Latest CMS results on low x physics and diffraction

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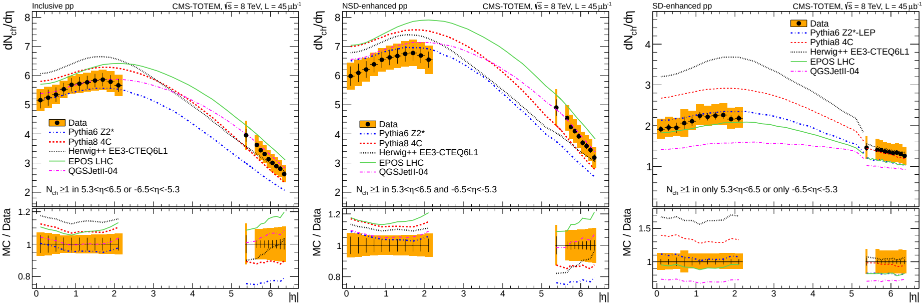
Outline

- Study QCD in the largest possible phase-space
  - Towards the lowest possible p_T
  - Towards the largest possible $|\eta|$
- To be able to probe
  - The different components of the hadrons production
  - The transition from the perturbative to the non-perturbative region
  - The importance of the higher-order emissions
  - The asymptotic behaviour of QCD at small-x
- Using inclusive and exclusive observables
  - Pseudorapidity distributions of charged particles
  - Inclusive diffractive cross sections
  - Integrated leading jet cross section
  - Underlying event description
  - Multijets production

Pseudorapidity distributions of charged particles at 8 TeV

Eur. Phys. J. C 74 (2014) 10, 3053

Inclusive **NSD-enhanced** **SD-enhanced**

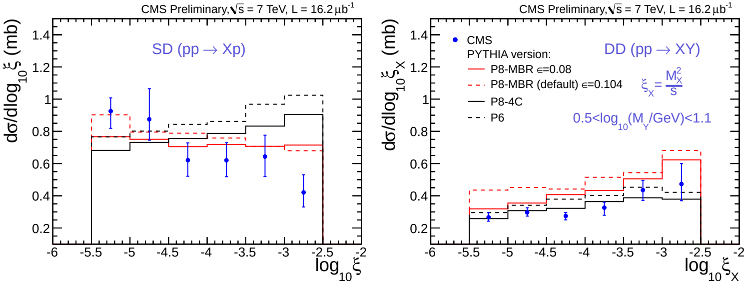


- Bulk of particles produced in pp collisions from **semi-hard (multi)parton interactions** → Phenomenological models → Tuning based on experimental data
- NSD: sensitive to MPI - SD: sensitive to diffraction modeling
- **No consistent description** of the distributions over the full η range
- Up to 20 % (30 %) discrepancy in the central (forward) region → **valuable input for tuning**

Inclusive diffractive cross sections

FSQ-PAS-12-005

SD and DD cross sections as a function of ξ



- None of the models is able to reproduce the falling behavior of the SD cross section
- **Valuable input for tuning**

Integrated leading jet cross section at low-p_T

Phys. Rev. D 86 (2012) 117501

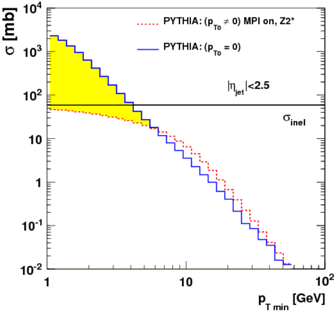
- Total $2 \to 2$ **partonic cross section**: $\sigma(p_{T\,min}) \propto \frac{1}{p^2_{T\,min}}$

  is **divergent towards low $p_{T\,min}$** and eventually becomes **larger than σ_{inel}**
- At LHC energies: $\sigma(p_{T\,min}) > \sigma_{inel}$ already for $p_{T\,min} \sim 5$ GeV
  $\to$ **Cross section needs to be tamed in the low p_T region**
- In PYTHIA: the rise of the $2 \to 2$ partonic cross section is controled by:
  - a regularization factor p_{T0} tuned to data:

$$\sigma(p_{T\,min}) \propto \frac{1}{p^2_{T\,min} + p^2_{T0}}$$

  - multiple partonic interactions (MPI):

