Quantum Chromodynamics at the Large Hadron Collider

A (hopefully brief) Introduction

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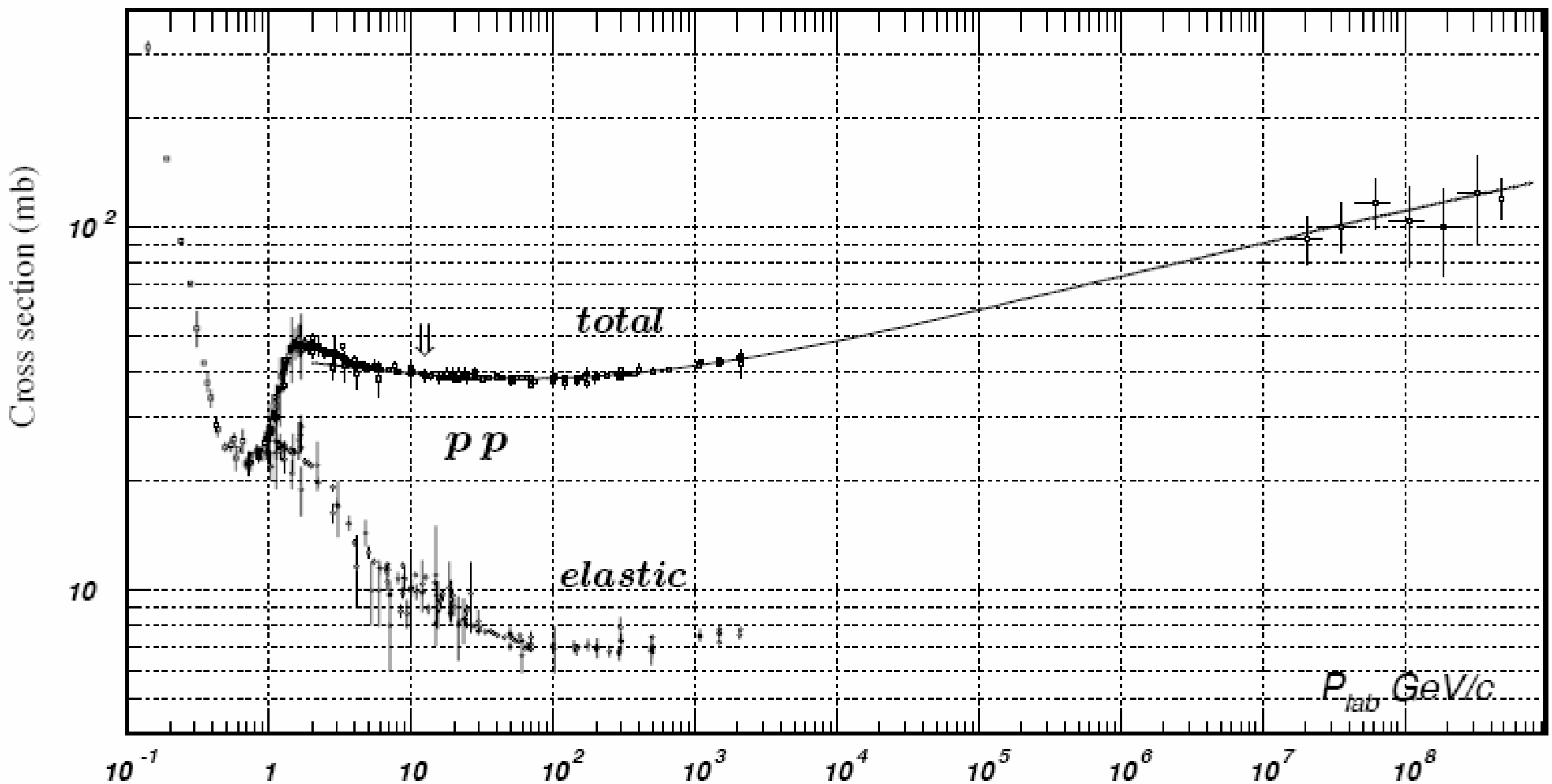
Major Goals of QCD Studies

- Greater precision in Standard Model parameters
  - Parton Distribution Functions
  - Strong Coupling Constant
- … Leading to background reduction in other processes
- New Physics beyond the SM

