ZEUS Measurement of Inelastic $J/\psi \rightarrow \mu^+\mu^-$ Production in DIS

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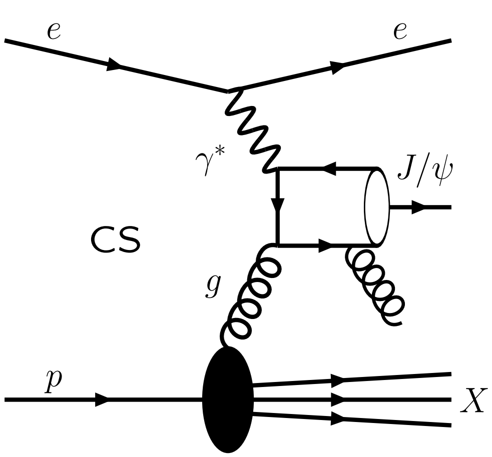
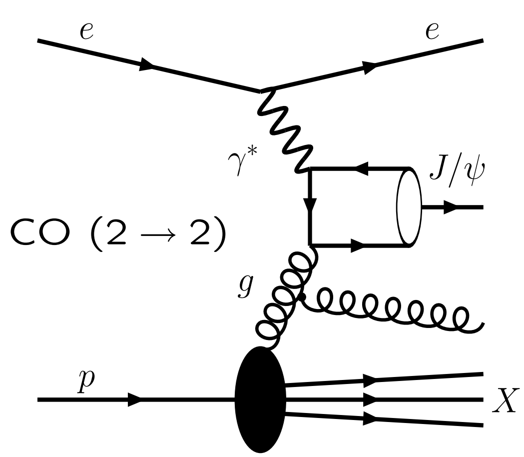
- Introduction
- Inelastic J/ψ Electroproduction
- Conclusions

Introduction

- Inelastic charmonium production =
  $c\bar{c}$ creation (short-distance scales) $\otimes$
  bound state formation (long-distance scales)
- Photon-Gluon Fusion (DIS)
  different approaches to parton dynamics and
  $c\bar{c}$ bound state formation





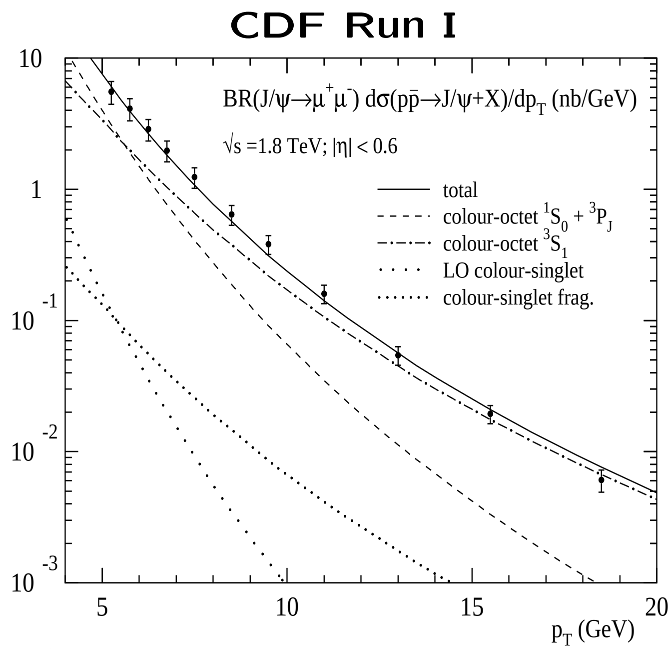
Advantages of electroproduction:
- → diffractive processes suppressed
- → resolved-photon processes suppressed
- → reduced uncertainties of perturbative calculations

