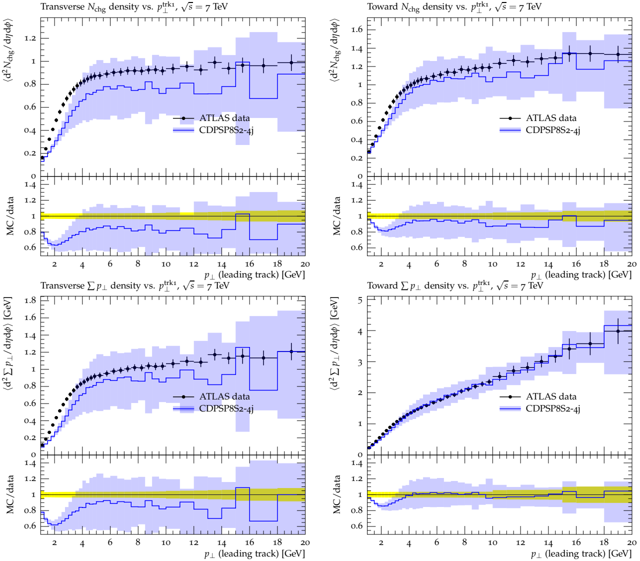
ATLAS_2010_S8894728: charged particle multiplicity and p_T sum

→ Samples obtained by changing the parameters given by Professor's eigentunes



Testing CDPSTS2-4j:

- nominal tune: blue continuous line
- set of four eigentunes: uncertainties represented by the blue band

Not optimal description of the nominal tune
→ lower activity predicted

Measurement well contained within the tune uncertainties only in some regions of the phase space

Charged particle multiplicity (top) and p_T sum (bottom) for transverse (left) and toward (right) regions

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NEW!

Are σ_{eff} values compatible among the different tunes?

Tune name	σ_{eff} value (mb)
P8 4C	30.3
CDPSTP8S1	$21.3^{+1.2}_{-1.6}$
CDPSTP8S2	$18.95^{+4.6}_{-2.97}$
CUETP8S1-CTEQ6L1	$27.8^{+1.2}_{-1.3}$
CUETP8S1-HERAPDF	$29.1^{+2.3}_{-2.0}$

- UE tunes tend to have high σ_{eff} values → Lower DPS contribution
- DPS tunes predict lower σ_{eff} values → Higher DPS contribution

A tension appears between the description of "softer" and "harder" MPI within the same framework

Summary and Conclusions about DPS tunes

Four-jet final state has been measured in CMS

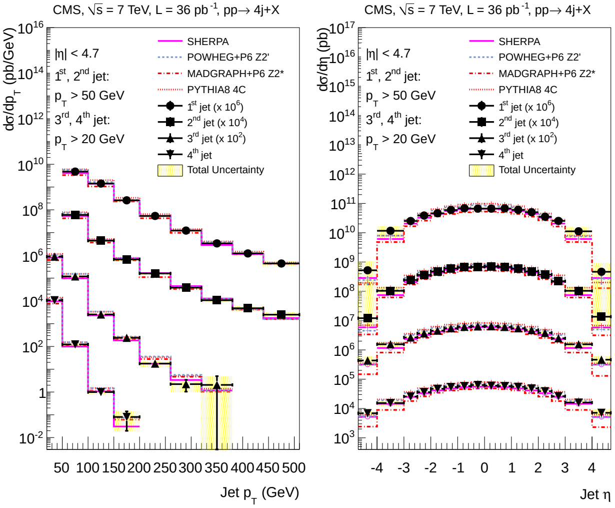
- The four-jet measurements are sensitive to the hard matrix element and to multiparton interactions
  - need for a proper admixture of ME and UE contributions
- Correlation observable measurements have been performed in a four-jet scenario
  - Need for a four-jet NLO calculation
- SHERPA gives the best description of the measurement but with the same tune fails to reproduce the UE data
- A Professor method for σ_{eff} extraction is available and has been tested in two different analyses (W+dijet, four-jets)
- FOUR-JETS: two different tunes have been performed:
  - Four-jet σ_{eff} estimation: the two tunes give compatible results
  - The UE description with the new tune agrees only in some regions
  - σ_{eff} from UE tunes tend to be higher than σ_{eff} from DPS tunes