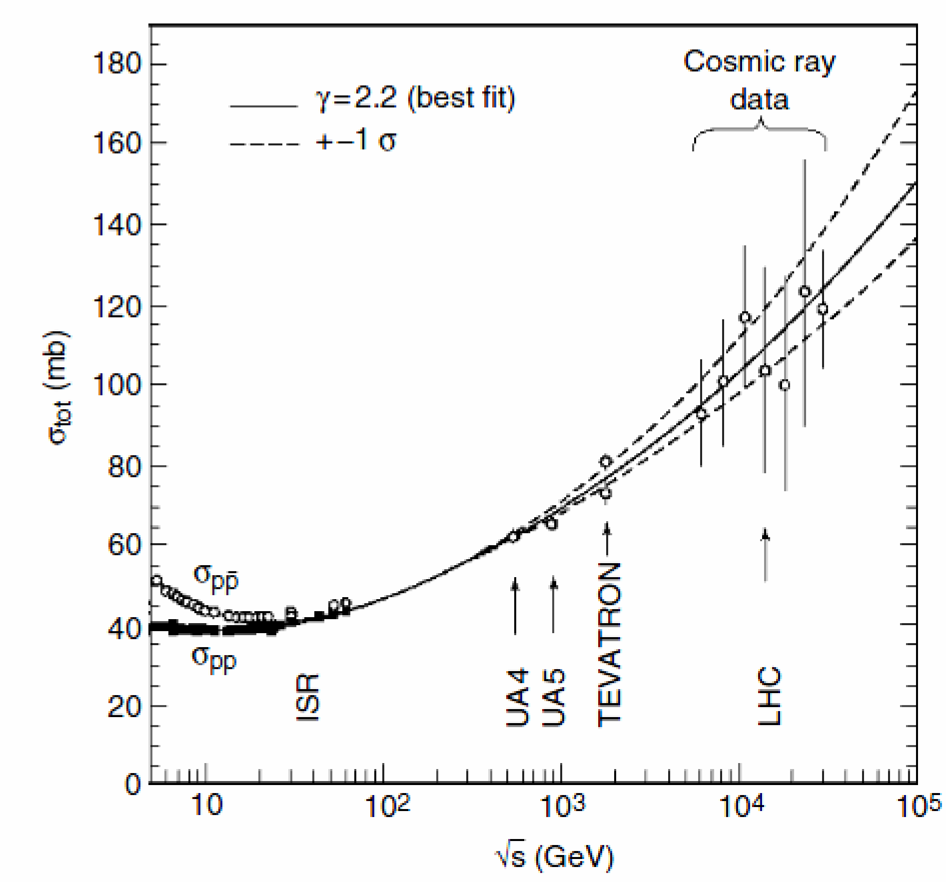
Challenges of QCD experiments

- Inability to directly observe hadronic decay products
- Breakdown of perturbation theory for low-energy interactions

Total p-p cross section



p-p σ_{tot} - Current Limits



- Interpolation between accelerator (Tevatron) and cosmic ray data

$\sqrt{s}$ (TeV)	σ_{tot}^{pp} (mb)
0.55	
Fit	61.8 ± 0.7
UA4	62.2 ± 1.5
CDF	61.5 ± 1.0
1.8	
Fit	76.5 ± 2.3
E710	72.8 ± 3.1
CDF	80.3 ± 2.3
E811	71.7 ± 2.0
16.0	
Fit	111.0 ± 8.0
40.0	
Fit	130.0 ± 13.0

P´erez-Peraza et. al., Proton–proton total cross-sections at HE from accelerator data, 2005

