Impact of CMS Measurements on Parton Distribution Functions and QCD parameters

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PDF CONSTRAINTS FROM LHC

need improvements in quark flavor separation at medium x, gluon at low and at high x

- impact of the LHC measurements

- jets: gluon, $\alpha_s$ (today)
  medium-high x

- top-pairs: gluon (today)
  high x

- DY: light quarks, flavor separation, gluon

- V+HQ: s-quark, intrinsic charm
  (S.Pflitsch’s talk)
Jet production in pp collisions directly sensitive to PDFs and $\alpha_s$

CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$:
- inclusive jet production: *JHEP 03 (2017) 156*
- 3D dijet production: *arXiv:1705.02628 (submitted to EPJC)*
- multijet production: *CMS-PAS-SMP-16-008*

Details about measurements: P.Kokkas’ talk.
CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$ inclusive jet production JHEP 03 (2017) 156

Double-differential cross sections vs of jet $p_T$ and rapidity

Constraints on PDFs and $\alpha_S$ : QCD analysis at NLO using herafitter 1.1.1

**simultaneous fit with PDFs:**

$$\alpha_S(M_Z) = 0.1185^{+0.0019}_{-0.0026}(PDF) + 0.0022^{+0.0022}_{-0.0018}(scale)$$

**using fixed PDFs:**

**CT10NLO**

$$\alpha_S(M_Z) = 0.1164^{+0.0060}_{-0.0043}$$

**NNPDF3.0 NLO**

$$\alpha_S(M_Z) = 0.1172^{+0.0083}_{-0.0075}$$

Significant impact on the gluon distribution, $\alpha_S$ consistent with world average, dominant uncertainty emerges from the variations of the scales
Probing $x_1$ and $x_2$ using different event topologies

CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$ dijet production: arXiv:1705.02628 (submitted to EPJC)

3-differential cross sections vs of jet average $p_T$, rapidity separation and boost

for details see talk by P.Kokkas

Novel technique to access highly boosted regime ($x_1 << x_2$)
Probing $x_1$ and $x_2$ using different event topologies

CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$ dijet production: arXiv:1705.02628 (submitted to EPJC)

3-differential cross sections vs of jet average $p_T$, rapidity separation and boost

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PDF dominant uncertainty

dominant $gq$ ($x_g < x_q$)

JETS @ CMS: GLUON AND STRONG COUPLING

arXiv:1705.02628

CMS Preliminary

19.7 fb$^{-1}$ (8 TeV)

$2 \leq y_b < 3$

$0 \leq y^* < 1$

$y^* = 1/2 |y_1 - y_2|$

$y_b = 1/2 |y_1 + y_2|$

$\gamma, gq$ (dominant $gq$)

PDF dominant uncertainty
By using dijet cross section in the QCD analysis in addition to HERA data...

- change in the gluon shape similar as observed in the case of inclusive jet data
- significant reduction of the uncertainty in g(x) at high x

similar to inclusive jet data (note different parametrisation)

- strong coupling determined simultaneously with PDFs:

\[ \alpha_s(M_Z) = 0.1199^{+0.0015}_{-0.0016}(PDF)^{+0.0026}_{-0.0016}(scale) \]
JETS @ CMS: GLUON AND STRONG COUPLING

CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$ multi-jet production CMS-PAS-SMP-16-008

Ratio of 3/2 inclusive jet cross sections

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma_{pp \rightarrow n \text{ jets} + X; n \geq 3}}{\sigma_{pp \rightarrow n \text{ jets} + X; n \geq 2}} = \frac{\sum \begin{array}{c} \text{anti-k}_{\perp} \text{ R = 0.7} \\ \text{Iy} < 2.5 \end{array} + \cdots}{\sum \begin{array}{c} \text{anti-k}_{\perp} \text{ R = 0.7} \\ \text{Iy} < 2.5 \end{array} + \cdots} \sim \alpha_s$$

Advantage of $R_{32}$: partial or full cancellation or reduction of experimental uncertainties, theory uncertainties due to NP effects, PDFs, scale choice, EWK corrections

$\alpha_s$ determined by minimizing $\chi^2$ between the measurement and the theory

MMHT14: $\chi^2/n_{\text{dof}} = 24/28$

$$\alpha_s(M_Z) = 0.1142 \pm 0.0010(\text{exp}) \pm 0.0013(\text{PDF})$$

$$\pm 0.0014(\text{NP})^{+0.0049}_{-0.0006}(\text{scale})$$
CMS 8 TeV, $\mathcal{L} = 19.7$ fb\(^{-1}\) multi-jet production CMS-PAS-SMP-16-008

