Recent QCD results from the Tevatron

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Outline

Introduction: Experiments and data sample
Results with full $\mathcal{L}$: Prompt photons, W/Z+jets, soft QCD
Conclusions: Impact on theory
Proton-antiproton collider operating at $\sqrt{s} = 1.96$ TeV from 2/2002 to 10/2011 (Run II) + $\sqrt{s} = 300, 900$ GeV in 9/2011

Currently 400 + 400 members
From 55 + 70 institutions
Detectors

Lepton coverage:
\[ |\eta| < 2.0 \ (\mu), \ |\eta| < 2.6 \ (e) \]

Jets to \[ |\eta| < 4.2 \]

b-tagging with \[ |\eta| < \sim 2 \]

Resolution similar to CDF

Lepton coverage:
\[ |\eta| < 1.5 \ (\mu), \ |\eta| < 2.0 \ (e) \]

Jets to \[ |\eta| < 3.8 \]

b-tagging with \[ |\eta| < \sim 1.5 \]

EM \[ \sigma_E/E \sim 13.5\%/\sqrt{E} \oplus 1.5\% \]

HAD \[ \sigma_E/E \sim 50\%/\sqrt{E} \oplus 3\% \]
Delivered 12 fb\(^{-1}\)
Acquired 10 fb\(^{-1}\)/experiment

- 15B + 9B events total in Run II
- Total dataset 10 + 9 PB (including Monte Carlo)

- [http://www-d0.fnal.gov/Run2Physics/WWW/results.htm](http://www-d0.fnal.gov/Run2Physics/WWW/results.htm)
QCD at the Tevatron

Proton-antiproton initial state favors valence quark-initiated processes → smaller PDF uncertainties

Situation complementary to LHC where proton-proton initial state favors gluon-initiated processes
Fixed-order NLO calculations available for all $V+$jets production processes ($V = \gamma, Z, W$)

Undergoing effort for full NNLO calculations started with $\gamma\gamma$ production

Variety of parton-shower models (Pythia, Herwig, Sherpa) matched to tree-level and full NLO calculations (Alpgen, Madgraph, MC@NLO, Powheg, Blackhat)

Resummed calculations matched to NLO matrix elements (Resbos, $k_T$-factorization) stand in between fixed-order and parton-shower

Extensive soft QCD phenomenology (long-range matrix elements, diffractive physics, underlying event)
γ + jet cross sections

PRD 88, 072008 (2013)

- Parton-x sensitivity tested in y regions
- Full NLO+frag. successful in central y
- Tree-level PS underestimates the data
γ + b/c cross sections

PRL 111, 042003 (2013)

Full NLO fails

k_T-factorization & Sherpa work best
**NLO fails**

**$k_T$-factorization & Sherpa work best**
γ + 2b cross sections

PLB 737, 357 (2014)

- Sherpa fails
- $k_T$-factorization & NLO work best
Only Sherpa & NNLO (almost) describe the data
Only Sherpa & NNLO (almost) describe the data
W(l\nu + jets cross sections

CDF public note 11167

Tree-level PS describes the data
$W(\mu \nu) + b/c$ cross sections

PLB 743, 6 (2015)

Both tree-level PS & fixed-order NLO fail
CDF Run II Preliminary

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Fixed-order and PS NLO work reasonably well
Z(\(\Pi\)) + b cross sections

CDF public note 10594

Fixed-order NLO works reasonably well
Fixed-order NLO works well for $Z+b$, but not for $Z+c$
Z(\(\Pi\)) + 2b/2c cross sections

PRD 91, 052010 (2015)

Tree-level PS describes the data
Probing long-range matrix elements in W/Z + h.f. production
DPS in $\gamma + 3$ jets events

PRD 89, 072006 (2014)

- $\Delta S$ measures imbalance between $p_T$-ordered pairs in 4-body final state
- Sherpa MPI model describes the data well
DPS in $2\gamma + 2$ jets events

D0 conference note 6470

- Overlaid $2\gamma + 2j$ data MixDP + Sherpa SP model describe the data well
- Consistent overall picture for $\sigma_{\text{eff}} = \sigma_{12}\sigma_{34} / \sigma_{12+34}$
DPS in $J/\psi + J/\psi$ events

PRD 90, 111101 (2014)

Data well described by NRQCD (DJpsiFDC+Pythia)
Energy scan of underlying event

CDF public note 10874

Pythia UE model works over wide energy range
Constrains diffractive t-channel double pomeron exchange

Probes an entirely unexplored region of soft QCD
Conclusions

✧ Tevatron experiments keep producing high-precision results, stringently testing QCD calculations

✧ Experimental precision challenges the precision of NLO calculations in most cases

✧ NNLO calculations generally needed to adequately describe production of prompt photons

✧ W/Z+jets data adequately described, in general, by NLO calculations, except W+h.f. production

✧ Multiple parton interactions reasonably well understood

✧ Long-range matrix elements and diffractive physics more precisely probed with full luminosity