p-p σ_{tot} – Measurement Prospects

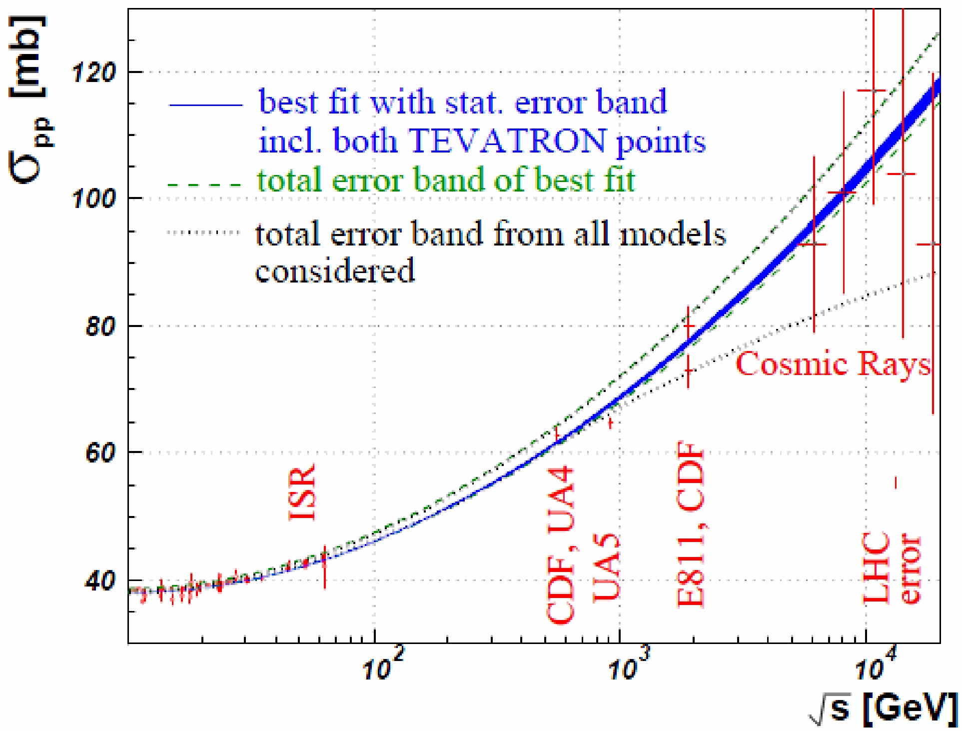


Figure 5. Predictions for total *pp* cross sections [3], including ISR and cosmic ray data.

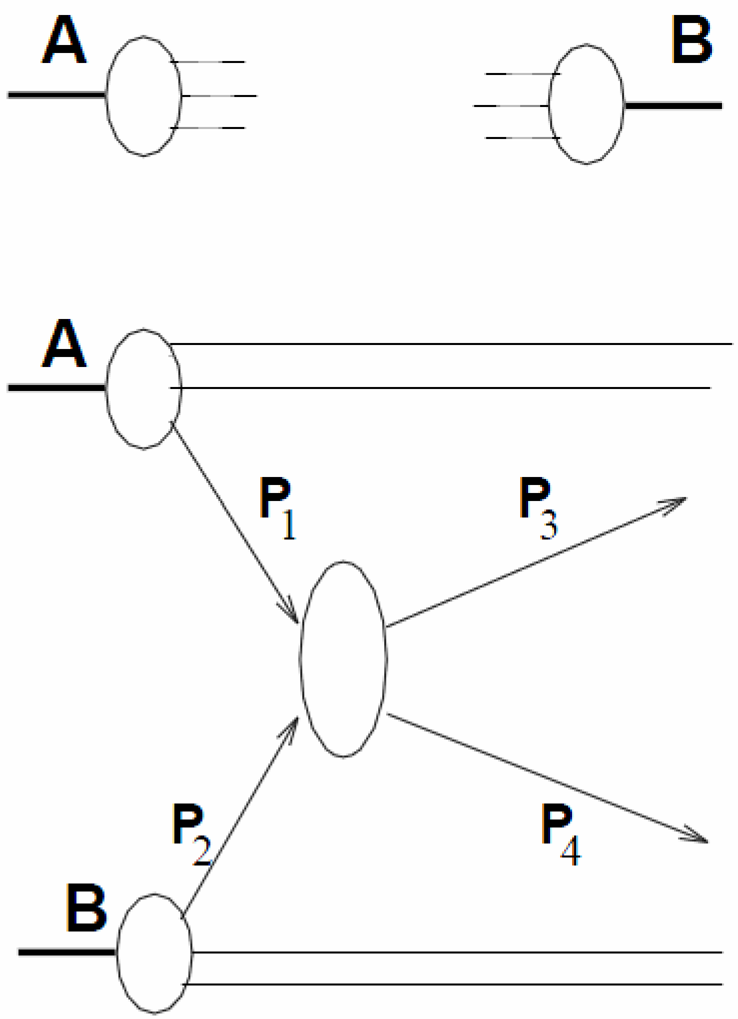
- TOTEM experiment aims to reduce uncertainty to ~1% at LHC energies