$$< n_{MPI} >= \sigma(p_{T\,min})/\sigma_{inel}$$

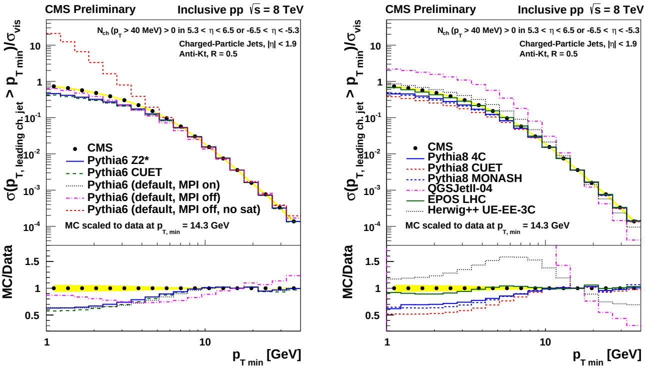


- **Saturation in the low p_T region can be measured**
  $\to$ Normalized integrated leading jet cross section:

$$\frac{1}{N_{events}} \sum_{p_{T\,leading} > p_{T\,min}} \Delta p_{T\,leading} \frac{dN_{jets}}{dp_{T\,leading}}$$

Integrated leading jet cross section at low-p_T

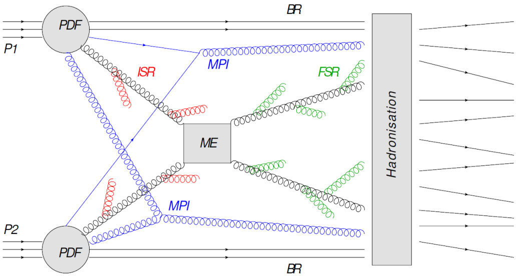
FSQ-PAS-12-032



- **Saturation at low p_T observed experimentally**
- Event cross section → no sensitivity to jet multiplicities → no sensitivity to MPI
- Normalized cross section → converges to one at low p_T by construction
- **Global behavior reproduced by the MC - detailed description may be improved**
- PYTHIA and HERWIG do not describe the data
- Cosmic Ray MC: data described by EPOS, not by QGSJET

Underlying Event

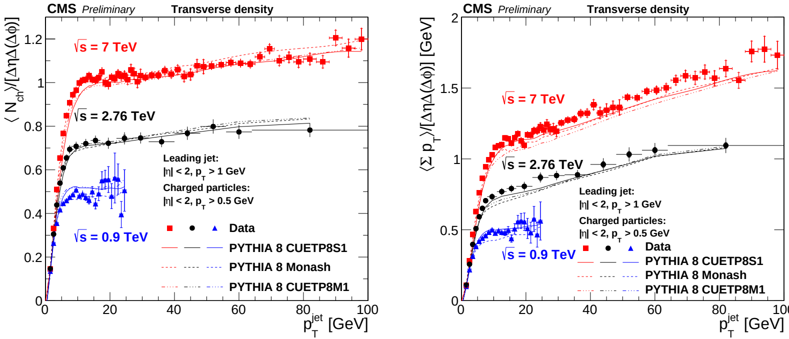
- Underlying Event: activity not attributed to the hard scattering between partons
  - Initial-State Radiation and Final-State Radiation
  - Beam Remnants
  - Multiple Partonic Interactions (with its own ISR and FSR)



- The Underlying Event is characterized by a smaller scale than the hard scattering
- **Semi-hard (multi)parton interactions**
  $\rightarrow$ Phenomenological models $\rightarrow$ Tuning based on experimental data
- Measurement at 0.9 and 7 TeV were available $\rightarrow$ **2.76 TeV was missing**
- Some MPI can be **harder** $\rightarrow$ **Double Parton Scattering**

Underlying Event at 0.9, 2.76 and 7 TeV

FSQ-PAS-12-025



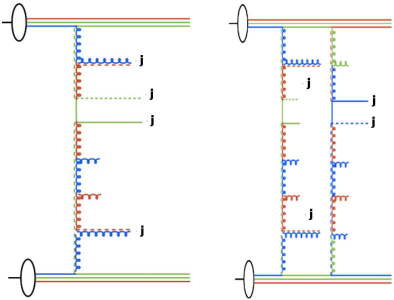
- Reference: direction of the leading track jet
- Transverse region ($60^\circ < |\Delta\phi| < 120^\circ$) most sensitive to the UE activity
- **Fast rise at low p_T** due to the increase of **MPI** activity
- **Plateau region:** MPI saturated, increase of activity due to **ISR and FSR**
- Strong growth of the UE activity with $\sqrt{s}$
- **New tunes predict energy dependence very well**

