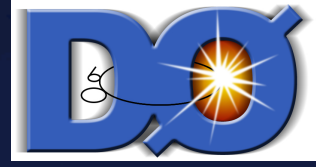


Recent QCD results from the Tevatron

Costas Vellidis
Fermilab

DPF 2015, Ann Arbor MI, August 5

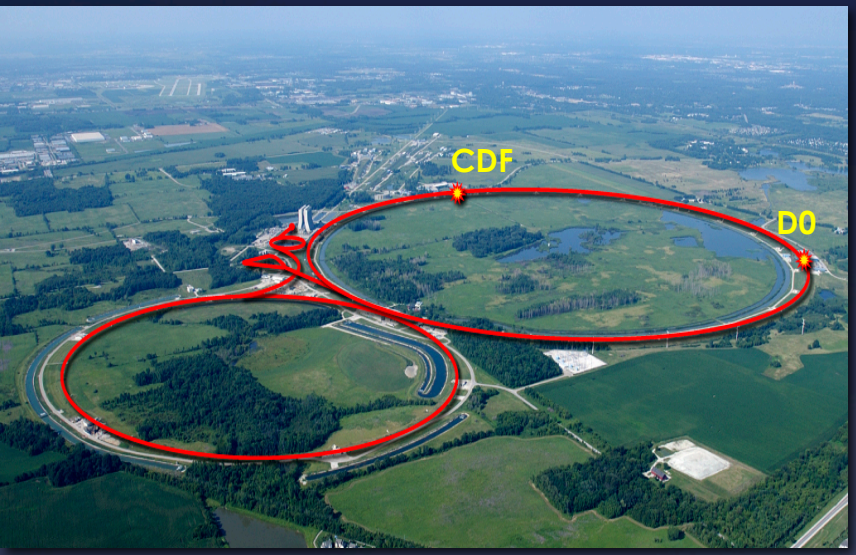
Outline

Introduction: Experiments and data sample

Results with full $\mathcal{L}$: Prompt photons, W/Z+jets, soft QCD

Conclusions: Impact on theory

Tevatron

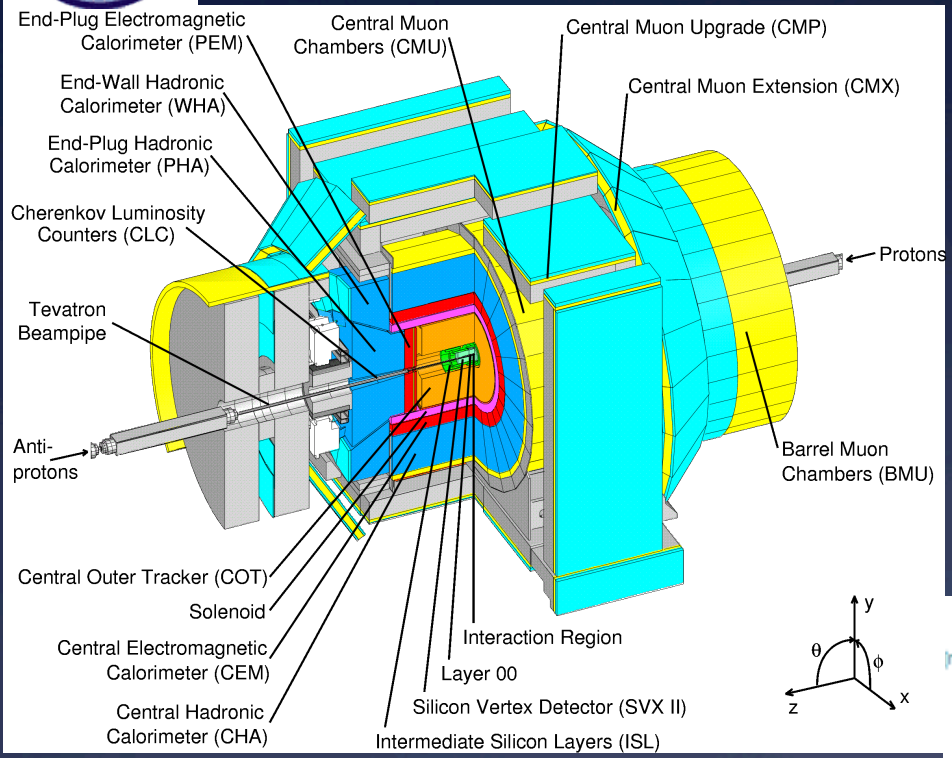


Proton-antiproton collider
operating at $\sqrt{s}$ = 1.96 TeV
from 2/2002 to 10/2011 (Run II)

+ $\sqrt{s}$ = 300, 900 GeV in 9/2011

Currently
400 + 400 members
From 55 + 70 institutions

Detectors



Lepton coverage:
$|\eta| < 1.5$ (μ), $|\eta| < 2.0$ (e)

Jets to $|\eta| < 3.8$

b-tagging with $|\eta| < \sim 1.5$

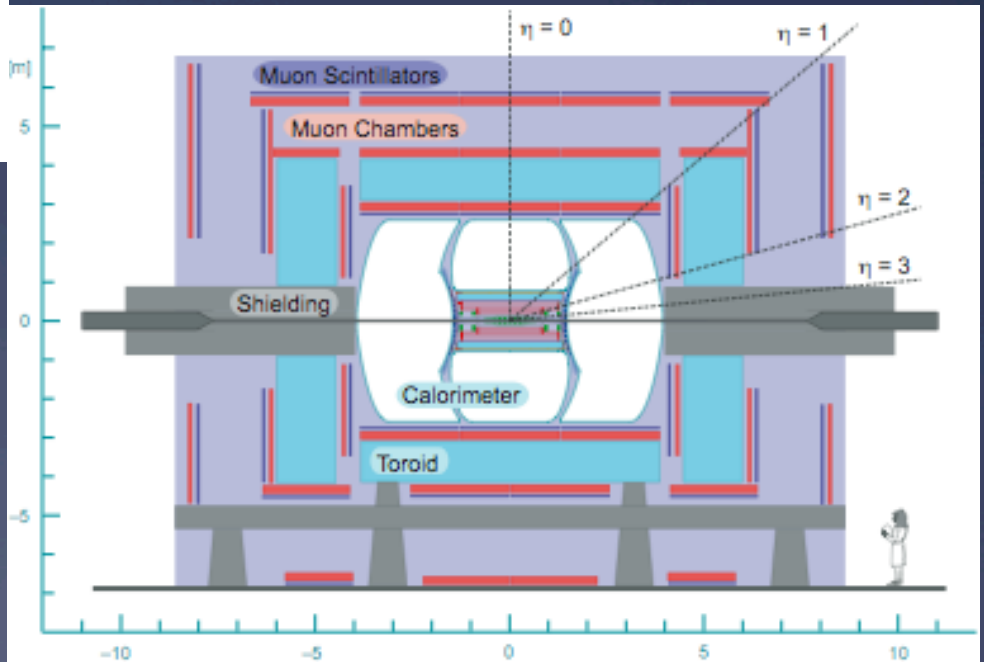
EM $\sigma_E/E \sim 13.5\%/\sqrt{E} \oplus 1.5\%$
HAD $\sigma_E/E \sim 50\%/\sqrt{E} \oplus 3\%$

Lepton coverage:
$|\eta| < 2.0$ (μ), $|\eta| < 2.6$ (e)

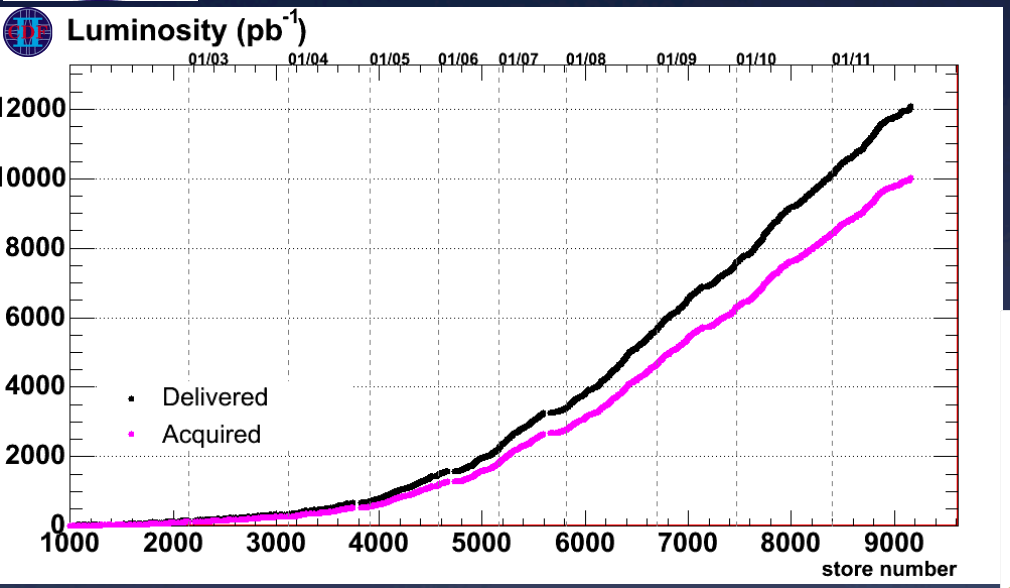
Jets to $|\eta| < 4.2$

b-tagging with $|\eta| < \sim 2$

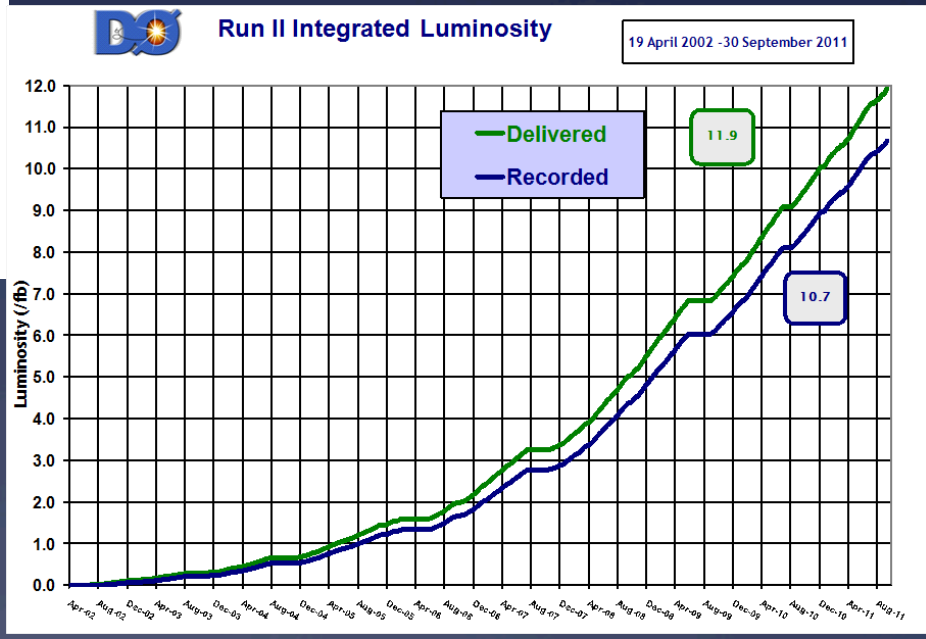
Resolution similar to CDF



Sample



Delivered 12 fb^{-1}
Acquired 10 fb^{-1}/experiment

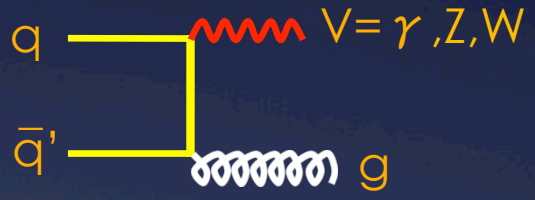


- ✧ 15B + 9B events total in Run II
- ✧ Total dataset 10 + 9 PB (including Monte Carlo)