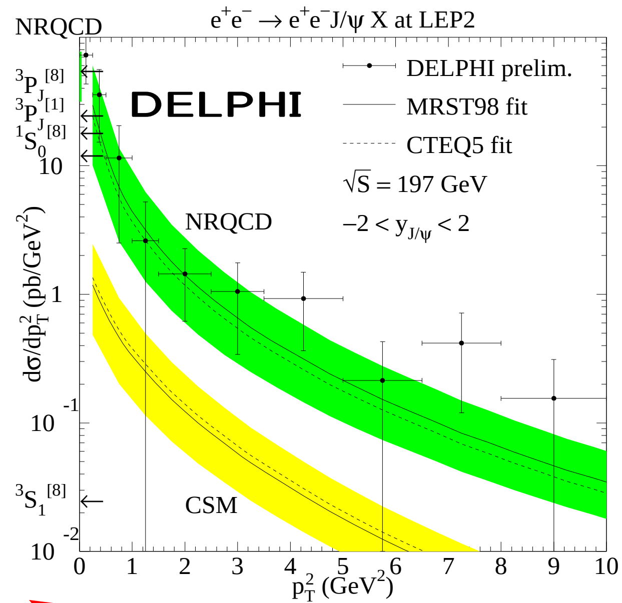
Introduction (cont'd)

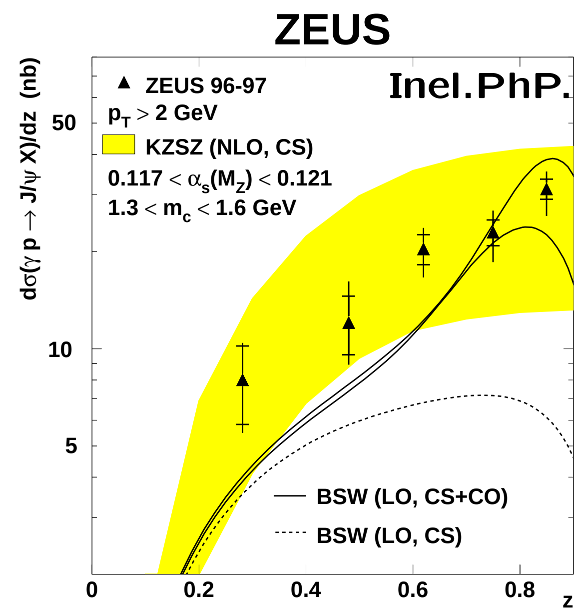
- Colour Singlet Model:
  → $c\bar{c}$ must have quantum numbers of Charmonium
  → one phenomenological parameter fixed from l^+l^- decay width
  → failed to describe high-p_T charmonia production at Tevatron by orders of magnitude ⇒ what about HERA?

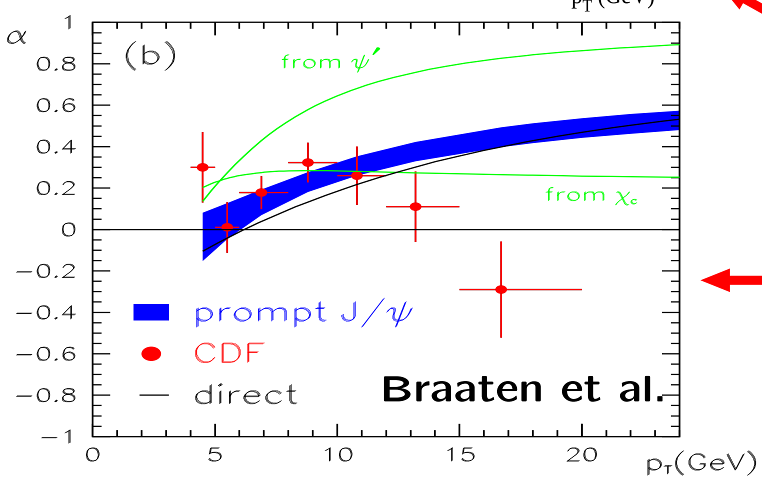
- NRQCD factorisation formalism:
  → $c\bar{c}$ in Colour Octet states must contribute to charmonium production (evolution into physical charmonium via soft gluon emission at long-distance scales)
  → "$c\bar{c} \rightarrow$ charmonium" transition parametrised using a (universal) set of Long Distance Matrix Elements; currently fixed from hadroproduction or B-decays data ⇒ can HERA data be included in this global analysis?