DPS in four-jet events

Phys. Rev. D 89 (2014) 092010

- A four-jet final state may arise from one or two chains
  The two additional jets may be produced via a hard radiation or a second hard scattering

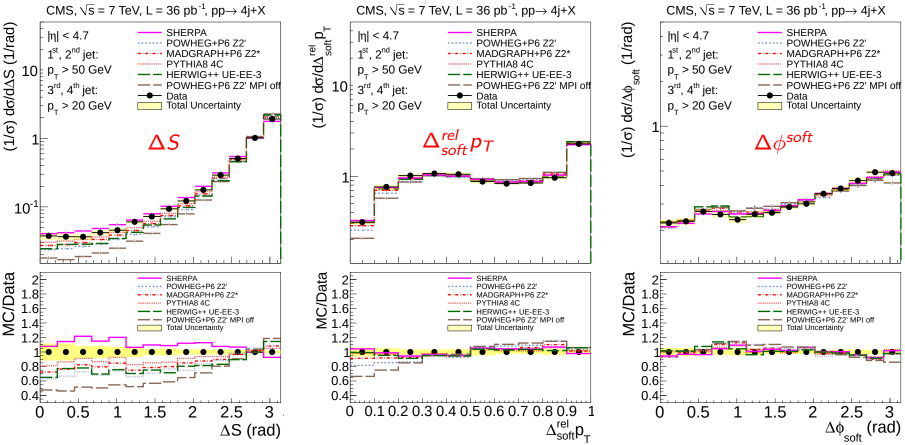
SPS background **DPS signal**



- Selection of exactly four jets in $|\eta| < 4.7$:
  - 2 jets with $p_T > 50$ GeV
  - 2 jets with $p_T > 20$ GeV
- **Jets associated in pairs:**
  - **hard-jet pair**: the two leading jets with $p_T > 50$ GeV
  - **soft-jet pair**: the two other jets with $p_T > 20$ GeV

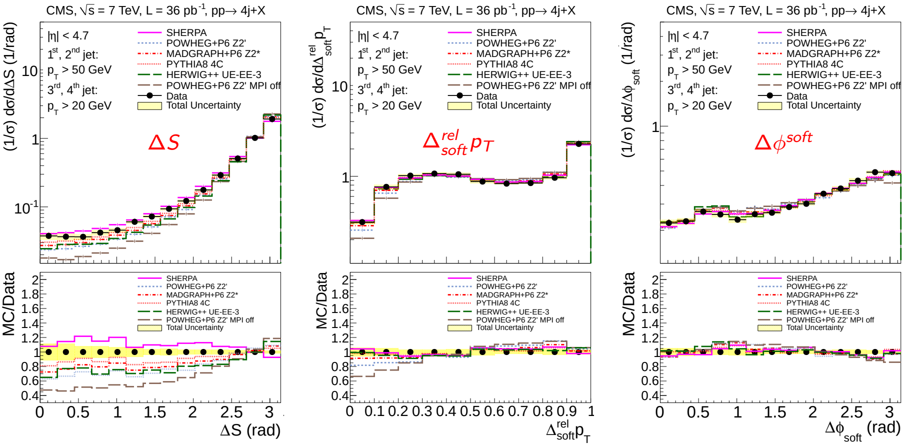
- **Discriminating observables** $\rightarrow$ topology of the jets in the transverse plane:
  - $\Delta S = \arccos\left(\frac{\mathbf{p_T}^{soft} \cdot \mathbf{p_T}^{hard}}{|\mathbf{p_T}^{soft}|\,|\mathbf{p_T}^{hard}|}\right)$ $\rightarrow$ DPS $\sim$ flat - SPS $\sim$ peak at π
  - $\Delta^{rel}_{soft} p_T = \frac{|\mathbf{p_T}^{soft\,1} + \mathbf{p_T}^{soft\,2}|}{|\mathbf{p_T}^{soft\,1}| + |\mathbf{p_T}^{soft\,2}|}$ $\rightarrow$ DPS $\sim$ peak at 0 - SPS $\sim$ peak at 1
  - $\Delta\phi^{soft} = |\phi_{soft\,1} - \phi_{soft\,2}|$ $\rightarrow$ DPS $\sim$ peak at π - SPS $\sim$ flat

