Measurement of four-jet production including two heavy-flavour jets in pp collisions at CMS

Paolo Gunnellini

on behalf of the CMS Collaboration
Outline

- Motivation
- Sensitivity studies to double parton scattering
- Detector level distributions
- Unfolding procedure
- Evaluation of systematics
- Results and MC comparisons
- Method for DPS signal extraction
- Summary and Conclusion

arXiv 1609.03489
Accepted by PRD
Physics of a four-jet scenario (I)

- Study of QCD evolution in a heavy flavour scenario

- One of the two jet pairs is emitted by the hard scattering
- Hard radiation can produce additional jets

Further measurement of a 4-jet final state: multijet scenario with $b\bar{b}$ production

Comparison with different Monte Carlo models and test of their performance:
- in Leading Order (LO) MCs, the additional jets come from the parton shower;
- in POWHEG, a third parton is already in the matrix element while the forth comes from the parton shower;
- in other generators, like MADGRAPH, all the jets can be produced by partons in the matrix element.

→ extension of the four-jet analysis CMS Collaboration, Phys.Rev.D89(2014)092010
Physics of a four-jet scenario (II)

- Study and separate the different topologies for events coming from single chain and double chain processes

The jets need to be associated in pairs:
(→ natural way thanks to the different flavour → light and bottom pair)

The different kinematical configuration can be exploited to discriminate the two processes using the observables:

\[ \Delta \phi(j^l_i, j^l_k) = | \phi_i - \phi_k | \]
\[ \Delta S = \arccos \left( \frac{\vec{p}_T^b \cdot \vec{p}_T^l}{| \vec{p}_T^b | \cdot | \vec{p}_T^l |} \right) \]
\[ \Delta_{\text{rel}}^\text{pair} p_T = \frac{| p_T(j^l_i, j^l_k) |}{| p_T(j^l_i) | + | p_T(j^l_k) |} \]

The equal scale of the two jet pairs should suppress the SPS contribution

- DPS sensitivity expected mainly from \( \Delta S \) and \( \Delta_{\text{rel}}^\text{pair} p_T \)
- Useful baseline for estimation of DPS contribution
Preliminary studies of SPS and DPS contributions performed with PYTHIA8 4C: 
\( \rightarrow \text{jet } p_T > 20 \text{ GeV for both pairs} \) (mimicking the experimental measurement)

**Inclusive QCD sample to compare:**
- Inclusive: Standard Pythia8 sample
- DPS: Two hard scatterings above threshold
- SPS: Standard Pythia8 sample with hard MPI vetoed

**Left:** \( \Delta \phi_{\text{light}} \), **Center:** \( \Delta_{\text{rel}}^{\text{light}} p_T \), **Right:** \( \Delta S \)

**Discriminating power:**

The two processes fill different regions of the phase space.

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**DESY-THESIS-15-010**

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MPI@LHC 2016

November 2016
Event selection

- Use of low $p_T$ jet trigger data recorded in 2010 ($\sim 3$ pb$^{-1}$)
- Request for at least one good reconstructed primary vertex
- Particle Flow Jets clustered with the 0.5 anti-$k_T$ algorithm
- B-tag algorithm: Combined secondary vertex
  - Tagging efficiency
  - Misidentification efficiency
- Jet selection:
  - at least 4 jets with $p_T > 20$ GeV;
  - 2 leading b-jets in $|\eta| < 2.4$
  - 2 leading light-jets in $|\eta| < 4.7$

The jets are associated in pairs:
- b-jet pair: the two leading b-tagged jets above 20 GeV
- light-jet pair: the other two selected jets above 20 GeV

Absolute cross sections as a function of jet $p_T$ and $\eta$, normalized cross sections as a function of jet $p_T$, $\eta$ and correlation obs.
Detector corrections applied

Trigger strategy

- Detector corrections applied
- Trigger strategy

Exclusive division method

doi:10.1016/j.nima.2009.03.173

- Pile-up reweighting
- Trigger efficiency correction
- B-tag performance: Scale factors for matching the tagging performance in data and simulation
- Purity: Scale factors for matching the flavour composition of the tagged sample
- Reweighting as a function of $\hat{p}_T$: additional correction due to non-optimal description of the jet transverse momentum spectra
Control distributions at detector level

![Graphs showing control distributions at detector level](image)

**Good agreement between data and simulation at detector level**

Slight differences only in the very forward region

**LEFT: Leading b-tagged jet**

**RIGHT: Leading other jet**

arXiv 1609.03489
→ **D’AGOSTINI METHOD:**

How to decide the optimal number of iterations?