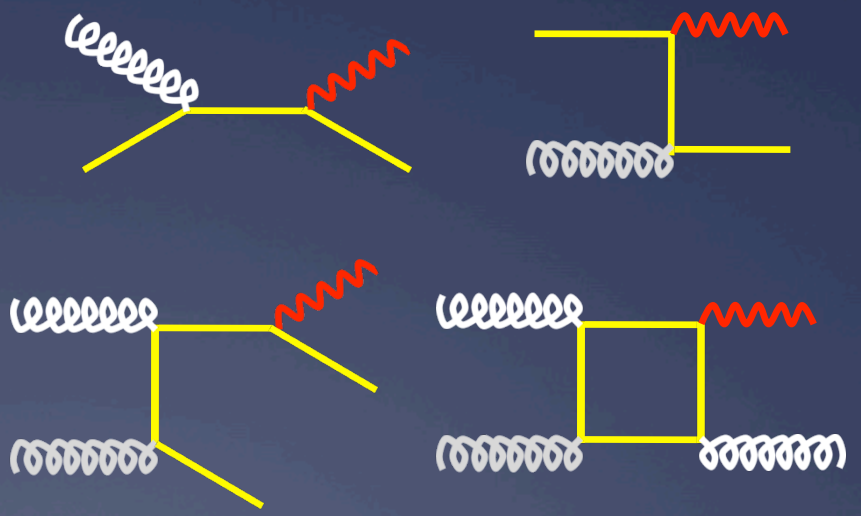
- ➢ http://www-cdf.fnal.gov/physics/physics.html
- ➢ http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

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

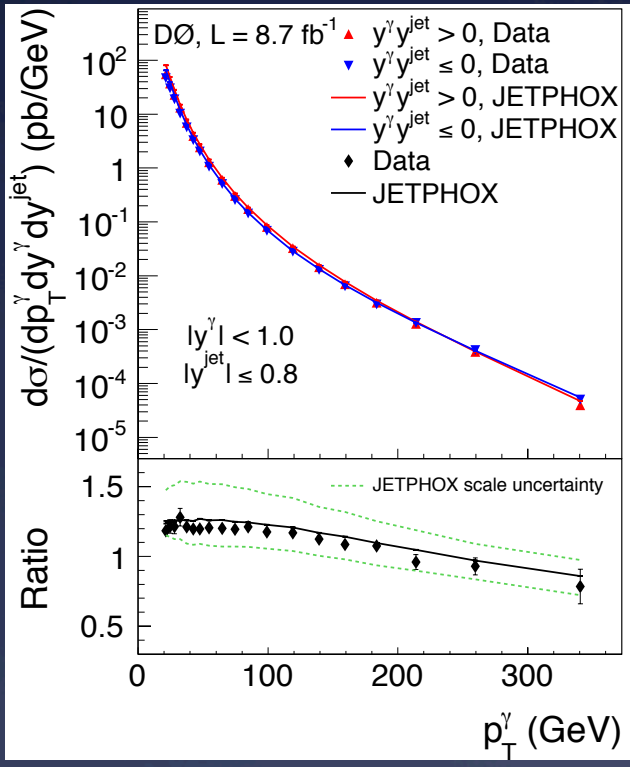


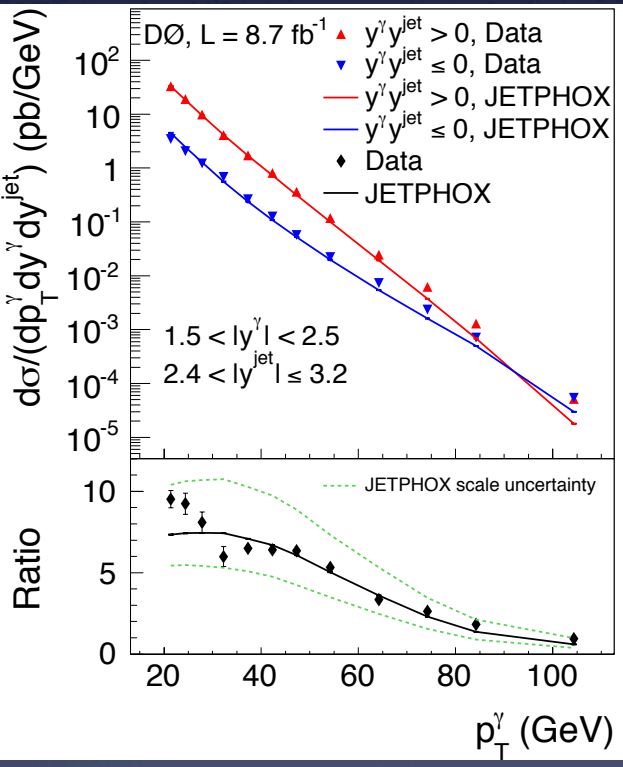
Status of theory

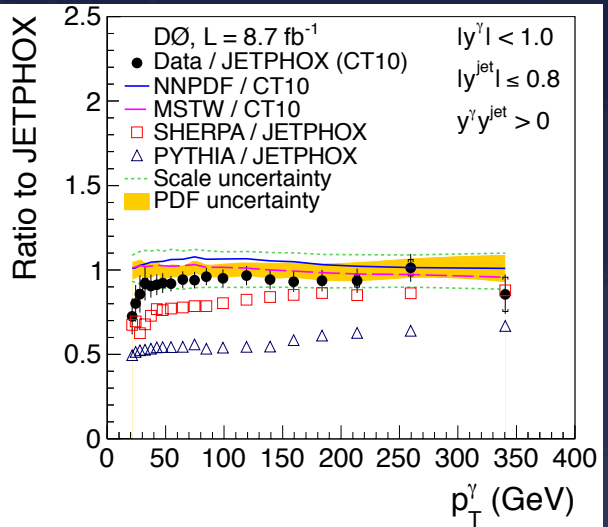
- ✓ Fixed-order NLO calculations available for all V+jets production processes (V= γ , Z, W)
- ✓ Undergoing effort for full NNLO calculations started with $\gamma\ \gamma$ production
- ✓ Variety of parton-shower models (Pythia, Herwig, Sherpa) matched to tree-level and full NLO calculations (Alpgen, 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)

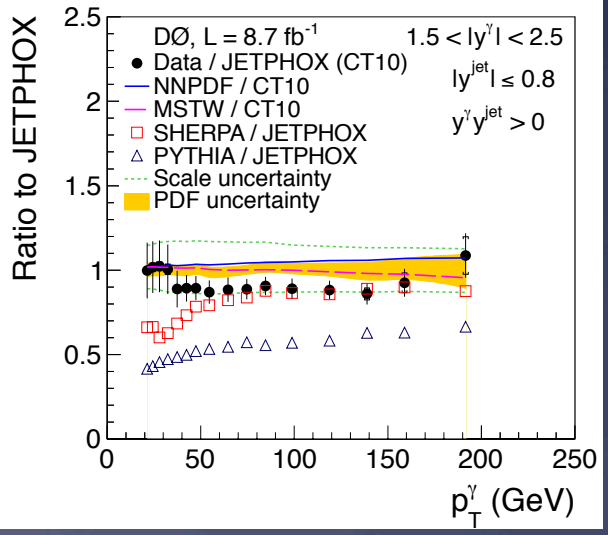
γ + jet cross sections

PRD 88, 072008 (2013)





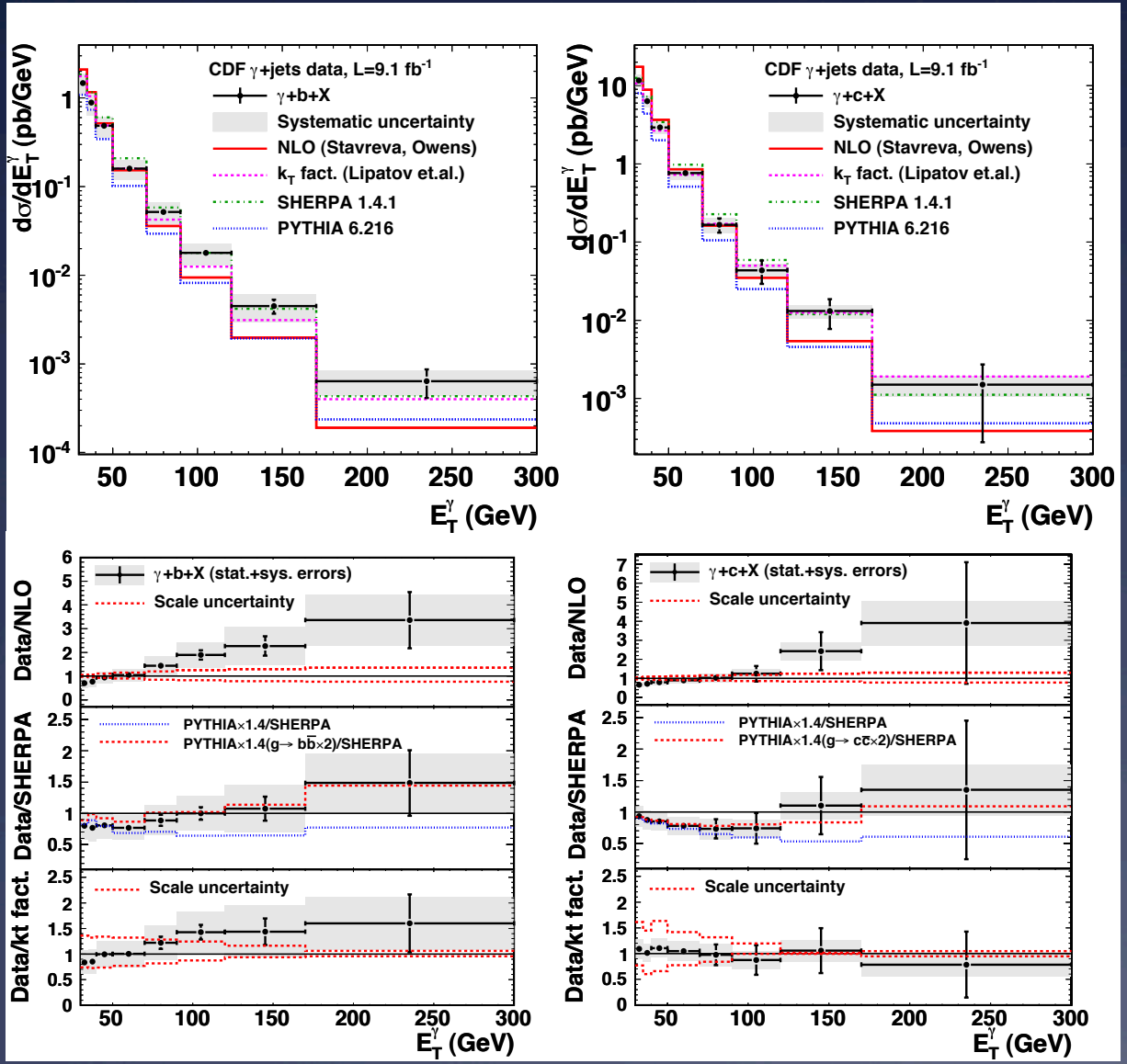




- Parton-x sensitivity tested in y regions
- Full NLO+frag. successful in central y
- Tree-level PS underestimates the data

γ + b/c cross sections

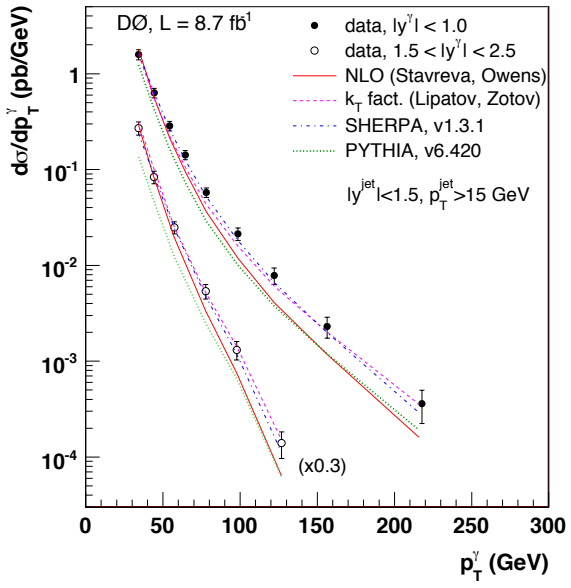
PRL 111, 042003 (2013)