S. Lamia, arXiv:hep-ex/0612049v1 21 Dec 2006

Proton Collisions – Hard Scattering

- Best understood strong interactions are high-energy single parton interactions

Proton Collisions - Jets



A + B $\longrightarrow$ jet + jet + X

- Primary background for all other processes

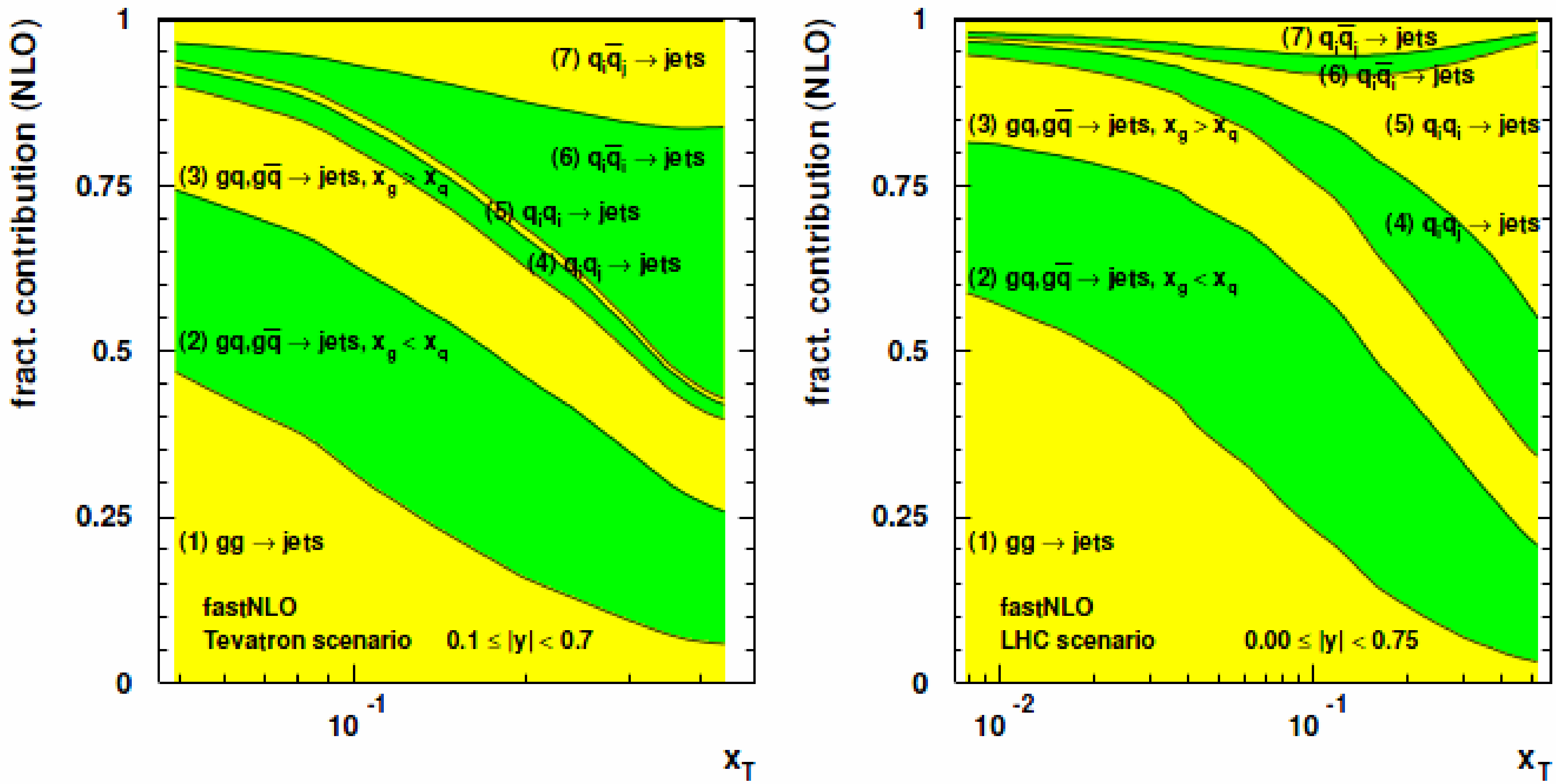


Figure 7.1: Decomposition of the total jet cross section into the partonic processes for $p\bar{p}$ collisions at the Tevatron (left) and pp collisions at the LHC (right). The fractional contributions are shown versus the scaling variable $x_T = 2p_T/\sqrt{s}$.