- Correction with different models (PYTHIA, HERWIG) and comparison with generator level
- Backfolding → The detector effects are added back to the unfolded distributions and compared to the detector level

\[
N_{det}^i = \sum_{j=1}^{N_{bins}} P_{ij} \cdot N_{\text{unfold}}^j \cdot \left(1 - \text{Miss}^i\right) / \left(1 - \text{Fake}^i\right)
\]

The quality of the backfolding is estimated by evaluating:

\[
\chi^2 = \sum_{i=1}^{N_{bins}} \left( \frac{X_{det}^i - X_{fold}^i}{\sqrt{\sigma_{det}^2 + \sigma_{fold}^2}} \right)^2
\]

*Phase space of the applied selection:*

- At least four jets \( p_T > 20 \text{ GeV} \)
- Two leading b-jets \( |\eta| < 2.4 \)
- Two leading additional jets \( |\eta| < 4.7 \)

The minimum of the \( \chi^2 \) has been chosen as optimal number of iteration
Systematic uncertainties quantified for the different observables

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Absolute cross sections</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b-tagged jet $p_T$</td>
<td>20%</td>
<td>25%</td>
<td>4%</td>
<td>15%</td>
<td>12%</td>
<td>6%</td>
<td>4%</td>
<td>38%</td>
</tr>
<tr>
<td>light-jet $p_T$</td>
<td>10%</td>
<td>25%</td>
<td>4%</td>
<td>15%</td>
<td>12%</td>
<td>6%</td>
<td>4%</td>
<td>34%</td>
</tr>
<tr>
<td>Jet $</td>
<td>\eta</td>
<td>\leq 3$</td>
<td>10%</td>
<td>25%</td>
<td>4%</td>
<td>15%</td>
<td>12%</td>
<td>5%</td>
</tr>
<tr>
<td>Jet $</td>
<td>\eta</td>
<td>&gt; 3$</td>
<td>20%</td>
<td>35%</td>
<td>4%</td>
<td>15%</td>
<td>12%</td>
<td>5%</td>
</tr>
<tr>
<td>Normalized cross sections</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \phi_{\text{light}}$</td>
<td>13%</td>
<td>5%</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>4%</td>
<td>15%</td>
</tr>
<tr>
<td>$\Delta S$</td>
<td>20%</td>
<td>5%</td>
<td>10%</td>
<td>2%</td>
<td>2%</td>
<td>1%</td>
<td>4%</td>
<td>23%</td>
</tr>
<tr>
<td>$\Delta_{\text{rel}}^{p_T \text{light}}$</td>
<td>13%</td>
<td>5%</td>
<td>7%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>4%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Dominant contribution: jet energy scale (abs.) and model dependence (norm.)

THEORY UNCERTAINTY: evaluated for POWHEG+PYTHIA 8 (with consistent use of PDF for matrix element and UE tune)

PDF: $\sim 10$-50%, Scale: $\sim 10$-15%

Future: need for consistent variations of PDF and scales between ME and UE tunes
Measurement of correlation observables in the four-jet channel
Results: cross section measurements and MC comparison

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

<table>
<thead>
<tr>
<th>Sample</th>
<th>PDF</th>
<th>Cross section (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PYTHIA 6 Tune Z2*</td>
<td>CTEQ6L1</td>
<td>77</td>
</tr>
<tr>
<td>PYTHIA 6 Tune CUETP6S1</td>
<td>CTEQ6L1</td>
<td>77</td>
</tr>
<tr>
<td>HERWIG ++ Tune UE-EE-3</td>
<td>MRST2008**</td>
<td>44</td>
</tr>
<tr>
<td>HERWIG ++ Tune UE-EE-5-CTEQ6L1</td>
<td>CTEQ6L1</td>
<td>47</td>
</tr>
<tr>
<td>PYTHIA 8 Tune CUETP8S1-CTEQ6L1</td>
<td>CTEQ6L1</td>
<td>96</td>
</tr>
<tr>
<td>POWHEG+PYTHIA 8 CUETS1</td>
<td>CT10</td>
<td>65 ± 12</td>
</tr>
<tr>
<td>POWHEG+PYTHIA 8 CUETS1 MPI off</td>
<td>CT10</td>
<td>31 ± 6</td>
</tr>
<tr>
<td>MADGRAPH+PYTHIA 8 Tune CUETM1</td>
<td>CTEQ6L1</td>
<td>39</td>
</tr>
<tr>
<td>DATA</td>
<td>-</td>
<td>69 ± 3 (stat.) ± 24 (syst.)</td>
</tr>
</tbody>
</table>