THANKS FOR YOUR ATTENTION

BACK-UP SLIDES

Jet spectra: pseudorapidity and transverse momentum

A comparison between data and predictions from different generators is provided



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- MADGRAPH underestimates the low-p_T region
- SHERPA offers an overall agreement for all the jet cross sections
- HERWIG++ (not shown) is not able to reproduce the high-p_T region

Correction to stable particle level and systematic effects

Unfolding technique

- Different methods used for cross-check:
  - Bin-by-bin correction
  - Bayes unfolding
- Low migration effects inside the phase space
- Detector effects well under control

Systematic effects: total uncertainty $\sim$ 15-18%

- Jet energy scale: $\sim$ 13-15%
- Model dependence: $\sim$ 3-6%
- Jet energy resolution: $\sim$ 2-3%
- Pile-up reweighting: $\lesssim$ 0.1%
- Trigger efficiency: $\lesssim$ 0.4%

Systematic uncertainties assigned to the normalized distributions: $\sim$ 5-8%

CMS-PAS-FSQ-12-013

Formalism of the double parton scattering

A bit of (simplified) theory of the double parton scattering..

The cross section for a generic process that involve DPS can be written:

$$\sigma_{AB} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

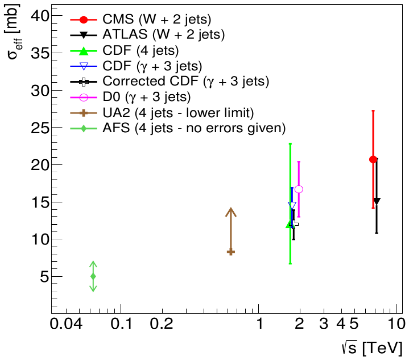
where σ_{eff} is the effective area parameter for the DPS

$$\sigma_{eff} \approx 20 \text{ mb}$$

How to measure it?

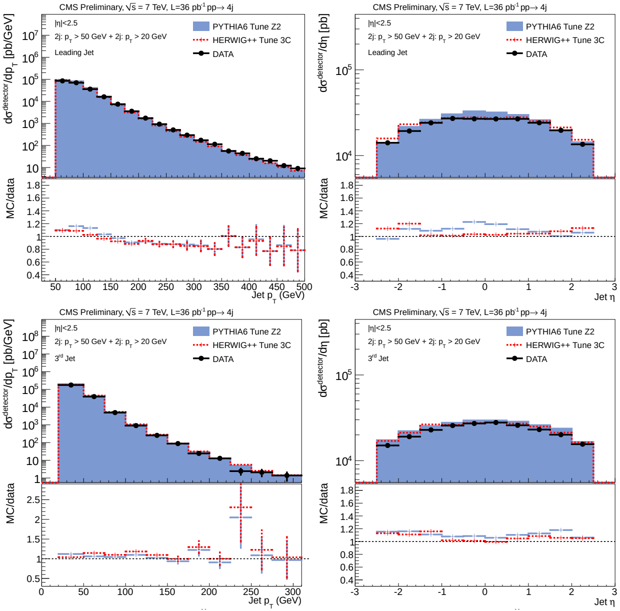
Evaluating the fraction of DPS events that occur in a given physics channel wrt the single chain processes

Theory says that it's independent on the collision energy and the process type



- a high energy phase for the LHC extends the study of the energy dependence
- with increasing energy, partons with lower x start to be relevant and detectable

Control distributions at the detector level



Preliminary plots available for jets selected in the central region

- Good agreement at detector level for PYTHIA6 and HERWIG++
- Discrepancy observed in the forward region (not shown here):
  - generator dependence
  - big energy scale uncertainty

TOP: 1st jet p_T, η
BOTTOM: 3rd jet p_T, η

CMS strategy for the DPS measurement

1st step

Corrected
distributions
DPS-sensitive
variables

2nd step

Data interpretation
and unambigous
definition
of signal and
background templates

3rd step

Extraction of the DPS
fraction and study of
the process
dependence

- Compare the data to your own favourite predictions!