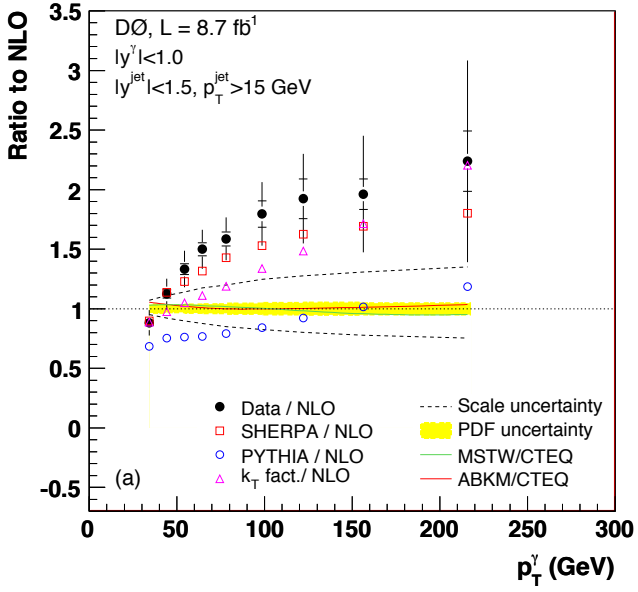


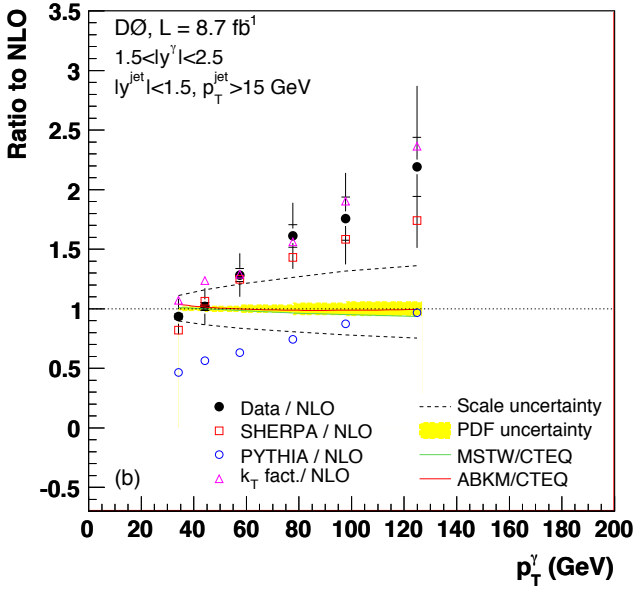
- Full NLO fails
- k_T-factorization & Sherpa work best

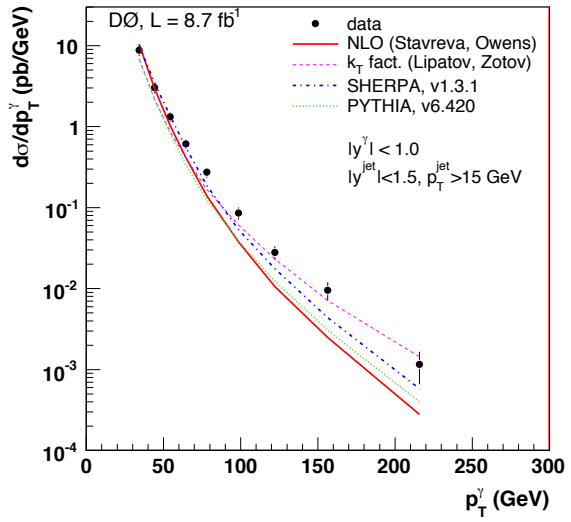
γ + b/c cross sections

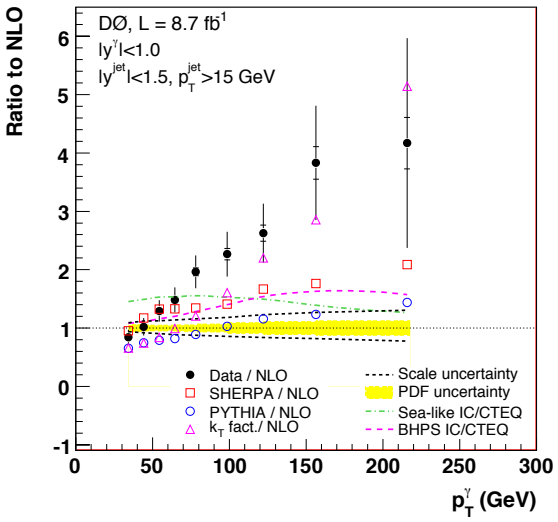
PLB 714, 32 (2012) PLB 179, 354 (2012)







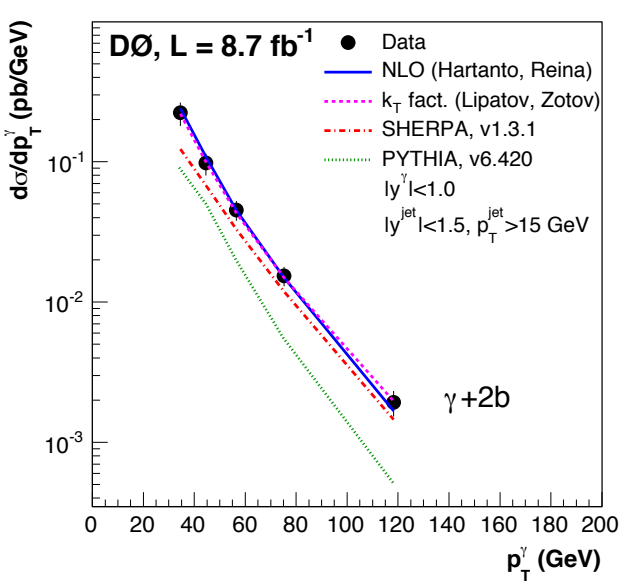


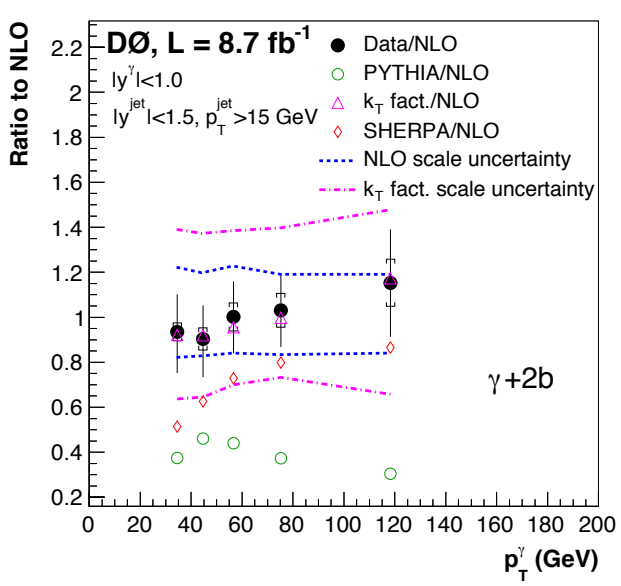


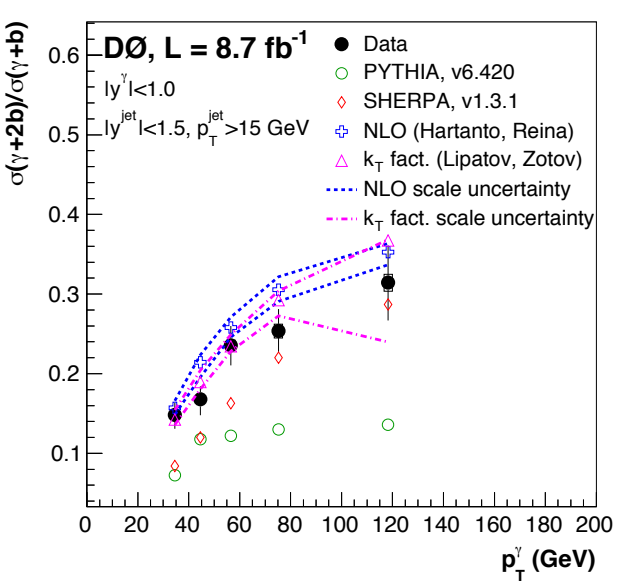
- NLO fails
- k_T-factorization & Sherpa work best

γ + 2b cross sections

PLB 737, 357 (2014)





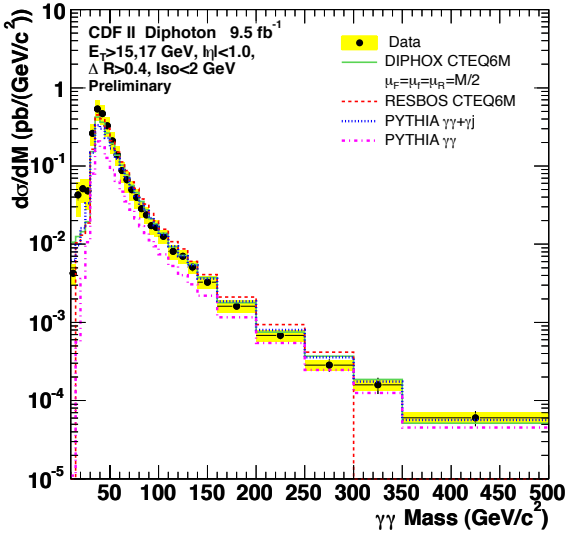


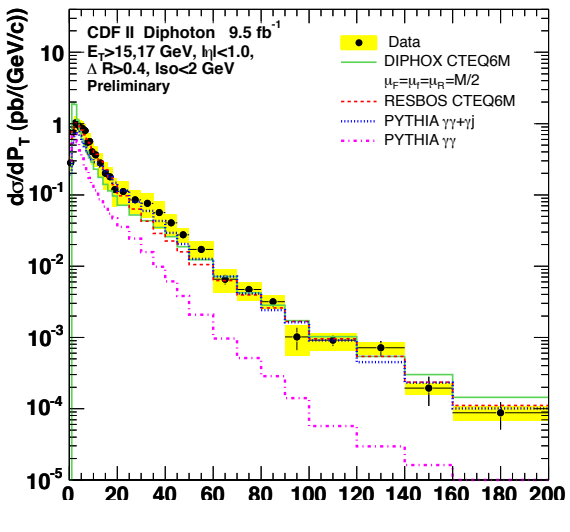
- Sherpa fails
- k_T-factorization & NLO work best

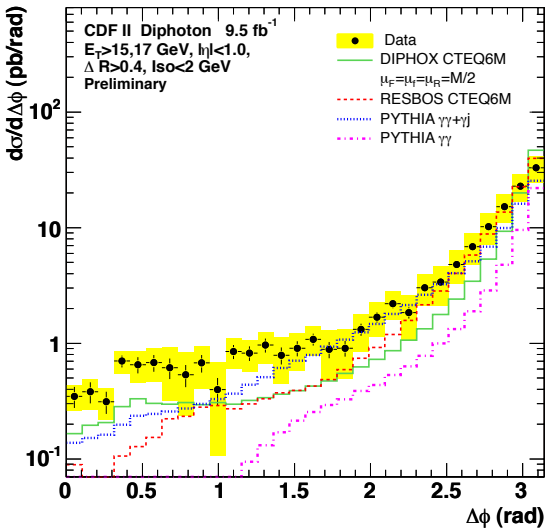
$\gamma\gamma$ cross section

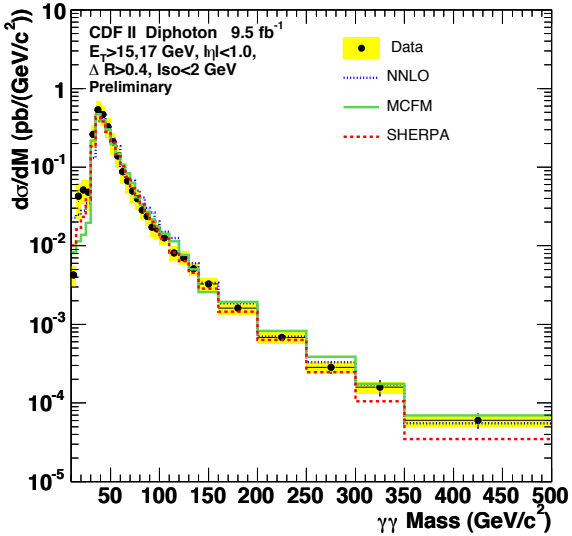
PRL 110 101801 (2013)