CMS TDR 8.2, 2006

Estimated cross section by process

Luminosity = 10^{33} $cm^{-2}s^{-1}$

Process	$\sigma(nb) \equiv$ # of events/sec	events/yr
Total cross-sections	10^8	10^{15}
$W^\pm \to e\nu$	20	2×10^8
$Z \to e^+e^-$	2	2×10^7
$t\bar{t}$	0.8	8×10^6
$b\bar{b}$	5×10^5	5×10^{12}
central jets ($P_T > 10GeV$)	2.5×10^6	2.4×10^{13}
central jets ($P_T > 100GeV$)	10^3	10^{10}
central jets ($P_T > 1000GeV$)	1.5×10^{-3}	1.5×10^5

Parton Distribution Functions

- A dependency (along with α_s) of the cross section for all other LHC processes
  - Weak processes dominated by low momentum ($x < \sim 0.1$) distributions
  - Dominates uncertainty in high-E_T (> ~2TeV) jet analysis
- Determined from a combination of hadronic scattering processes:
  - Jet and direct photon production best determine gluon distribution
  - Semi-lepton final states best determines quark/antiquark distribution

Tricoli, Parton Densities at the LHC, 2008

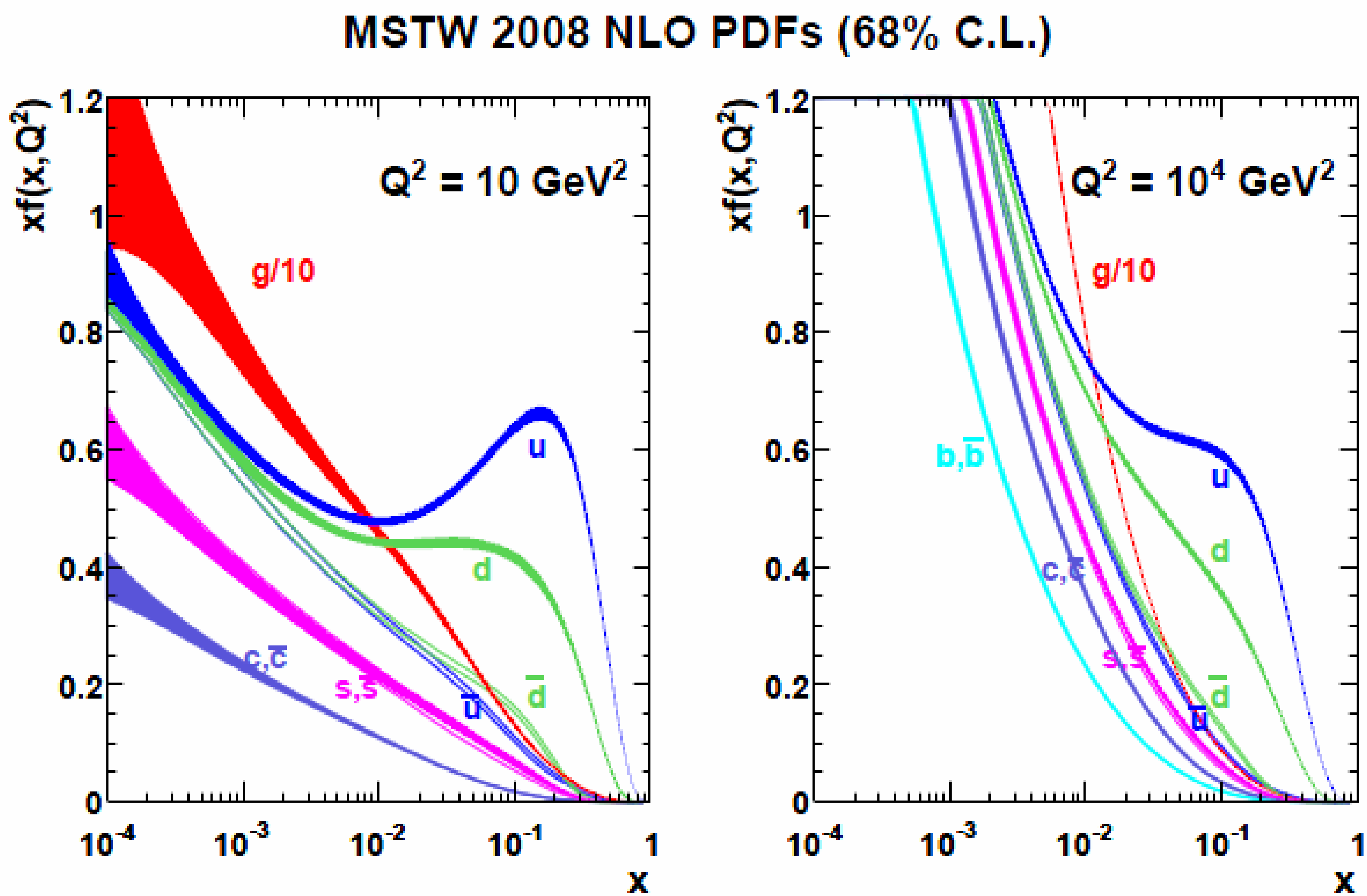
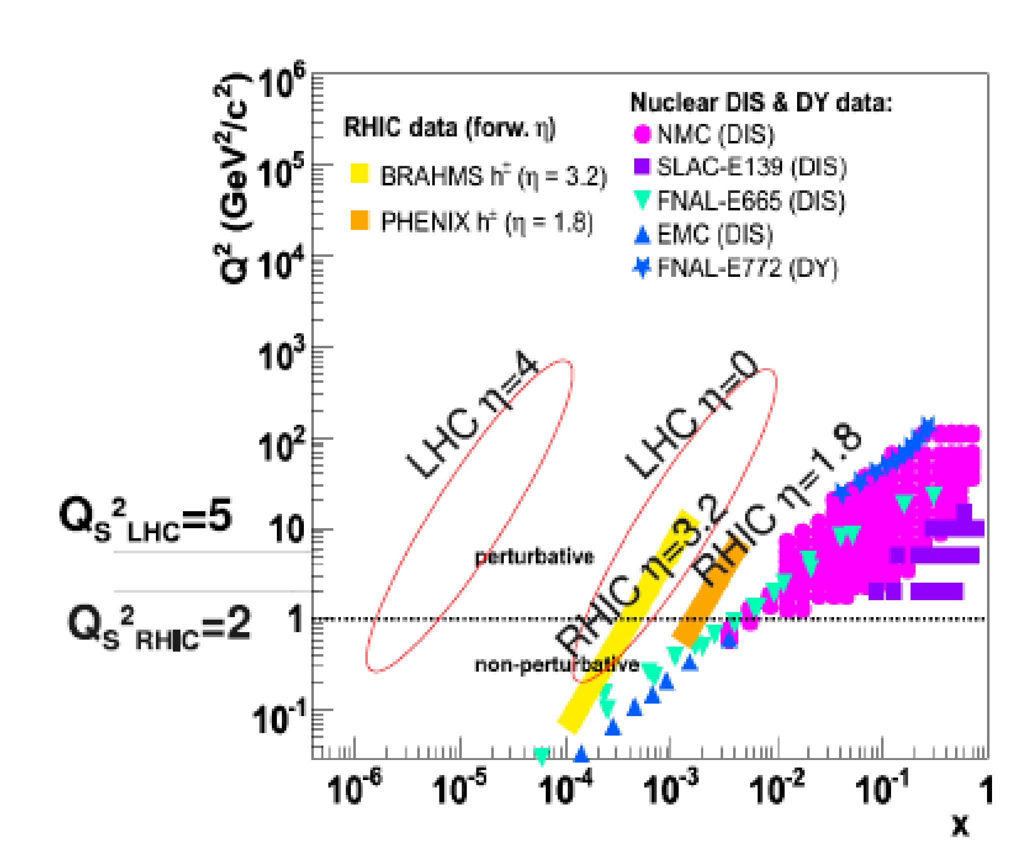


Figure 1: MSTW 2008 NLO PDFs at $Q^2 = 10$ GeV^2 and $Q^2 = 10^4$ GeV^2.

PDF Measurements at the LHC

- New constraints on PDF uncertainties:
  - Inclusive Jet Production
  - Prompt photon production
  - W boson rapidity distribution
- New constraints can be used to tighten uncertainties in Monte-Carlo simulations

Heavy Ion Experiments



The kinematic regions in x and Q2 explored by nuclear DIS and Drell-Yan experiments, by RHIC experiments, and by experiments in preparation at LHC.