4th (future) step: differential distributions with high luminosities..

Physics of a four-jet scenario (III)

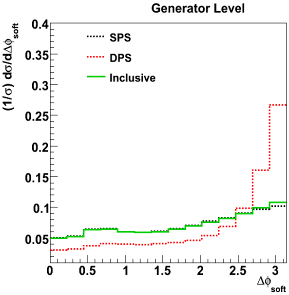
Which regions of the phase space are interested for DPS detection?

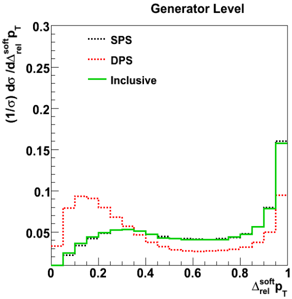
Studies of SPS and DPS contributions performed with PYTHIA8 generator tune 4C:

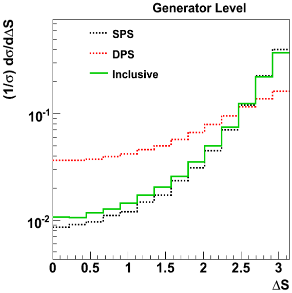
Selection of a four-jet final state in $|\eta| < 4.7$ at two different p_T thresholds (20 and 50 GeV)

A preliminary (MORE REALISTIC) scenario:

- Inclusive: nominal PYTHIA8 sample
- SPS: MPI switched off
- DPS: two hard scatterings at the parton level with parton shower

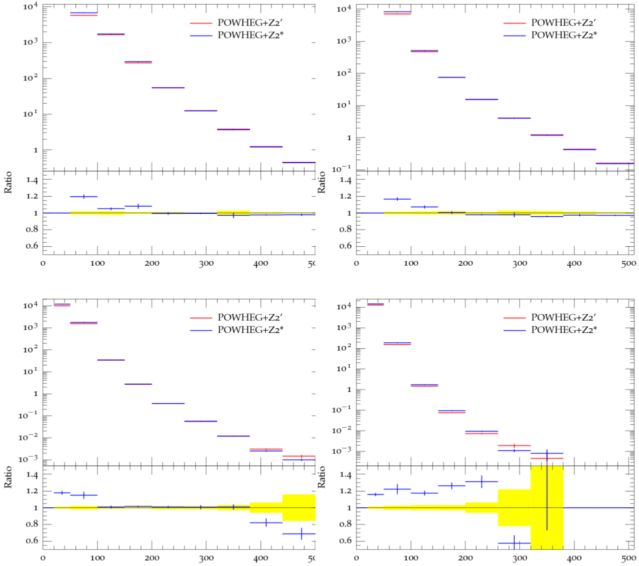






- Still differences between SPS and DPS distributions
- Small difference between inclusive and SPS samples

Checking the validity of the tunes...(II)



→ Z2' is obtained by changing:

- PARP(67) = 1
- PARP(71) = 1

→ They set the upper scale for the ISR and FSR phase space → Default value in Z2* is 4

→ Effect in the four-jet scenario

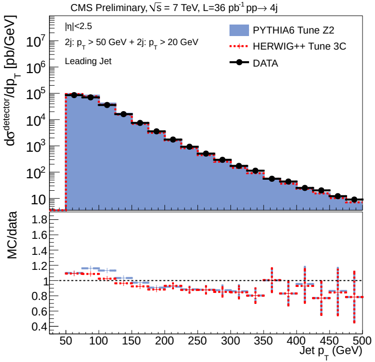
- lower contribution at low p_T
- better agreement with the data