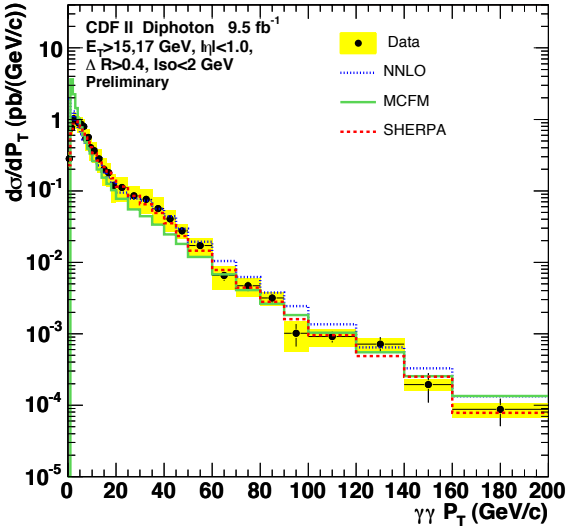
Only Sherpa & NNLO (almost) describe the data

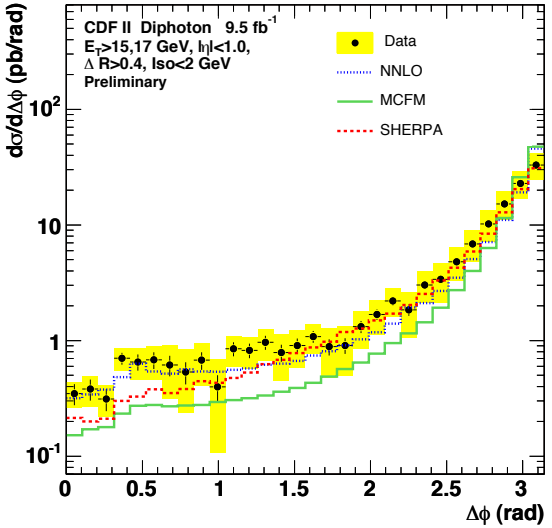






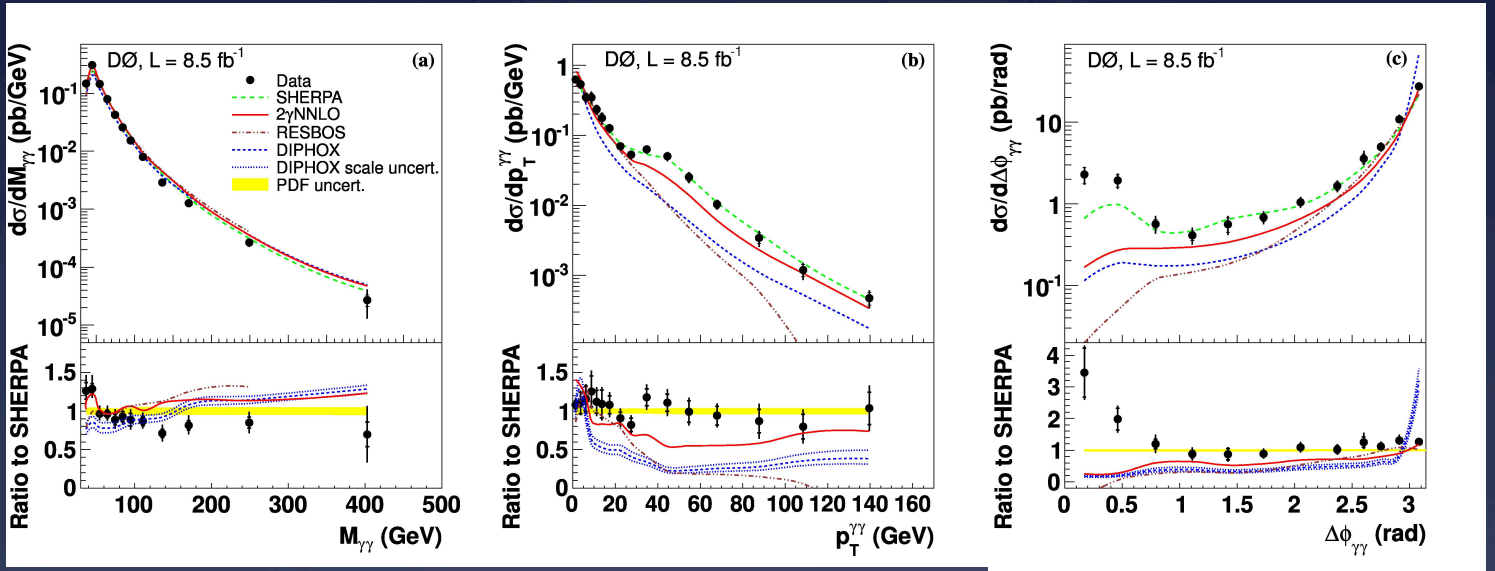




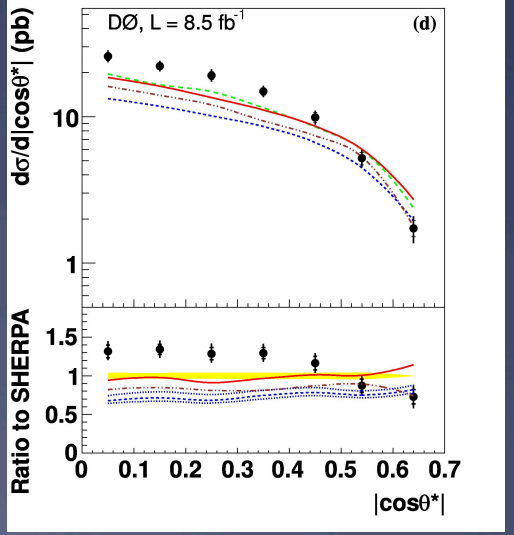


$\gamma\gamma$ cross section

PLB 725, 6 (2013)