Motivation: World DATA vs NRQCD





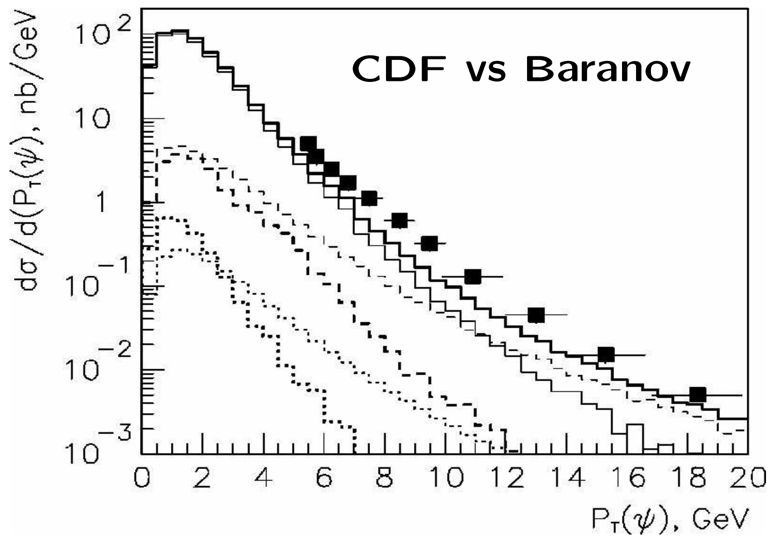


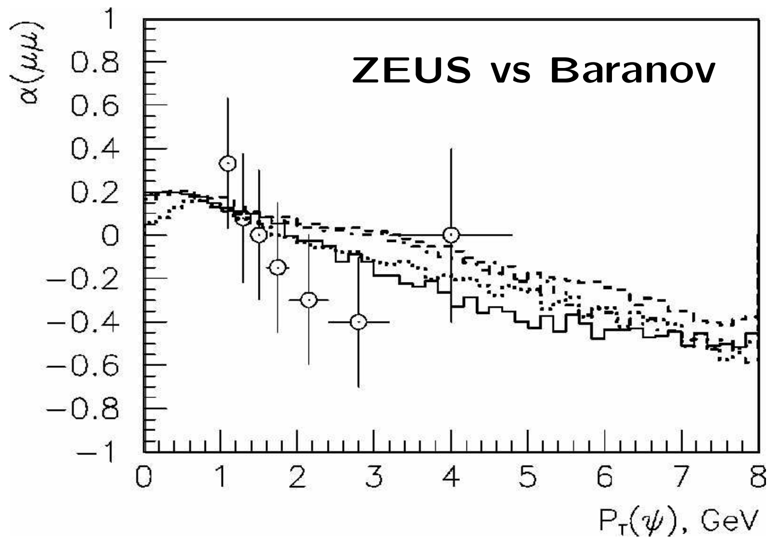


- Mainstream - NRQCD $\Rightarrow$ CO contributions: essential to describe high-p_T ψ production @ Tevatron, BUT...
- Polarisation properties?
- NRQCD factorisation holds for ψ? ME universality? ME uncertainties? Soft gluon emission under control (resummation)?

Motivation: k_T-factorisation - BFKL/CCFM

- k_T-factorisation approach:
  → non-collinear parton dynamics (BFKL/CCFM evolution equations)
  → σ = unintegrated (transverse momentum dependent) gluon densities $\otimes$ off-shell matrix elements
  → less significant CO contributions than in NRQCD
  → broader p_T spectra, specific polarisation properties
- Succeeded in describing the p_T spectra and quarkonium polarization properties measured at Fermilab and HERA.