TOP: 1^{st}, 2^{nd} jet p_T
BOTTOM: 3^{rd}, 4^{th} jet p_T

Strong tune dependence in the four-jet scenario → choice of Z2' tune

Unfolding and systematic effects

- Low migration effects inside and outside the phase space
- Detector effects well under control
- Bayes unfolding

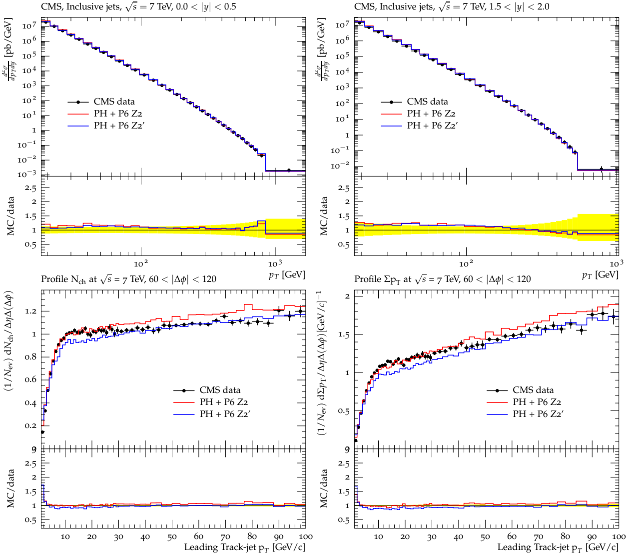


Measured observable	Model	Jet Energy Scale	Jet Energy Resolution	Luminosity	Total
Jet p_T	2%	13-14%	1%	4%	**15%**
Jet η	2%	13-14%	1%	4%	**15%**
$\Delta\phi_{\text{soft}}$	3% (3%)	14% (3%)	2% (2%)	4% (-)	**15% (5%)**
$\Delta^{\text{rel}}_{\text{soft}} p_T$	3% (3%)	13% (3%)	1% (2%)	4% (-)	**14% (5%)**
ΔS	5% (4%)	15% (3%)	4% (3%)	4% (-)	**16% (5%)**

CMS-PAS-FSQ-12-013 → Submitted to PRD

NEW!

Checking the validity of the tunes... (I)



POWHEG is interfaced with PYTHIA6 for PS and UE:

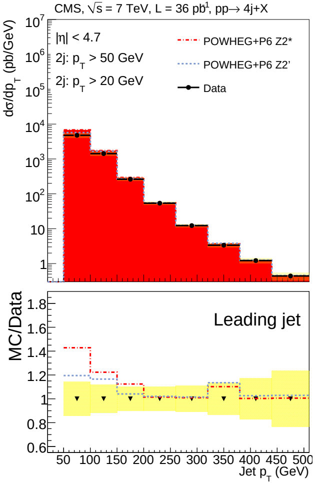
→ Z2': ad-hoc tune where the ISR and FSR phase space is reduced

- Good description for inclusive jet distributions and UE data
- Little tune dependence

CMS Collaboration, *Measurement of the Inclusive Jet Cross Section in pp collisions at $\sqrt{s}$ = 7 TeV*, **10.1103/PhysRevLett.107.132001**
CMS Collaboration, *Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 7 TeV*, **10.1007/JHEP09(2011)109**

Checking the validity of the tunes...(II)

What happens in high jet multiplicity selections?