Ratio of 3/2 inclusive jet cross sections

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma_{pp \rightarrow n \text{ jets} + X; n \geq 3}}{\sigma_{pp \rightarrow n \text{ jets} + X; n \geq 2}} = \frac{\sum \text{---} + \text{---} + \text{---}}{\sum \text{---} + \text{---}} \sim \alpha_s$$

$\alpha_s(M_Z)$ value for each $H_{T,2}/2$ range $\rightarrow \alpha_s(Q)$
In pp collisions top-quark pairs are produced via gg fusion probing gluon at high $x$

CMS 8 TeV, $\mathcal{L} = 19.7$ fb$^{-1}$:

2d-differential $t\bar{t}$ cross sections arXiv:1703.01630 (Submitted to EPJC)

M$(tt)$ and $y(tt)$
most sensitive to PDFs at LO:

$$x_{1,2} = \frac{M(tt)}{\sqrt{s}} e^{\pm y(tt)}$$

for details see talk T.Arndt
strongest constraints achieved by using 2d distributions in $M_{tt}$ and $y_{tt}$

Recommend to use both data sets for further improvement of $g(x)$ at high $x$
In pp collisions top-quark pairs are produced via gg fusion probing gluon at high $x$.

**CMS 5.02 TeV, $\mathcal{L} = 27.4$ pb$^{-1}$**

CMS-PAS-TOP-16-023

for details see talk T.Arndt

New kinematic range probed

XFitter 2.0.0

Theory: HATHOR, $m_t = 172.5$ GeV

Modest effect on $g(x)$ at high $x$
LHC Run I CMS data used for improvement of PDF accuracy

• jet data: gluon at medium & high $x$, strong coupling
  → getting even more interesting with available NNLO calculation
• top quark pairs: gluon at high $x$

LHC Run II CMS data is forthcoming

Run I has shown high potential of the LHC
to improve the understanding of the proton structure,
more data are still to come to be used in precision QCD analyses
BACK UP
proton structure  

PDFs

Partons: quarks & gluons

\[ \text{Rate} = (\text{structure of 2 protons}) \otimes \sigma_{ij} \]

**Parton Distribution Functions**

\[ f_i(Q^2, x) \]

- provided by theory
- determined experimentally

at the very edge of theory and experiment, correlated with fundamental QCD parameters

**NEED FOR EXPERIMENTAL INPUT**

Improvement of PDFs precision demands theory & experiment collaboration and implies a variety of measurements and theory calculations
QCD analysis: XFitter 1.2. 2, baseline data HERA inclusive DIS [EPJ C 75 (2015) 580]
Theory via NLOJet++ via fastNLO, scale $\mu_r = \mu_f = p_{T,\text{max}} \cdot e^{0.3y^*}$

$$xg(x) = A_g x B_g (1 - x)^{C_g} - A'_g x B'_g (1 - x)^{C'_g},$$

$$xu(x) = A_{u(x)} x^{B_{u(x)}} (1 - x)^{C_{u(x)}} (1 + D_{u(x)} x + E_{u(x)} x^2),$$

$$xd(x) = A_{d(x)} x^{B_{d(x)}} (1 - x)^{C_{d(x)}} (1 + D_{d(x)} x),$$

$$x\bar{U}(x) = x\bar{u}(x), \text{and } x\bar{D}(x) = x\bar{d}(x) + x\bar{s}(x)$$

$B_{u(x)} = B_{\bar{D}} \text{ and } A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$

$Bd_v \neq Bu_v$

$\Rightarrow$ 16-parameter fit

$Q^2 = 1.9 \text{ GeV}^2$

Data are consistent very good fit quality for the CMS jet data
CMS 8 TeV, \( \mathcal{L} = 19.7 \text{ fb}^{-1} \) dijet production: CMS-PAS-SMP-16-011

3-differential cross sections vs of jet average \( p_T \), rapidity separation and boost

Probing \( x_1 \) and \( x_2 \) using different event topologies

\[
y^* = \frac{1}{2} |y_1 - y_2|
\]

\[
y_b = \frac{1}{2} |y_1 + y_2|
\]

\[
gg (x_g < x_q)
\]

\[
gq (x_g < x_q)
\]

\[
0 \leq y_b < 1
\]

\[
0 \leq y^* < 1
\]

\[
200 \quad 300 \quad 500 \quad 1000
\]

\[
p_{T,\text{avg}} / \text{GeV}
\]