PYTHIA 8 overshoots a bit the measurement
P6, POWHEG+P8 and H++ predict the correct cross section
MADGRAPH+P8 slightly underestimates the measurement

arXiv 1609.03489
Results: differential measurements and MC comparison

Jet $p_T$ and $\eta$ spectra

- Enough statistics to have this measurement also at high $p_T$!
- Different $\eta$ spectrum depends on the selected phase space

CMS

$3 \text{ pb}^{-1} (7 \text{ TeV}), pp \rightarrow 2 b + 2 j + X$

$\eta_{Jet}$

$-4 -3 -2 -1 0 1 2 3 4$

POWHEG+P8 CUETS1

$\sigma (\text{pb})$

$10^{20} 10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{-1} 10^{-2} 10^{-3}$

$\frac{d\sigma}{dp_T} (\text{pb/GeV})$

$10^{20} 10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{-1} 10^{-2} 10^{-3}$

$0 100 200 300 400 500$

Jet $p_T$ (GeV)

$-4 -3 -2 -1 0 1 2 3 4$

Jet $\eta$

$3 \text{ pb}^{-1} (7 \text{ TeV}), pp \rightarrow 2 b + 2 j + X$

CMS

$p_T > 20 \text{ GeV}$

$1^{st}$, $2^{nd}$ b jet:

$|\eta| < 2.4$

$1^{st}$ other jet (x $10^2$)

$2$ other jets:

$2^{nd}$ other jet

$\eta$ Jet 
$-4 -3 -2 -1 0 1 2 3 4$

Jet $p_T$ (GeV)

$10^{20} 10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{-1} 10^{-2} 10^{-3}$

$\frac{d\sigma}{d\eta} (\text{pb})$

$10^{20} 10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{-1} 10^{-2} 10^{-3}$

$-4 -3 -2 -1 0 1 2 3 4$

arXiv 1609.03489

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Results: differential measurements and MC comparison (II)

$\mathbf{p_T > 20 \, GeV}$

1\textsuperscript{st}, 2\textsuperscript{nd} b jet:

| < 2.4 $\eta$ |

1\textsuperscript{st}, 2\textsuperscript{nd} other jet:

| < 4.7 $\eta$ |

$2 \ b + 2 \ j + X \rightarrow (7 \ TeV), pp$ -13 ... 

- PYTHIA 8 CUETP8S1-CTEQ6L1 overestimates the low $p_T$ region of leading jets
- HERWIG++ and MADGRAPH tend to underestimate the high $p_T$ region
- Good description achieved by PYTHIA 6 and POWHEG
Results: normalized measurements and MC comparison

\[ \Delta \phi(j_i, j_k) = |\phi_i - \phi_k| \]

\[ \Delta^{rel} p_T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|} \]

with \( i, k = \text{light jets} \)

LEFT: \( \Delta^{rel} p_T \)

RIGHT: \( \Delta \phi \)

- All nominal predictions give a reasonable description of the shapes
- POWHEG+P8 CUETS1 has a small deficit at low \( \Delta^{rel} p_T \)
- Theory uncertainty comparable to experimental one

arXiv 1609.03489
Results: normalized measurements and MC comparison

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

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

with $i, k = \text{light jets}$

LEFT: $\Delta^{\text{rel}} p_T$

RIGHT: $\Delta \phi$

- Absolute cross sections are not well described by predictions without MPI
- POWHEG+P8 CUETS1 has a big deficit at low $\Delta^{\text{rel}} p_T$
- $\Delta \phi$ is not very sensitive to DPS contributions

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Most DPS-sensitive observable!

\[ \Delta S = \arccos \left( \frac{\vec{p}_T^b \cdot \vec{p}_T^l}{|\vec{p}_T^b| \cdot |\vec{p}_T^l|} \right) \]

Predictions without MPI badly fail to describe the data

Best description provided by PYTHIA 8 and HERWIG++.. but not optimal!

