Small-x QCD and forward physics results from CMS

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on behalf of the CMS Collaboration

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Outline

- CMS: forward instrumentation
- Various aspects of soft, diffractive QCD and EWK (in the order of increasing “hardness”):
  - Bose-Einstein Correlations, emission source size
  - soft single- and double- diffraction
  - Double Parton Scattering
    - 2 light and 2 b-jets
    - γ + 3 jets
  - Underlying event at 2.76 TeV with a hard scale
  - Exclusive WW and Anomalous QGC
- New: $dN/d\eta$ of charged hadrons at 13 TeV
CMS Experiment

- Excellent instrumentation at high $\eta$ ("forward")

Common data taking during low-PU runs in 2012

BSC*: Beam Scintillator Counters (in front of HF) $3.2 < |\eta| < 4.7$
Bose-Einstein Correlations

- Identical boson-boson correlations can be used to determine the effective size of the emission source
- Identified particles, multi-dimensional analysis
- Scaling and similarity between pp, pPb, PbPb vs $N_{\text{ch}}$

CMS PAS FSQ-13-002, CMS PAS HIN-14-013
Soft diffraction at 7 TeV

- Diffraction studied using the $M_X, M_Y$ masses of subevents separated by the largest rapidity gap
- Measurements extrapolated to total single (SD) and double (DD) diffractive cross sections:
  - using PYTHIA 8 MBR
  - extrapolation around a factor of 2
- This measurement was made possible by the CASTOR detector

PRD 92, 012003
DPS in 2 jets and 2 b-jets

- QCD evolution with heavy flavour
- How to separate single and double chain processes?
- at least 4 jets with $p_T > 20$ GeV
- Correlation observables depend on the DPS contribution

\[ \Delta \phi(j_i, j_k) = |\phi_i - \phi_k| \]
\[ \Delta S = \arccos \left( \frac{\vec{p}_T^b \cdot \vec{p}_T^l}{|\vec{p}_T^b| \cdot |\vec{p}_T^l|} \right) \]
\[ \Delta_{pair}^T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|} \]
DPS in γ+3 jets

- Contributions: 3 jets + ...
  - direct photon
  - fragmentation photon
  - misidentified photon

- Selections:
  - gamma and one jet in the central region with $p_T > 75$ GeV
  - two jets with $p_T > 20$ GeV and $|\eta| < 2.4$

- MC describes the data well
  - measurement not very sensitive to MPI with these high $p_T$ cuts

CMS PAS FSQ-12-017
Underlying Event: new result at 2.76 TeV

- Charged particle density and $\Sigma p_T$ density in the region transverse to the highest $p_T$ track-jet
- Good description by PYTHIA and HERWIG, well tuned
- Collision energy dependence well reproduced
Exclusive $W^+W^-$ and AQGC limits

- SM xsec not measured before, excess indicates new physics
- Using $WW\rightarrow\mu e$ channel to beat the QCD and DY bg
- Veto on additional tracks (reducing the inclusive diboson bg)
- Require high $p_T(e\mu)$

- 13 data events, $5.3\pm0.1$ signal, $3.5\pm0.5$ background

$$\sigma (pp \rightarrow p^{(*)}W^+W^-, p^{(*)} \rightarrow p^{(*)}\mu^+\mu^- p^{(*)}) = 12.3^{+5.5}_{-4.4} \text{ fb}$$

- New AQGC limits:
dN/dη of charged hadrons at 13 TeV

- Several methods employed
  - tracking, tracklets, pixel counting
- Trigger:
  - zero bias, PU = 0.05, ~170k collisions in a special run
- Definition of a ‘collision’:
  - inelastic (leads to a few % MC dependence)
- Datasets:
  - data taken June 7, 2015
  - number of collisions per bunch crossing: ~0.05
  - CMS tracker and pixel detectors ON
  - CMS magnet off, B=0 (straight tracks)
- First LHC publication at 13 TeV
dN/dη: tracklets