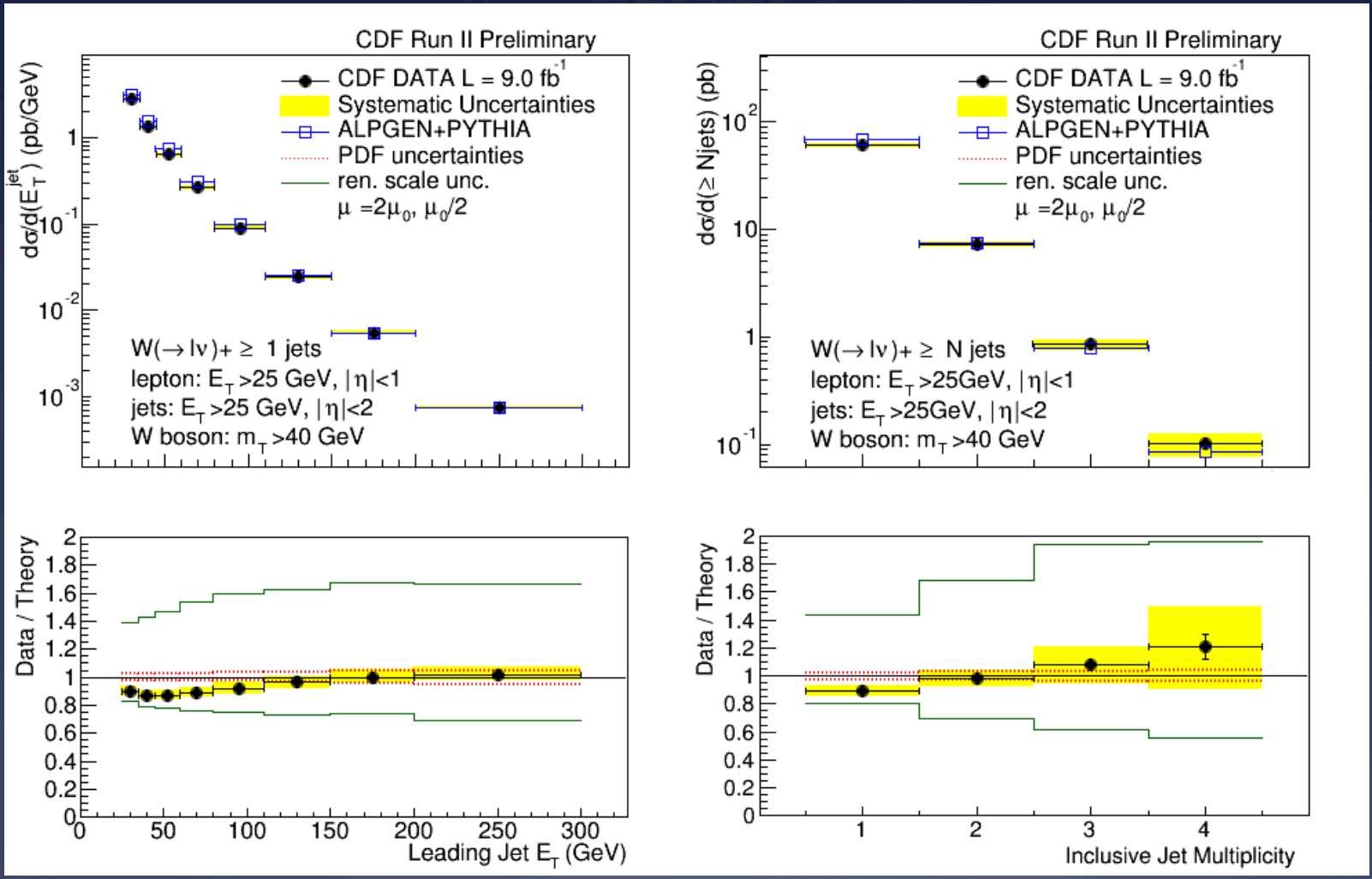


Only Sherpa & NNLO
(almost) describe the data



W(lν) + jets cross sections

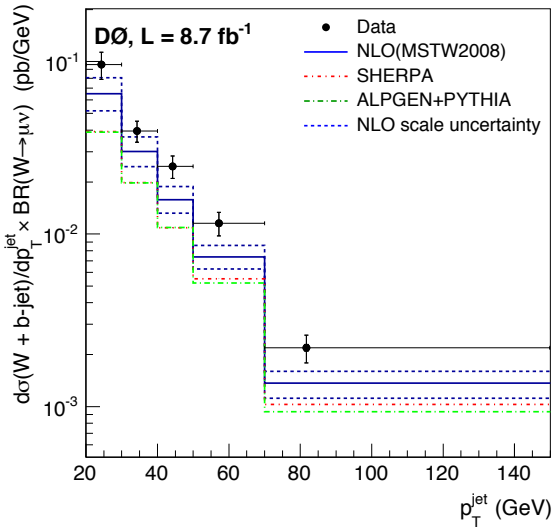
CDF public note 11167

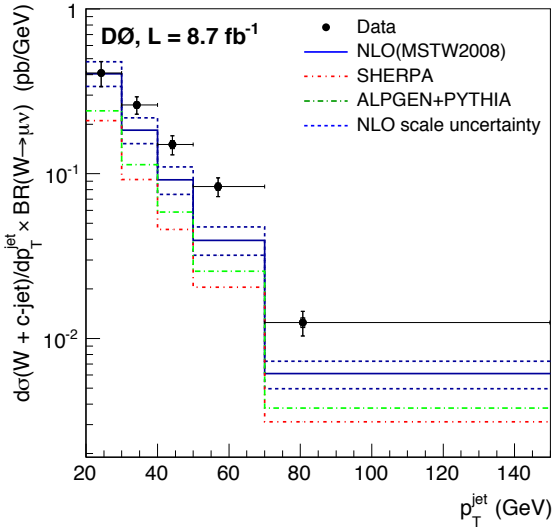


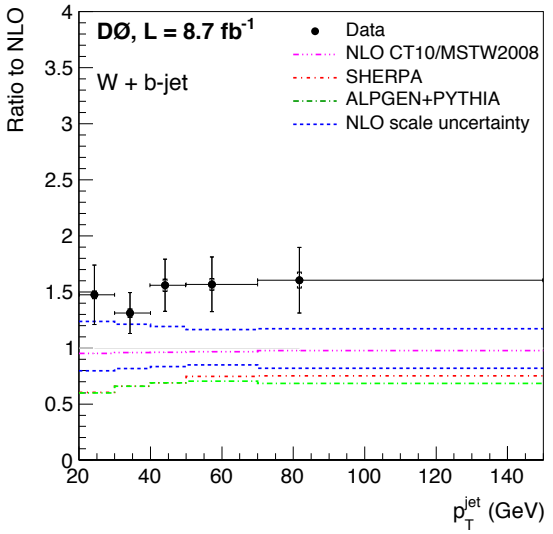
Tree-level PS describes the data

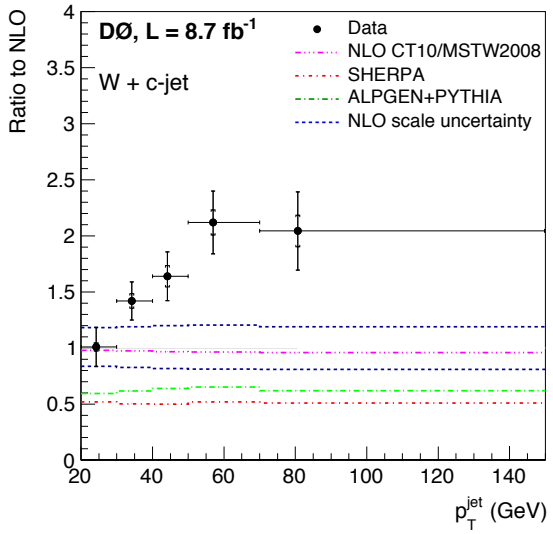
W(μν) + b/c cross sections

PLB 743, 6 (2015)





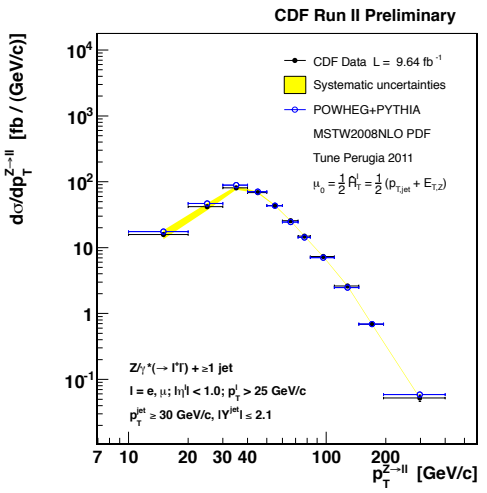


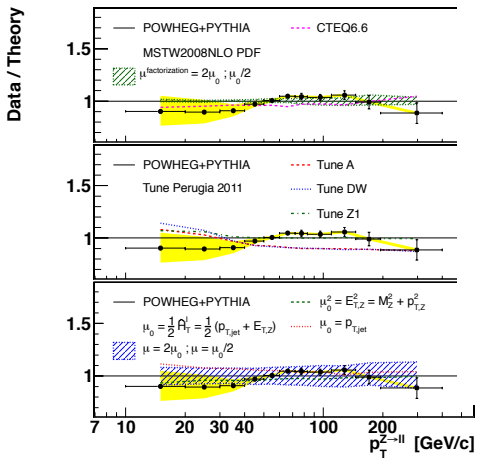


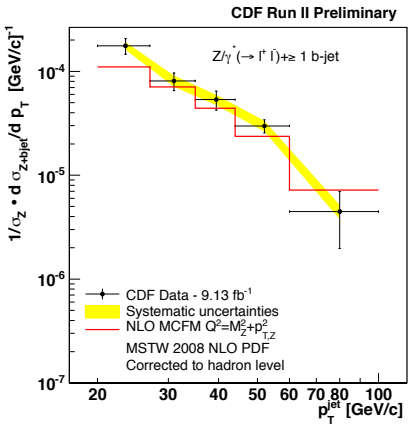
Both tree-level PS & fixed-order NLO fail

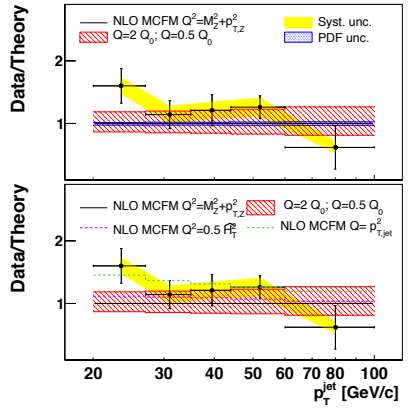
Z(ll) + jets cross sections

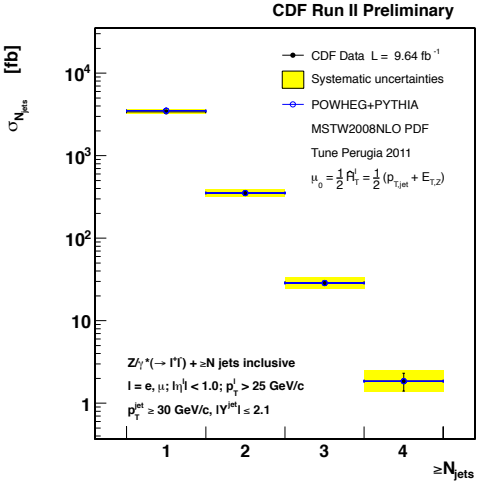
PRD 91, 012002 (2015)