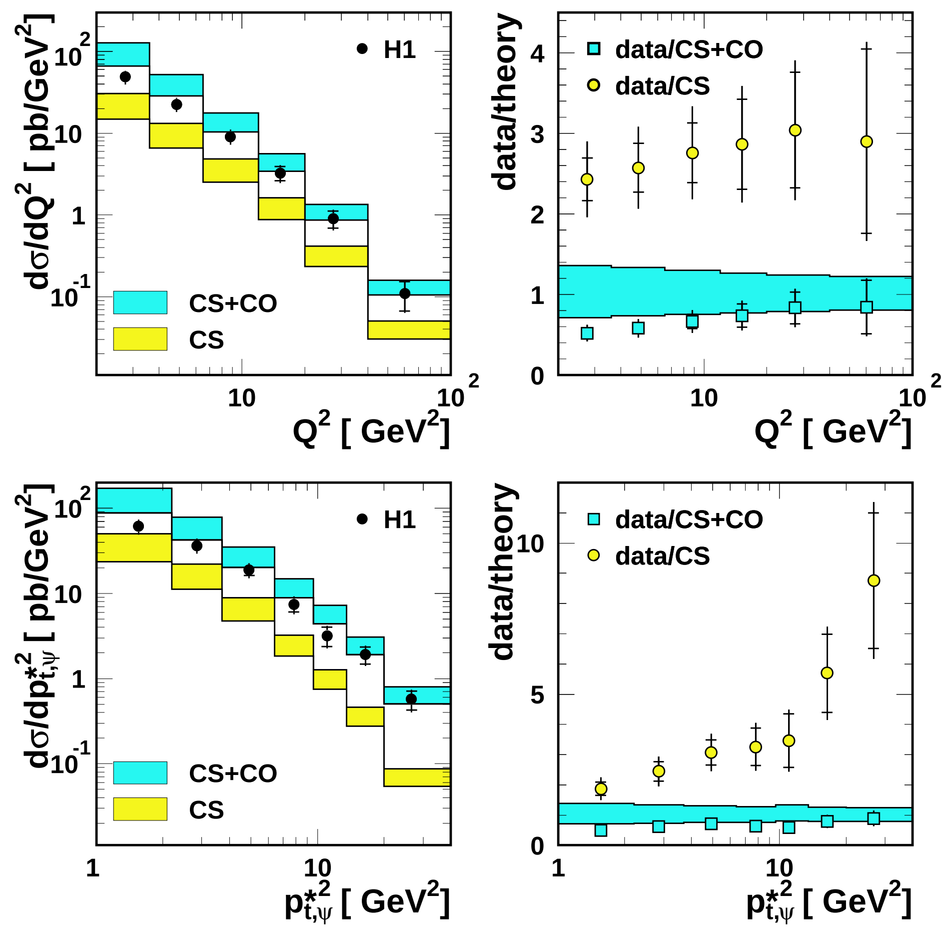




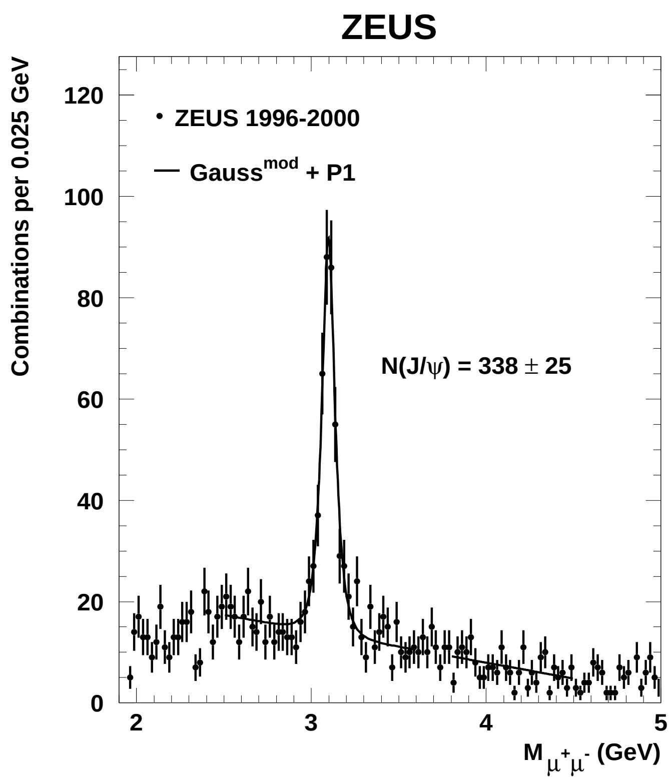
Motivation

- $e\,p \to e\,J/\psi\,X$ was believed to be a good gauge for gluon density.
- check H1 main conclusion on the same analysis: inclusion of CO contributions provides better description of shapes except for bad description of inelasticity distribution
- Search for signatures of CO, test possible alternatives $\Rightarrow$ e.g. k_t-factorization