→ Z2' is obtained by changing:

- PARP(67) = 1
- PARP(71) = 1

→ They set the upper scale for the ISR and FSR phase space → Default value in Z2* is 4

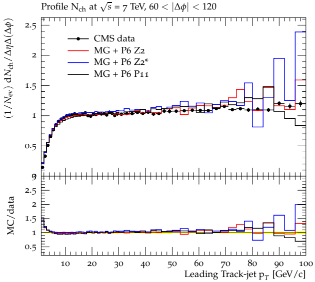
→ Effect in the four-jet scenario

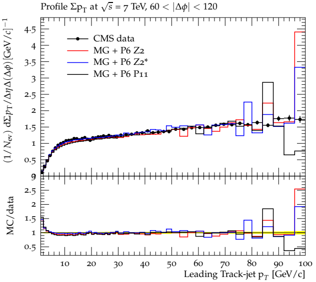
- lower contribution at low p_T
- better agreement with the data

Strong tune dependence in the four-jet scenario → choice of Z2' tune

LEFT: 1^{st}, RIGHT: 2^{nd} jet p_T

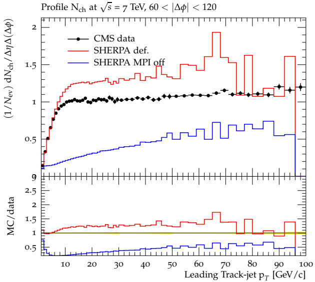
Checking the validity of the tunes... (III)

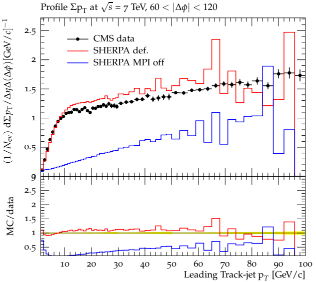




MADGRAPH is interfaced with existing PYTHIA6 tunes

- MADGRAPH reproduces well the UE CMS data and inclusive jet distributions
- Little tune dependence



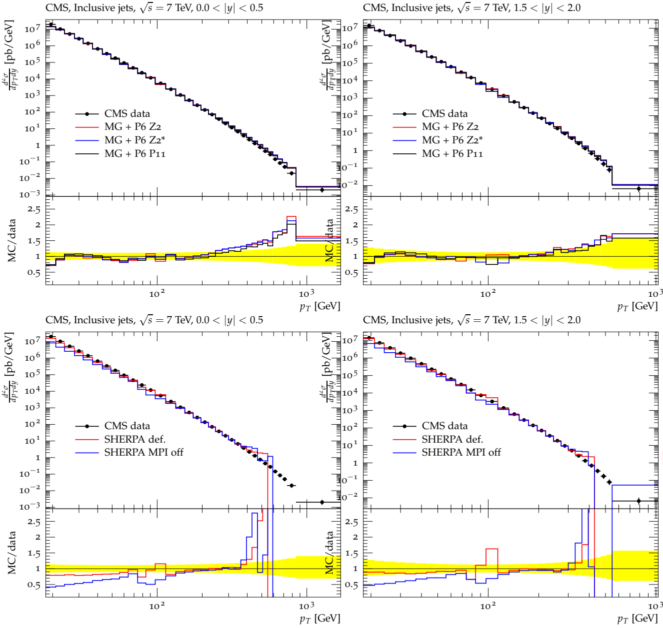


SHERPA contains its own PS model

- SHERPA predicts a higher particle multiplicity and p_T sum but reproduces inclusive jet distributions

CMS Collaboration, *Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 7 TeV*, **10.1007/JHEP09(2011)109**

Checking the validity of the tunes...



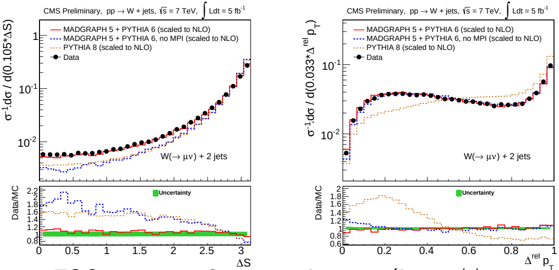
Nice description for MADGRAPH and SHERPA for inclusive jet p_T distributions