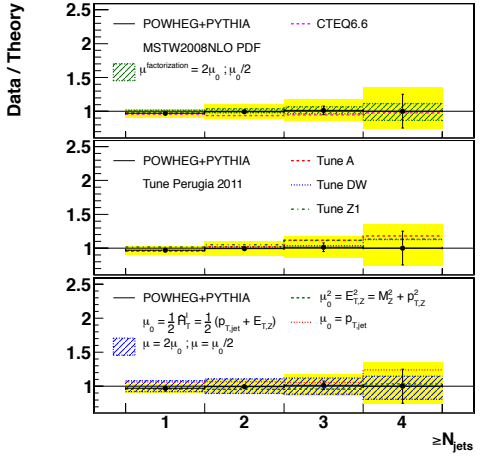


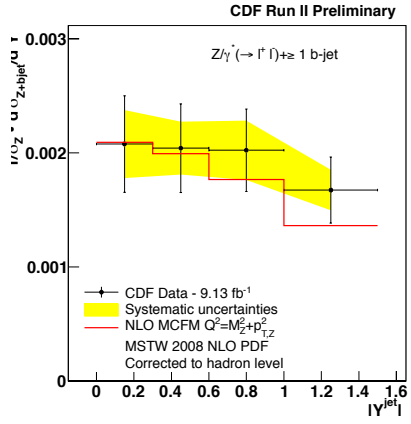


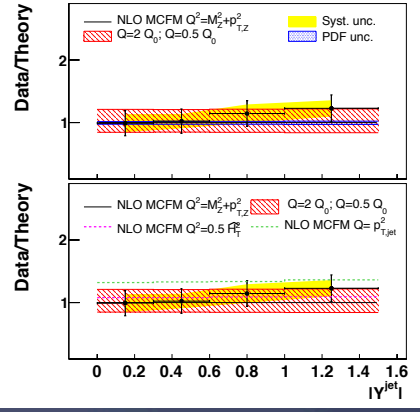








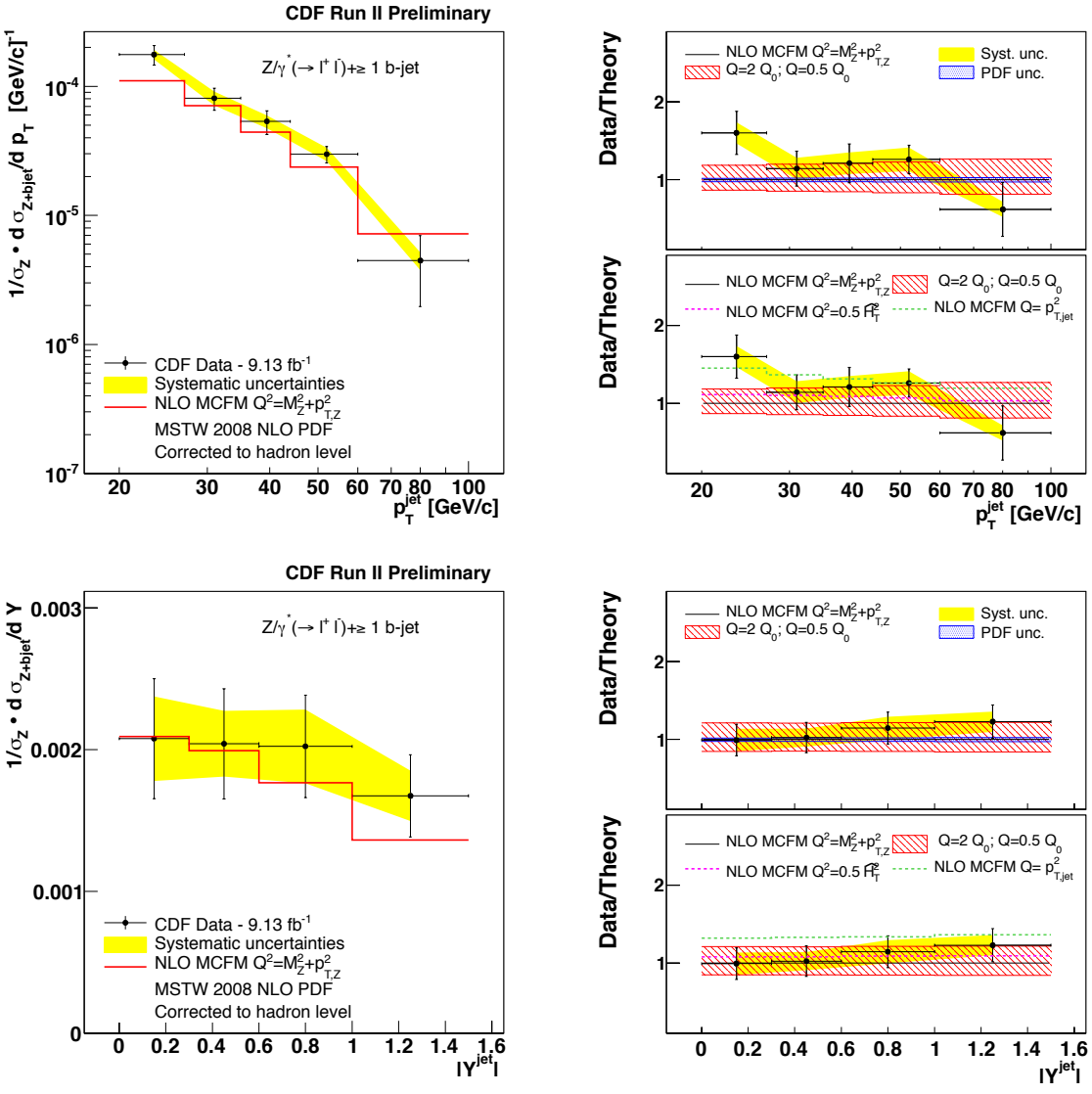




Fixed-order and PS NLO work reasonably well

Z(ll) + b cross sections

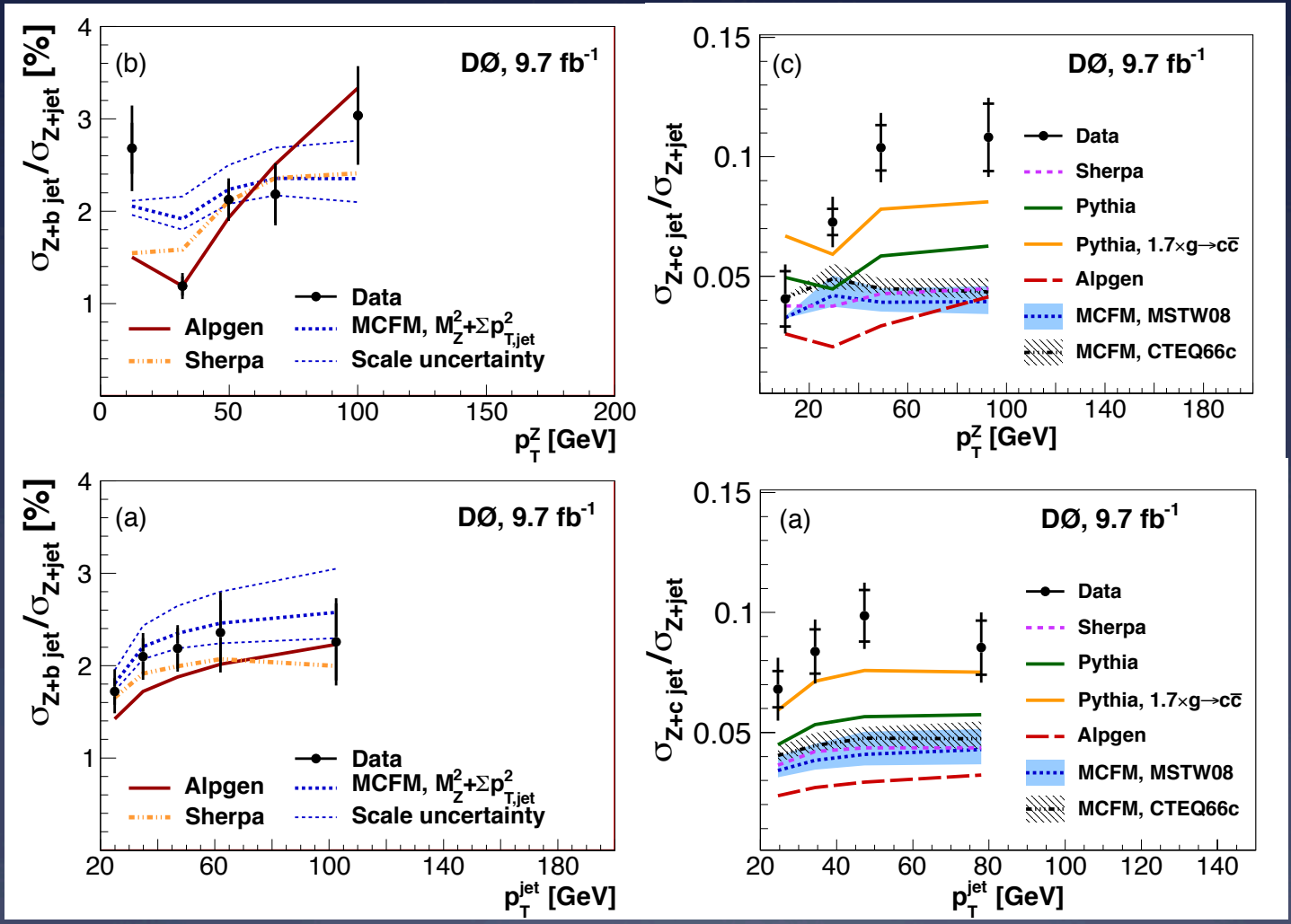
CDF public note 10594



Fixed-order NLO works reasonably well

Z(ll) + b/c cross sections

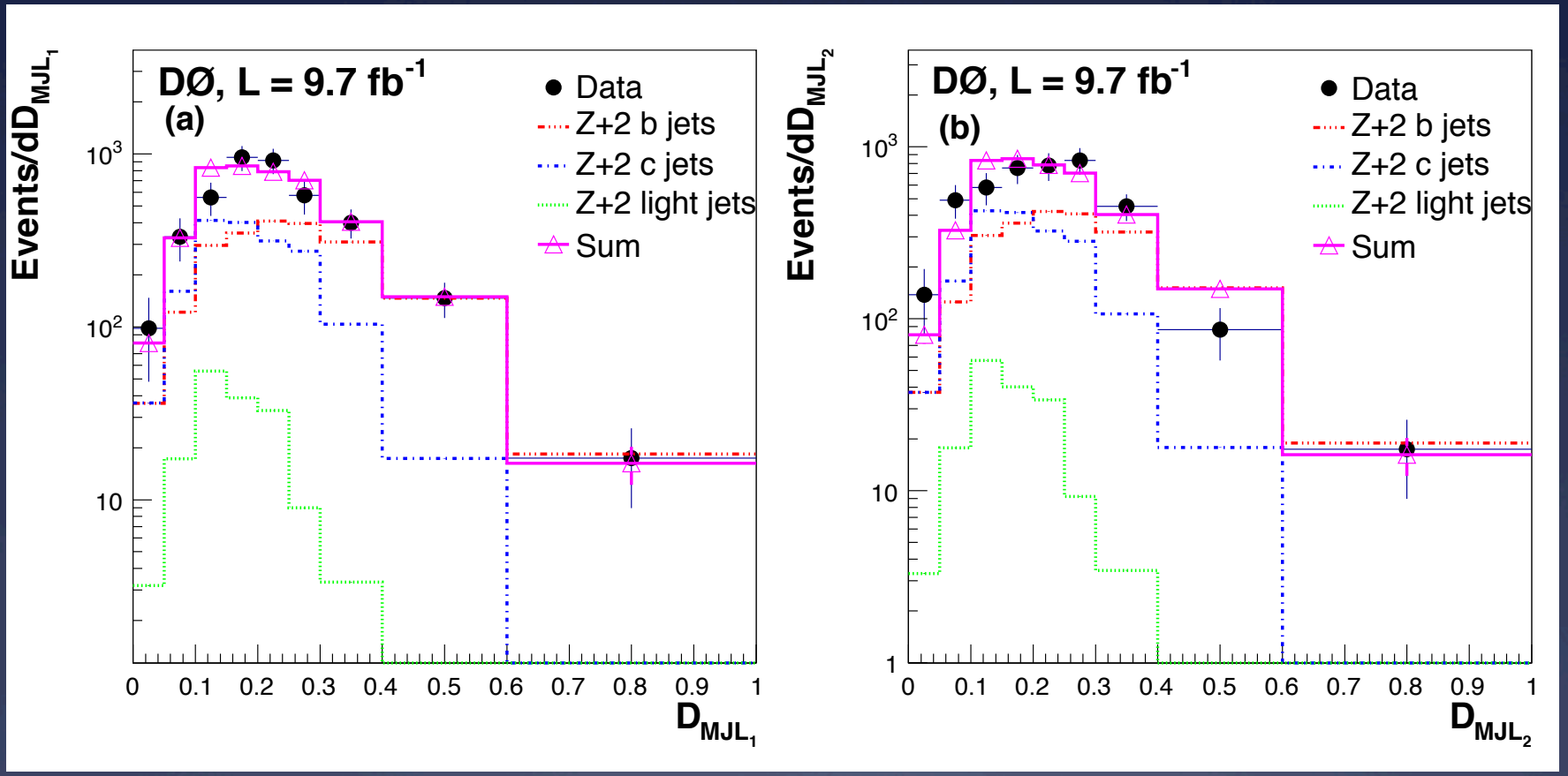
PRD 87, 092010 (2013) PRL 112, 042001 (2014)



Fixed-order NLO works well for Z+b, but not for Z+c

Z(ll) + 2b/2c cross sections

PRD 91, 052010 (2015)



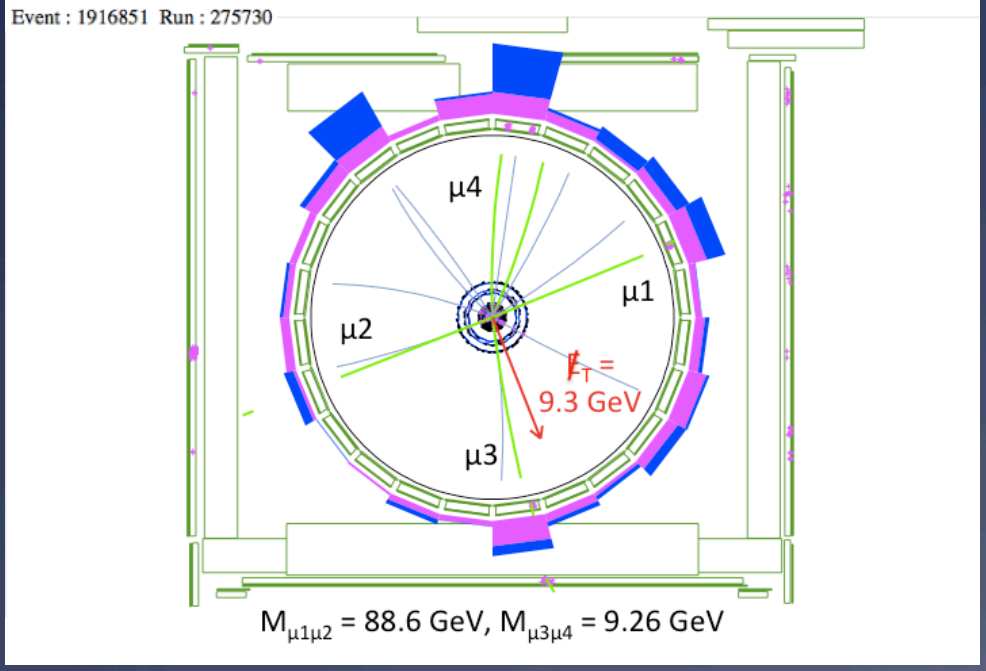
Tree-level PS describes the data

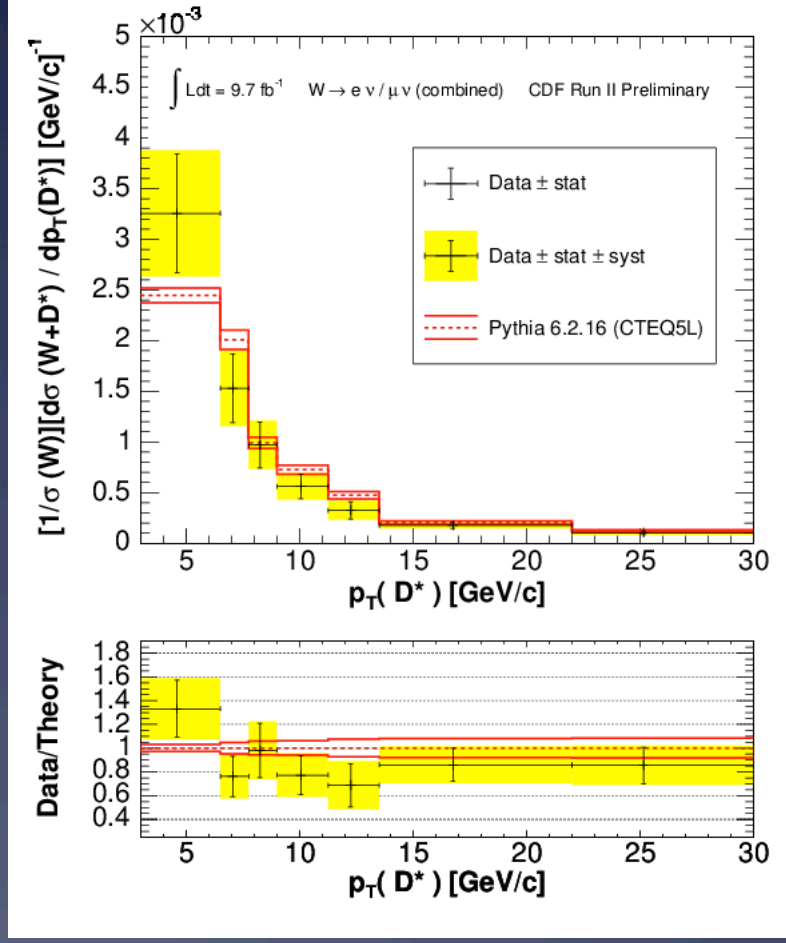
W/Z + Υ and W + D* production

PRD 91, 052011 (2015)