- Using pairs of pixel barrel layers (3 combinations)
- Insensitive to alignment, very robust
- Has its own vertexing (extremely efficient)
- straight tracklets, sharp correlations in Δη and Δφ

http://arxiv.org/abs/1507.05915
**dN/dη: tracks**

- Multiplicity distribution of reconstructed tracks

![Multiplicity distribution of reconstructed tracks](image)

- Comparison of corrected dN/dη results: tracks and tracklets

![Comparison of corrected dN/dη results](image)

- In both cases, agreement is better with EPOS LHC

dN/dη of charged hadrons at 13 TeV

- Averaged main dN/dη result for *inelastic* events

Collision energy dependence
- Central value: $5.49 \pm 0.01\,\text{(stat)} \pm 0.17\,\text{(syst)}$

http://arxiv.org/abs/1507.05915
Summary

- CMS has a **versatile** forward, diffractive, exclusive, soft QCD, MPI and low-x physics program
- CMS **forward instrumentation** is unique, especially complemented by the TOTEM experiment
  - a joint physics program and data taking is underway
  - CT-PPS will take off next year: tagging diffraction and CEP at high luminosity

- **BEC**: scaling between pp, pPb, PbPb
- **SD and DD** cross sections measured at 7 TeV, CASTOR
- **DPS** studied with 2 jets + 2 b-jets, and γ+3 jets
- New: **Underlying Event** at 2.76 TeV agrees well with models
- New limits on **AQGC** and measured xsec of exclusive WW
- The **first LHC paper** at 13 TeV: dN/dη of charged hadrons
Results that did not fit in this talk…:

- Identified particle spectra
- EWK production of Z + fwd/bckwd jets,
- Mueller-Navelet dijet decorrelations,
  - CMS PAS FSQ-12-002
- forward-central jet correlations,
  - CMS PAS FSQ-12-008
- Drell-Yan cross section with jets,
  - CMS PAS FSQ-13-003
- …

Please see the full collection at:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ
Results that did not fit in this talk…:

Please see the following related CMS talks:

- **Manfred Jeitler**: exclusive WW and AQGC
  - today 12:24, HS31
- **Hans Jozef H Van Haevermaet**: jets and diffraction
  - today 15:15, HS32
- ** Ankita Mehta**: Double Parton Scattering
  - today 17:45, HS32
- **Manfred Jeitler**: inelastic cross section
  - poster session

THANK YOU FOR YOUR ATTENTION!
END
Leading charged particle (jets)

- How is the $p_T$-integrated cross section of \(2 \rightarrow 2\) processes tamed?

\[
\sigma_{\text{int}}(p_T, \text{min}) = \int_{p_T, \text{min}} dp_T \frac{d\sigma}{dp_T}
\]

\[
\sigma_{\text{int}}(p_T, \text{min}) \propto \frac{1}{p_{T, \text{min}}^2} \quad \text{for} \quad p_{T, \text{min}} \rightarrow 0
\]

In PYTHIA:

\[
\sigma \rightarrow \sigma \times \frac{\alpha_s^2(p_{T0}^2 + p_T^2)}{\alpha_s^2(p_T^2)} \frac{p_T^4}{(p_{T0}^2 + p_T^2)^2}
\]

What do the data say?

CMS PAS FSQ-12-032
Leading charged particle (jets)

- How is the $p_T$-integrated cross section of 2→2 processes tamed?

\[ r(p_T^{\text{min}}) = \frac{1}{N_{\text{evt}}} \sum p_T^{\text{lead}} > p_T^{\text{min}} \Delta p_T^{\text{lead}} \left( \frac{\Delta N}{\Delta p_T^{\text{lead}}} \right) \]

normalized at 15 GeV

- Shape of the distribution is not well described in general
- EPOS gives the best (and excellent) description of the data

CMS PAS FSQ-12-032