- low statistics for MG at high p_T
- low statistics at central p_T for SHERPA (merging region between two samples)

TOP: MADGRAPH
BOTTOM: SHERPA

Brief overview of the used measurements

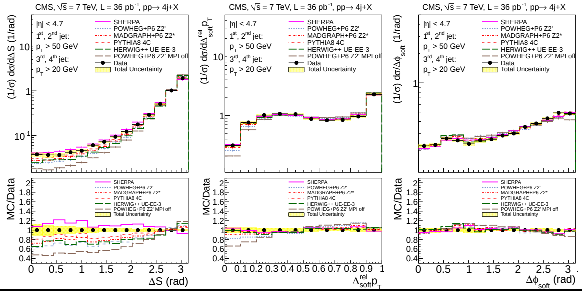
FSQ-12-028: W+2jets channel (http://arxiv.org/pdf/1312.5729v1.pdf)



ΔS, angle between the W- and the dijet-planes

$\Delta^{rel} p_T$, normalized p_T balance between the two jets

FSQ-12-013: four-jet channel (http://arxiv.org/pdf/1312.6440.pdf)



ΔS, angle between the hard- and the soft-pair planes

$\Delta^{rel}_{soft} p_T$, normalized p_T balance between the soft jets

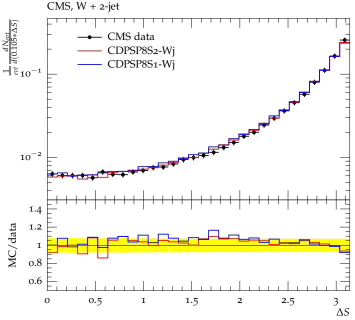
$\Delta \phi^{soft}$, angle between the soft jets

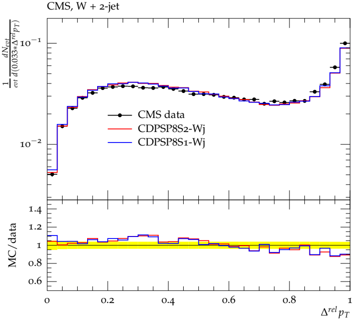
Effective cross section in the W-jets channel

Tuning the W-jet distributions for the usual UE tuning range

Parameter	CDPSTP8S1-Wj	CDPSTP8S2-Wj	4C
MultipleInteractions:expPow	1.523371	1.1197	2.0
MultipleInteractions:ecmPow	0.19	0.179	0.19
MultipleInteractions:pT0ref	2.09	2.5014	2.09
BeamRemnants:reconnectRange	1.5	2.5862	1.5
Goodness of fit	0.118	0.09	-
σ_{eff} (mb)	$25.9^{+2.4}_{-2.9}$	$25.8^{+8.2}_{-4.2}$	30.3

$\rightarrow$ CMS result $\sigma_{eff} = 20.7 \pm 0.8 \pm 6.6$ mb





Compatible results between the two tunes and in agreement with the published result

LEFT: ΔS
RIGHT: $\Delta^{rel}_{soft} p_T$

Tuned parameters

PYTHIA6 Parameter	Z2*lep	CUETP6S1
PARP(82) - MPI Cut-off	1.921	1.9096
PARP(90) - MPI Energy Extrapolation	0.227	0.2479
PARP(77) - CR Suppression	1.016	0.6646
PARP(78) - CR Strength	0.538	0.5454
PARP(83) - Matter fraction in core	0.356	0.8217
Reduced χ^2	-	0.915

PYTHIA8 Parameter	4C	CUETP8S1-CTEQ6L	CUETP8S1-HERAPDF1.5LO
MultipleInteractions:pT0Ref	2.085	2.1006	2.0001
MultipleInteractions:ecmPow	0.19	0.2106	0.2499
MultipleInteractions:expPow	2.0	1.6089	1.6905
BeamRemnants:reconnectRange	1.5	3.3126	6.0964
Reduced χ^2	-	0.952	1.13