H1 inelastic J/ψ is DIS



Analysis



The cross section for the process is

302 ± 23 (stat.) $^{+28}_{-20}$ (syst.) pb,

- Analysis of 96-00 data
  $\rightarrow$ Integrated lumi $\mathcal{L} = 109\,\mathrm{pb}^{-1}$
- The reaction $e\,p \rightarrow e\,J/\psi\,X$
  with $J/\psi \rightarrow \mu^+\mu^-$ is studied for:

$$2 < Q^2 < 80\ \mathrm{GeV}^2$$
$$50 < W < 250\ \mathrm{GeV}$$
$$0.2 < z < 0.9$$
$$-1.6 < Y_{\mathrm{lab}} < 1.3$$

z**: fraction of virtual photon energy transfered to** J/ψ **(in proton rest frame)**

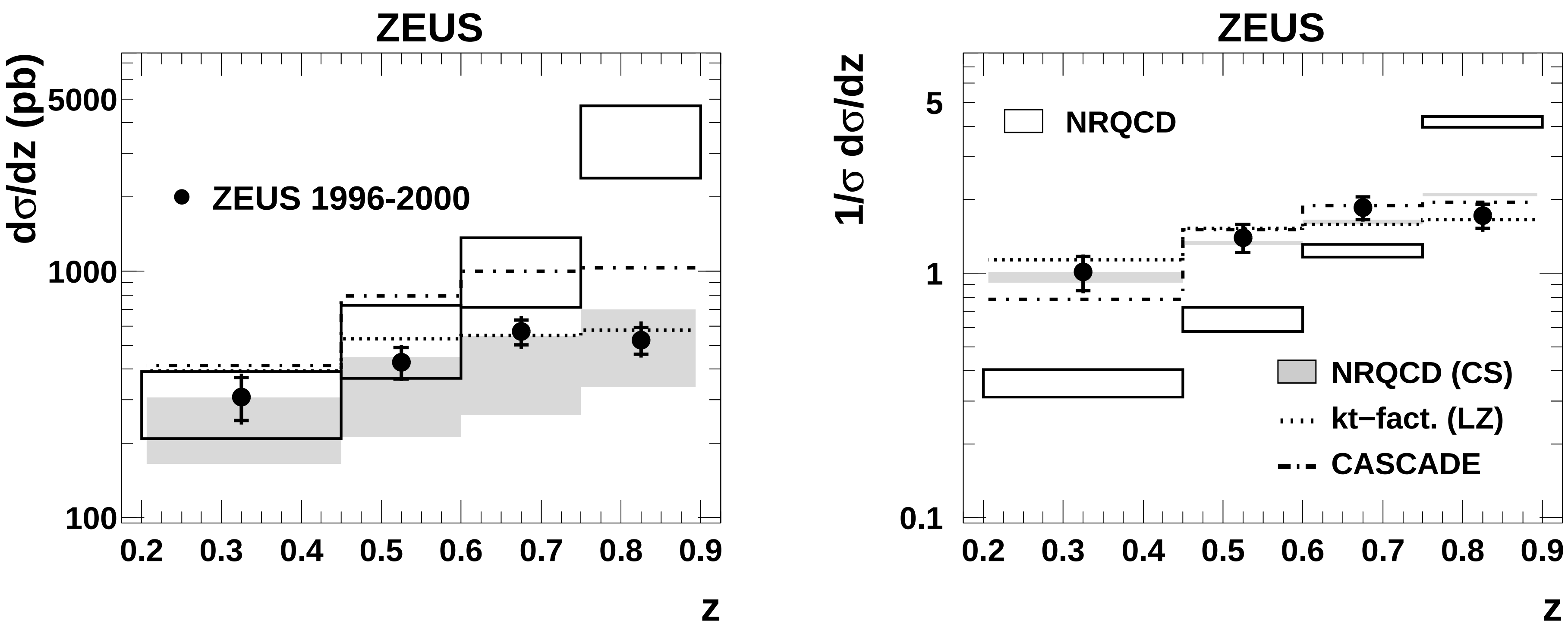
- The diffractive proton-dissociative background where estimated($\sim 6\%$) and subtracted from data.
- Data sample include contributions from ψ' and B–meson decays into J/ψ. This contributions were estimated and added to theoretical predictions.
- The contribution of χ_c radiative decays into J/ψ was neglected.