The DPS contribution is crucial for describing this observable

arXiv 1609.03489
Measurement of correlation observables in the four-jet channel (light sector)
Correlation observables: normalized cross sections

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

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

\[ \Delta_{soft}^{rel} p_T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|} \]

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

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

Soft jets are expected to be produced also by a 2\(^{nd}\) scattering
Extraction of DPS signal

Minimization of the binned $\chi^2 = \sum_O \sum_{b \in O} \frac{(MC^b - DATA^b)^2}{\Delta^2_b}$

Normalized $\Delta S$ in $pp \rightarrow 4j$ in $|\eta| < 4.7$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta_{\text{soft} p_T}$ in $pp \rightarrow 4j$ in $|\eta| < 4.7$ at $\sqrt{s} = 7$ TeV

$\sigma_{\text{eff}} = 19.0^{+4.7}_{-3.0}$ mb

LEFT: $\Delta S$

RIGHT: $\Delta_{\text{soft} p_T}$

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Preliminary results from tuning

Four-parameter tune of the separate measurements:

- PDF: CTEQ6L1 set

<table>
<thead>
<tr>
<th>Fitted measurement</th>
<th>$\sigma_{\text{eff}}$ value (mb)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2b2j</td>
<td>$23.2^{+3.3}_{-2.5}$</td>
<td>DESY-THESIS-15-010</td>
</tr>
</tbody>
</table>

Two-parameter tunes of the separate measurements and common fits:

- PDF: CTEQ6L1 set

<table>
<thead>
<tr>
<th>Fitted measurements</th>
<th>$\sigma_{\text{eff}}$ value</th>
<th>$\chi^2$/Ndf</th>
</tr>
</thead>
<tbody>
<tr>
<td>4j</td>
<td>$21.49$ mb</td>
<td>0.521</td>
</tr>
<tr>
<td>Wj</td>
<td>$27.49$ mb</td>
<td>0.823</td>
</tr>
<tr>
<td>2b2j</td>
<td>$23.96$ mb</td>
<td>0.543</td>
</tr>
<tr>
<td>4j+2b2j</td>
<td>$24.37$ mb</td>
<td>0.631</td>
</tr>
<tr>
<td>Wj+2b2j</td>
<td>$25.32$ mb</td>
<td>0.807</td>
</tr>
<tr>
<td>Wj+4j</td>
<td>$23.20$ mb</td>
<td>0.948</td>
</tr>
<tr>
<td>2b2j+Wj+4j</td>
<td>$22.57$ mb</td>
<td>0.876</td>
</tr>
</tbody>
</table>

All fitted $\sigma_{\text{eff}}$ values are very close between each other

It is possible to fit all measurements at the same time, with good fit quality

No uncertainties provided...still work ongoing from MC tuning side!
Interpretation of the results

- CUETP8M1: UE-based tune, describes overall measur. at 7 TeV ($\sigma_{\text{eff}} \sim 28$ mb)
- CDPSTP8S1: DPS-based tune, describes 4j observables at 7 TeV ($\sigma_{\text{eff}} \sim 19$ mb)
- EPJC.75.282: UE-based tune with dynamic $\sigma_{\text{eff}}$ values

The so-called $1\times2$ and $2\times2$ mechanisms also contribute to MPI processes

The $1\times2$ mechanisms lead to transverse-scale dependence of MPI cross sections

![Diagram showing MPI processes]

Dynamic dependence of $\sigma_{\text{eff}}$ is performed by reweighting plain PYTHIA 8 simulation (EPJC.75.282)
Interpretation of the results

- CUETP8M1: UE-based tune, describes overall measure at 7 TeV ($\sigma_{\text{eff}} \sim 28 \text{ mb}$)
- CDPSTP8S1: DPS-based tune, describes 4j observables at 7 TeV ($\sigma_{\text{eff}} \sim 19 \text{ mb}$)
- EPJC.75.282: UE-based tune with dynamic $\sigma_{\text{eff}}$ values

- UE tune description is good but not optimal
- Description from DPS tune or simulation with dynamic $\sigma_{\text{eff}}$ is better
Conclusion

- A scenario with four-jets in the final state in the heavy flavour sector has been measured at 7 TeV with the CMS experiment.
- Differential absolute and normalized distributions as a function of jet $p_T$, $\eta$ and correlation observables have been presented.
- Fixed-order ME calculations interfaced with PS are able to reproduce quite well single jet spectra.
- Description of correlation observables depends on DPS contribution whose amount is crucial for $\Delta S$.
- Useful baseline for future DPS extraction (ongoing work).
Conclusion

- A scenario with four-jets in the final state in the heavy flavour sector has been measured at 7 TeV with the CMS experiment.
- Differential absolute and normalized distributions as a function of jet $p_T$, $\eta$ and correlation observables have been presented.
- Fixed-order ME calculations interfaced with PS are able to reproduce quite well single jet spectra.
- Description of correlation observables depends on DPS contribution whose amount is crucial for $\Delta S$.
- Useful baseline for future DPS extraction (ongoing work).