CDF public note 11087

	$\Upsilon + W$	$\Upsilon + Z$
Expected limit (pb)	5.6	13
Observed limit (pb)	5.6	21
Run I observed limit (pb)	93	101

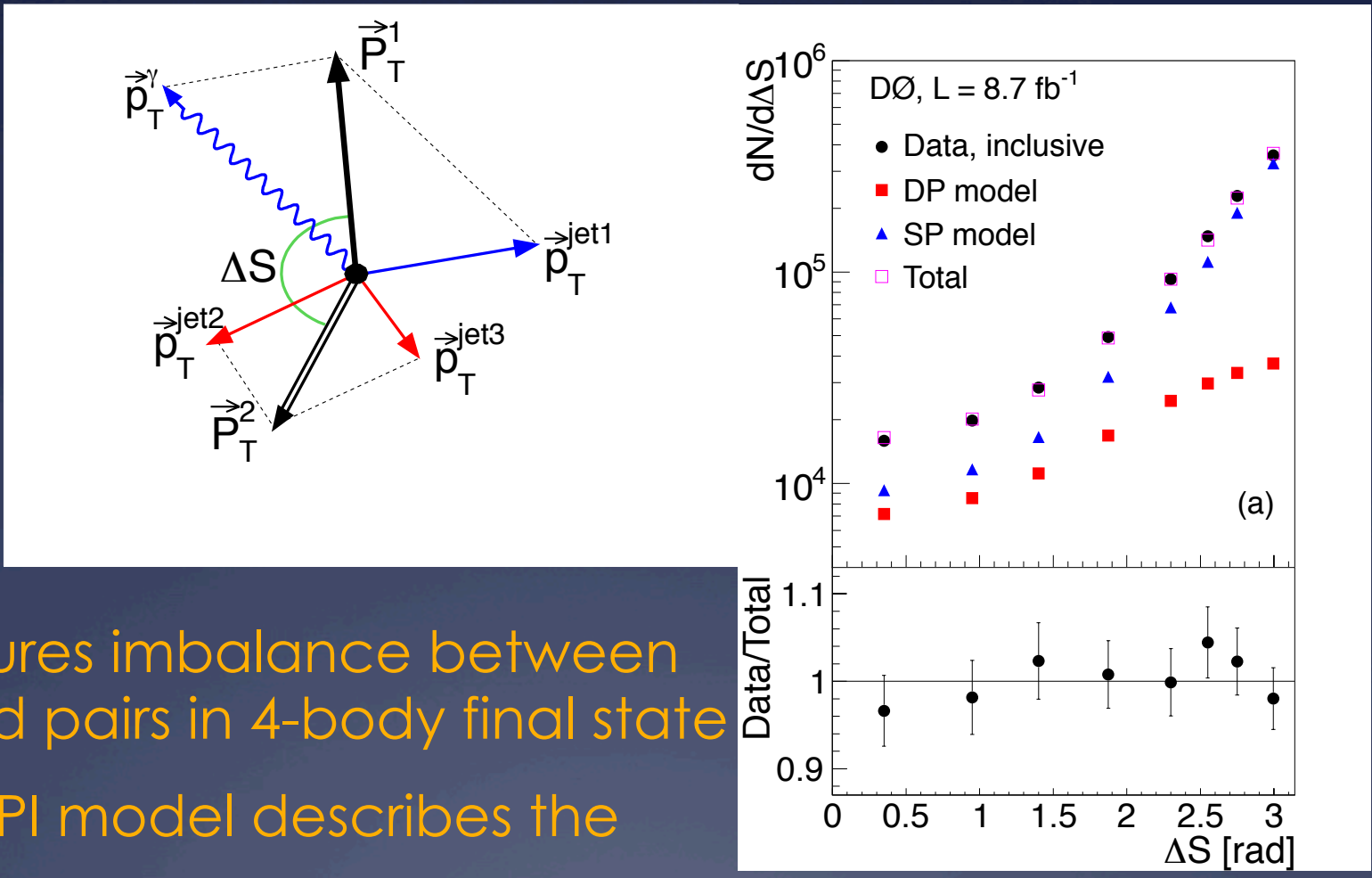




Probing long-range matrix elements in W/Z + h.f. production

DPS in γ + 3 jets events

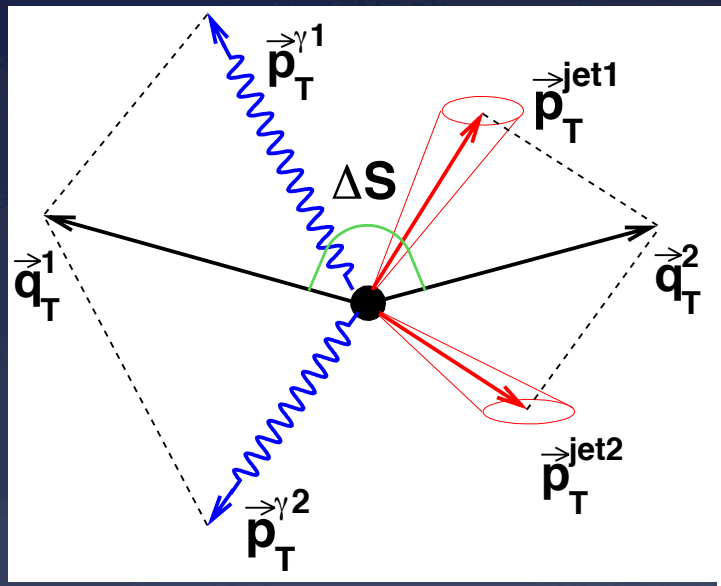
PRD 89, 072006 (2014)

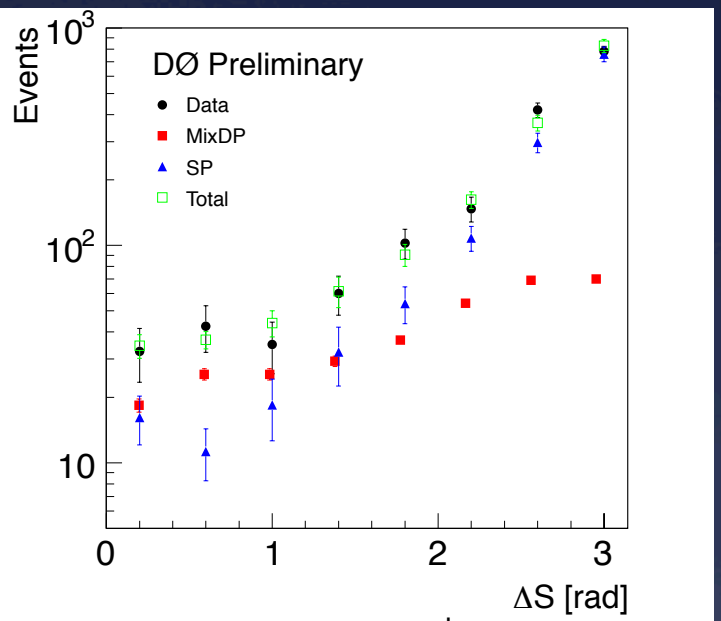


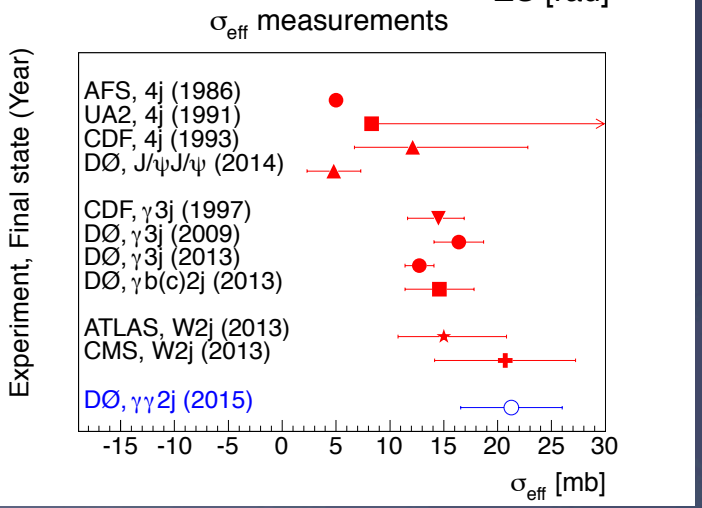
- ΔS measures imbalance between p_T-ordered pairs in 4-body final state
- Sherpa MPI model describes the data well

DPS in 2γ + 2 jets events

D0 conference note 6470



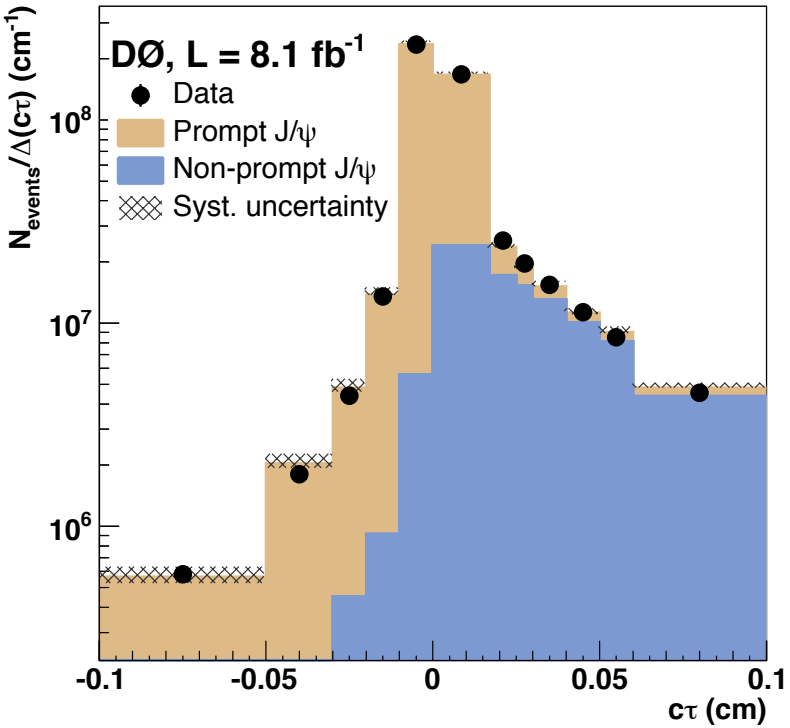


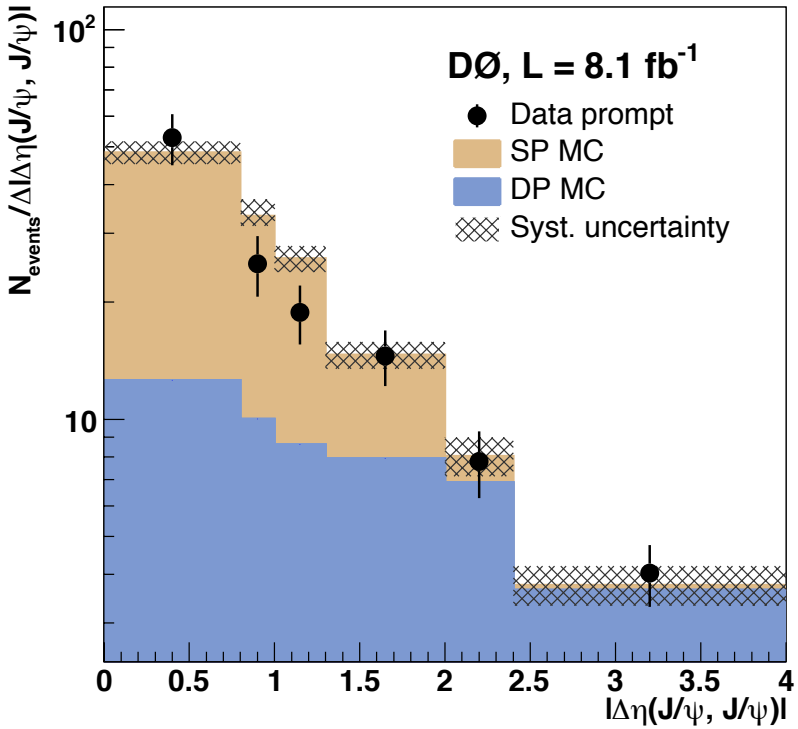


- Overlaid 2γ +2j data MixDP + Sherpa SP model describe the data well
- Consistent overall picture for $\sigma_{eff} = \sigma_{12}\sigma_{34} / \sigma_{12+34}$