Dainese, Heavy ions and parton saturation from RHIC to LHC, 2008

- Constrains low-momentum regime, particularly gluon distributions

Strong Coupling Constant

- Used in conjunction with PDFs to estimate cross sections using perturbation theory
- Most cleanly established using processes with completely leptonic final states

B Production

- Exploration of apparent inconsistency between observations and predictions of cross section
  - higher luminosities combined with higher energies yield much greater cross section for b production
- Requires careful jet analysis

CMS estimated b-tagging resolution

p_T > 170 GeV, resolutions are 13% and 6% for p_T respectively

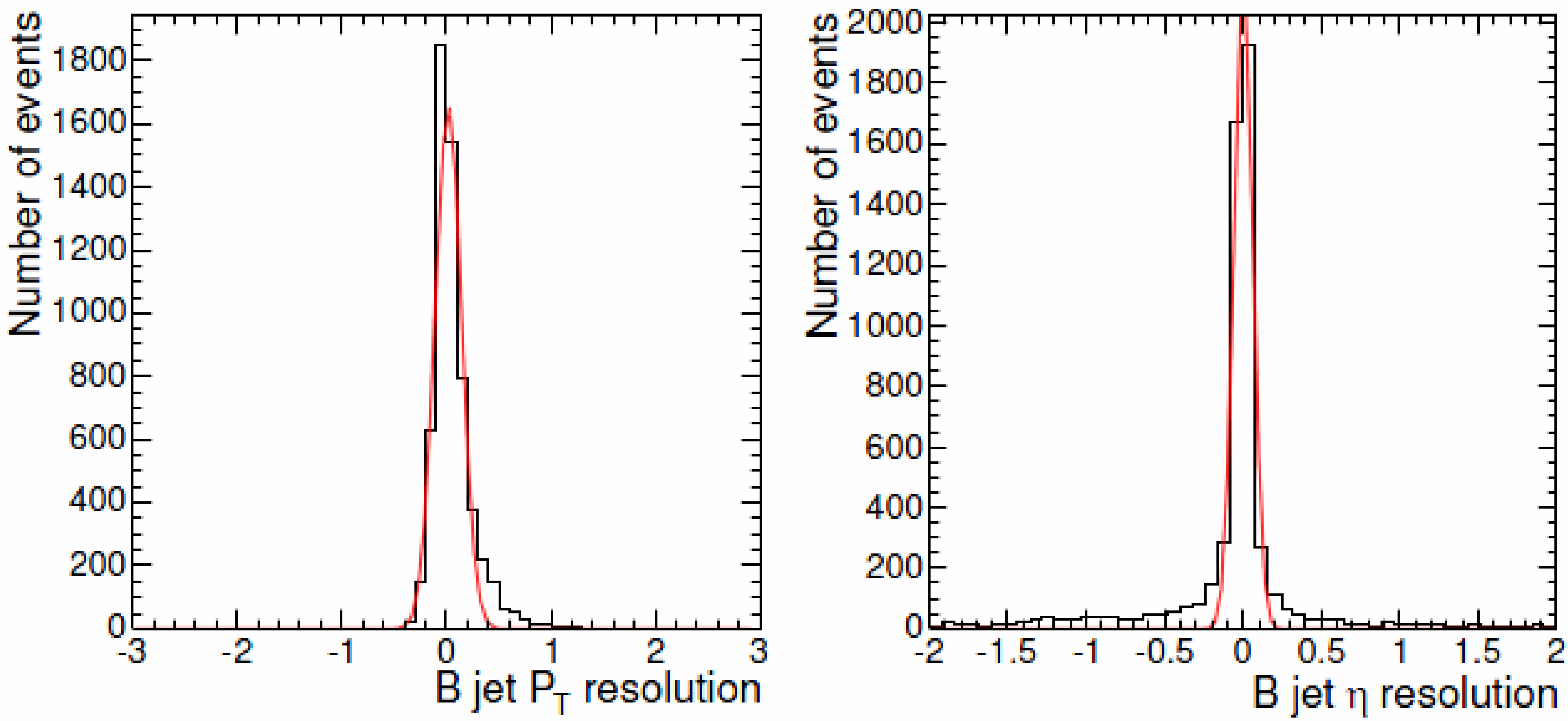


Figure 7.8: Relative resolution, (Reconstructed − True) / True, for p_T and pseudorapidity of b tagged jets in CMS.

CMS TDR 8.2, 2006

Higgs Production

- Higgs primarily produced through gluon – gluon fusion; improving gluon momentum distribution is a key aspect of QCD analysis
- $H \rightarrow \gamma\gamma$ channel irreducible background reduction

Conclusions

- QCD analyses are the essential groundwork required to understand the detectors and generally reduce backgrounds
- Better understanding of strong interactions constrains physics beyond the standard model

Acknowledgements

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