Correlation observables: normalized cross sections



- $\Delta^{rel}_{soft} p_T$ and $\Delta\phi^{soft}$: no significant differences among generators
- ΔS: better described by SHERPA and PYTHIA8
- **POWHEG without MPI underestimates the data for ΔS and $\Delta^{rel}_{soft} p_T$**
- **ΔS and $\Delta^{rel}_{soft} p_T$ sensitive to MPI contribution → DPS extraction**

Correlation observables: normalized cross sections

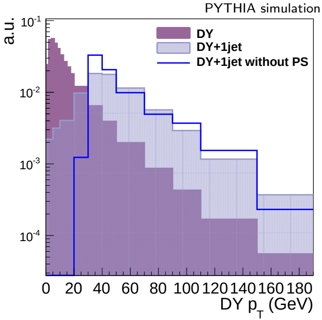


- Usual way: template method → ambiguous definition of background and signal
- **Here: tuning method → UE parameters from the best fit define the value of σ_{eff}**
- PYTHIA8 DPS tune CDPSP8S2-4j: $\sigma_{eff} = 19.0^{+4.7}_{-3.0}$ mb
- Value consistent with previous measurements

Drell-Yan + jets

FSQ-PAS-13-003

- Drell-Yan p_T spectrum used as a **tool to study higher-order QCD processes**

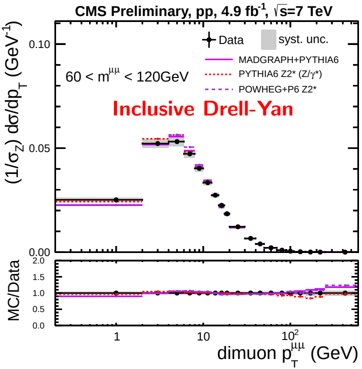


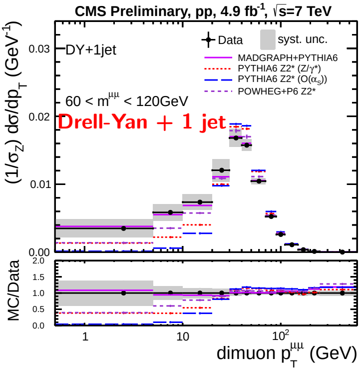
- **At large p_T**: Drell-Yan p_T spectrum described by **fixed-order** QCD matrix elements
- **At low p_T**: fixed-order calculation diverges and higher-order contributions need to be taken into account

  → low p_T region dominated by the **resummation of higher-order emissions**

- **Inclusive Drell-Yan production**: p_T spectrum is maximum around $p_T \sim 5$ GeV
  - Small phase-space for extra QCD emissions
- **Drell-Yan production in association with jets**: maximum shifted to higher value
  - Larger phase-space for extra QCD emissions
- PYTHIA: Higher-order emissions treated by the initial-state parton shower
  Without parton shower → higher-order emissions missing → sharp cutoff below the peak

Drell-Yan + jets





- **Inclusive Drell-Yan production**:
  - Lowest-order and higher-order calculations describe the data equally well
  - Maximum of the distribution at $p_T \sim 5$ GeV
- **Drell-Yan production in association with at least 1 jet**:
  - Maximum shifted to higher value - Larger phase-space for extra emissions
  - High-p_T tail described equally well by all Monte Carlo
  - **Low p_T not described by lowest-order prediction, higher-order needed**

Conclusion

- Presented several observables which enable to constrain QCD at **different scales**

- Distributions of charged particles - Underlying Event - Diffractive cross sections
  - **Semi-hard (multi)parton interactions**
  - Tuning of phenomenological models

- Integrated leading jet cross section
  - Transition from the perturbative to the non-perturbative region
  - **Saturation of the $2 \to 2$ partonic cross section**

- Four-jet events - Drell-Yan + jets
  - **Higher-order QCD emissions**