Thanks for your attention.
The stable-particle level is defined as:

- at least 4 jets with $p_T > 20$ GeV
- two b-jets in $|\eta| < 2.4$
- b-jet definition: presence of a b-quark inside the jet cone
- two additional jets in $|\eta| < 4.7$
- no flavour requirements for the additional jets

It loops over the quarks and if there is evidence of a b-quark inside a cone around the jet axis, the jet is identified as a b-jet (Different definitions checked, no visible dependence)
Extraction of DPS signal (I)

- Run predictions of the considered analysis for different choices of UE parameters
- Interpolate the generator response in a multidimensional parameter grid
- Tune the MC response in order to obtain the best data description

CMS-GEN-14-001

RIVET  (A. Buckley et al, doi:10.1016/j.cpc.2013.05.021)

- No separation between signal and background;
- Possibility to use any MC generator;
- Possibility to extract $\sigma_{\text{eff}}$ from any model;
Measurement of a four light-jet scenario in proton-proton collisions at 7 TeV with the CMS experiment
### Measurement of a four light-jet scenario at 7 TeV

**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)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cross section (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PYTHIA8, tune 4C</td>
<td>423</td>
</tr>
<tr>
<td>POWHEG + PYTHIA6, tune Z2’</td>
<td>378</td>
</tr>
<tr>
<td>MADGRAPH + PYTHIA6, tune Z2*</td>
<td>234</td>
</tr>
<tr>
<td>SHERPA</td>
<td>293</td>
</tr>
<tr>
<td>HERWIG++, tune UE-EE-3</td>
<td>343</td>
</tr>
<tr>
<td>Data</td>
<td>330 ± 5 (stat.) ± 45 (syst.)</td>
</tr>
</tbody>
</table>

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

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

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

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>New Tune</th>
<th>4C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MultipleInteractions:expPow</td>
<td>1.160</td>
<td>2.0</td>
</tr>
<tr>
<td>+Unc</td>
<td>1.2096</td>
<td>-</td>
</tr>
<tr>
<td>-Unc</td>
<td>1.1109</td>
<td>-</td>
</tr>
<tr>
<td>Goodness of fit</td>
<td>0.751</td>
<td>-</td>
</tr>
</tbody>
</table>

\[ \sigma_{\text{eff}} = 21.3^{+1.2}_{-1.6} \text{ mb} \quad \rightarrow \sigma_{\text{eff}} \text{ (Tune 4C)} \sim 30.2 \text{ mb} \]

Improved agreement with the new tune

New set of parameters: CDPSP8S1-4j

LEFT: \( \Delta S \)

RIGHT: \( \Delta_{\text{soft}}^{rel} p_T \)

CMS-GEN-14-001
Effective cross section in the four-jets channel (II)

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>New Tune</th>
<th>4C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MultipleInteractions:expPow</td>
<td>0.6921</td>
<td>2.0</td>
</tr>
<tr>
<td>MultipleInteractions:ecmPow</td>
<td>0.345</td>
<td>0.19</td>
</tr>
<tr>
<td>MultipleInteractions:pT0ref</td>
<td>2.125</td>
<td>2.09</td>
</tr>
<tr>
<td>BeamRemnants:reconnectRange</td>
<td>6.526</td>
<td>1.5</td>
</tr>
<tr>
<td>Goodness of fit</td>
<td>0.42</td>
<td>-</td>
</tr>
</tbody>
</table>

\[ \sigma_{\text{eff}} = 19.0^{+4.7}_{-3.0} \text{ mb} \quad \rightarrow \sigma_{\text{eff}} \text{ (Tune 4C)} \sim 30.2 \text{ mb} \]

Compatible results obtained with W-jet measurement

New set of parameters: CDPSP8S2-4j

LEFT: \( \Delta S \)

RIGHT: \( \Delta_{\text{soft}} p_T \)

CMS-GEN-14-001
DPS sensitivity of the two four-jet scenarios

Normalized $\Delta S$ in $pp \rightarrow 4j$ in $|\eta| < 4.7$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta S_{\text{rel}}^{\text{soft}}$ in $pp \rightarrow 4j$ in $|\eta| < 4.7$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta \phi^{\text{soft}}$ in $pp \rightarrow 4j$ in $|\eta| < 4.7$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta S$ in $pp \rightarrow 2b 2j$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta S_{\text{rel}}^{\text{soft}}$ in $pp \rightarrow 2b 2j$ at $\sqrt{s} = 7$ TeV

Normalized $\Delta \phi^{\text{soft}}$ in $pp \rightarrow 2b 2j$ at $\sqrt{s} = 7$ TeV

TOP: light-jet scenario, BOTTOM: heavy flavour scenario

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