DPS in J/ψ + J/ψ events

PRD 90, 111101 (2014)

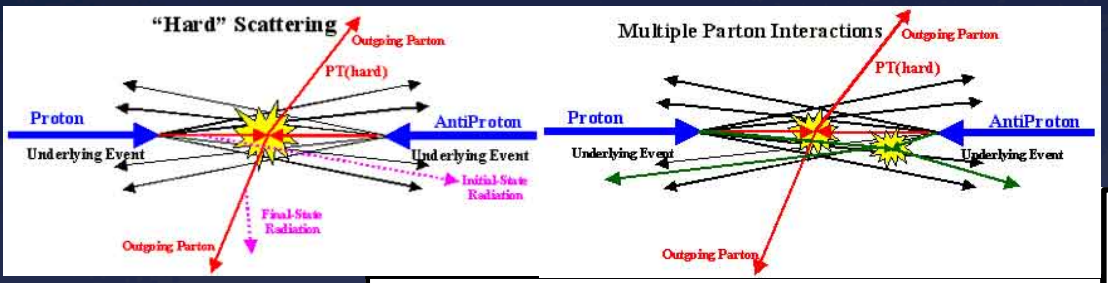




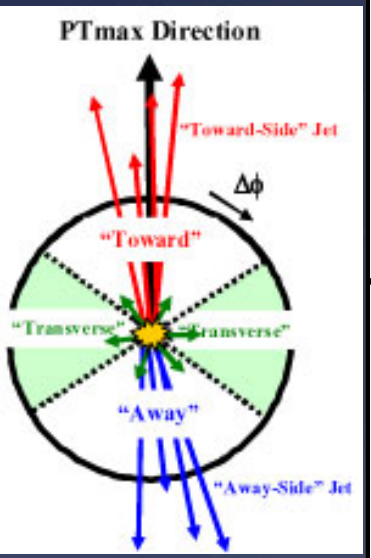
Data well described by NRQCD (DJpsiFDC+Pythia)

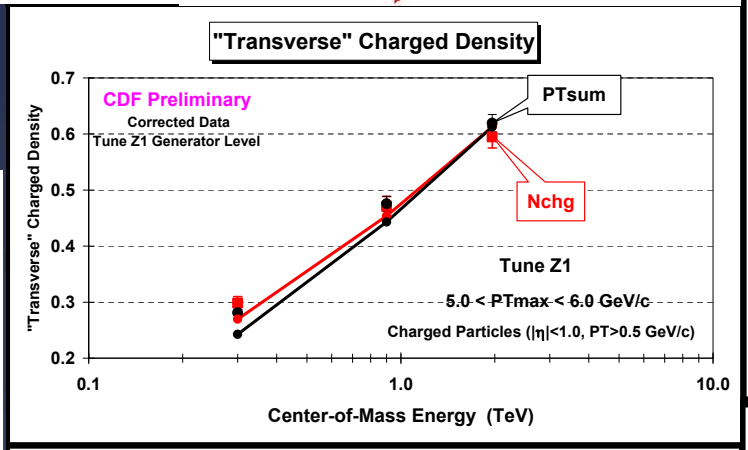
Energy scan of underlying event

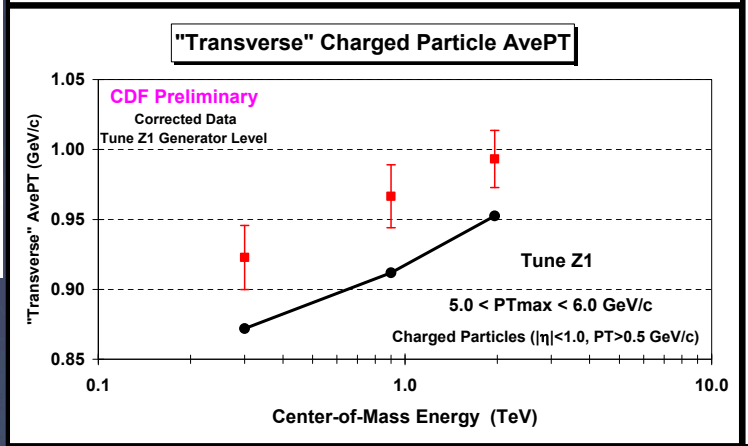
CDF public note 10874

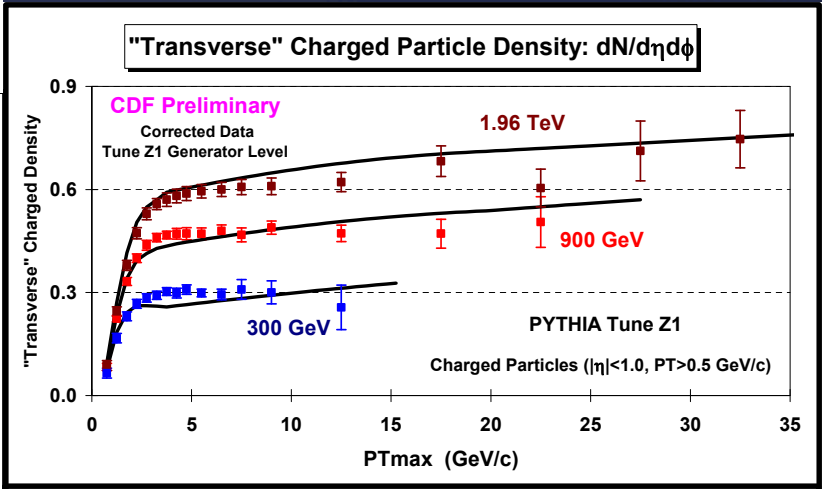


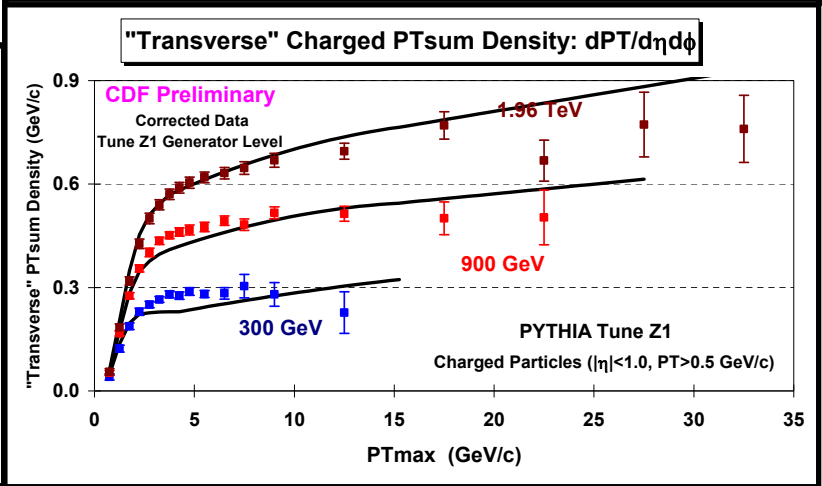
Pythia UE model works over wide energy range





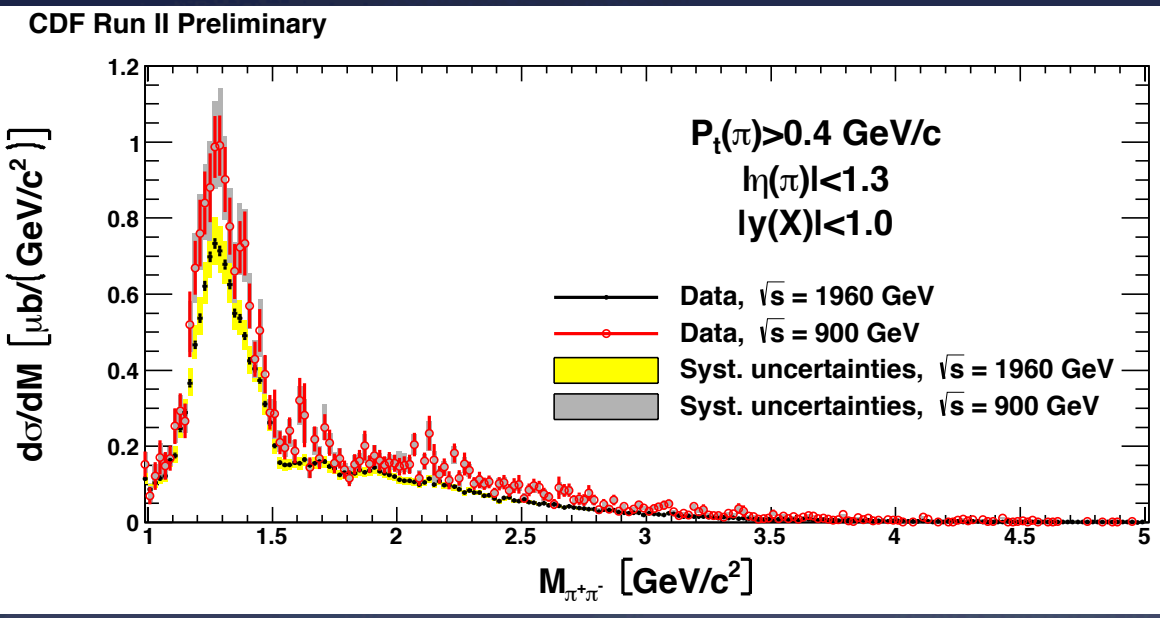


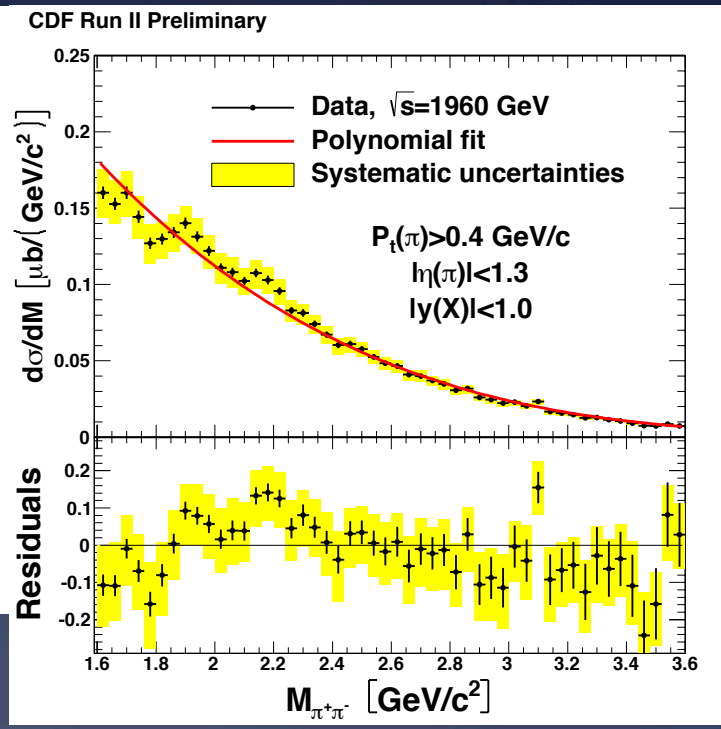




Exclusive $\pi^+\pi^-$ production

PRD 91, 091101 (2015)

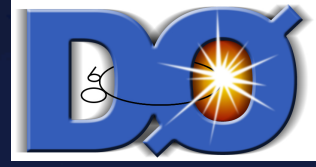




Constrains diffractive t-channel double pomeron exchange

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