Theoretical models

- NRQCD calculations by Kniehl and Zwirner. Marked as NRQCD(CS+CO) and NRQCD(CS).

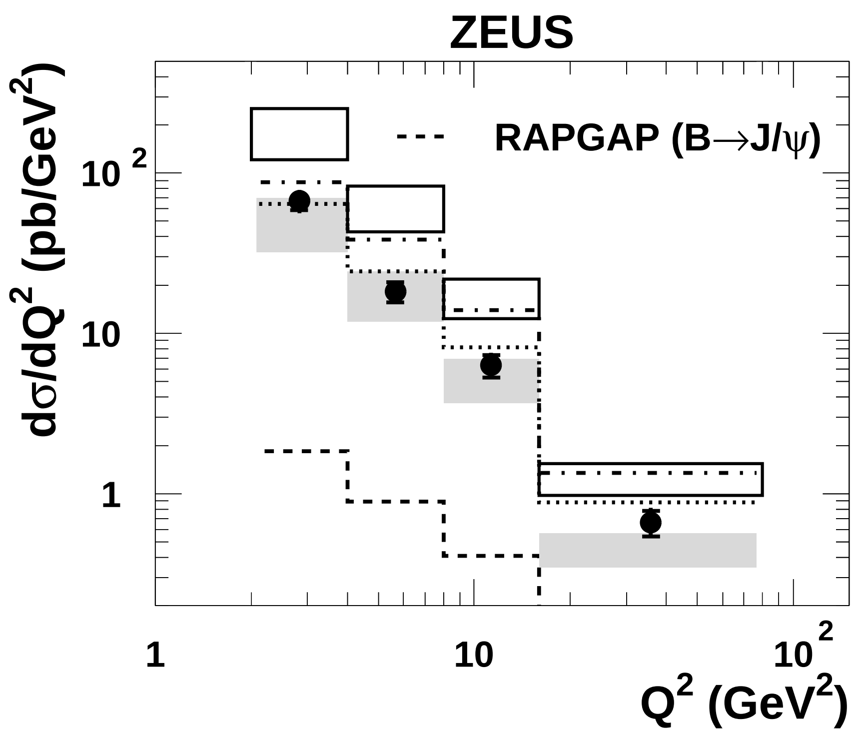
  Uncertainties (added in quadrature):
  - $\rightarrow m_c = 1.5 \pm 0.1$ GeV
  - $\rightarrow \mu = (0.5 \div 2)\sqrt{Q^2 + M_\psi^2}$
  - $\rightarrow$ PDF set MRST98LO (CTEQ5L)
  - $\rightarrow$ non-perturbative ME from hadroproduction
- k_t-factorization calculations by Lipatov and Zotov. Marked as k_t-fact.(LZ) BFKL evolution of parton cascade.
  - $\rightarrow$ KMS unintegrated gluon density, low k_T cut-off 1 GeV;
  - $\rightarrow m_c = 1.4$ GeV(KMS)
  - $\rightarrow \mu = k_T$ for $k_T > 1$ GeV, for $k_T \leq 1$ GeV the scales were fixed at 1 GeV.
- CASCADE: (MC implementation of CCFM evolution)
  - $\rightarrow m_c = 1.5$ GeV
  - $\rightarrow \alpha_s = \alpha_s(m_T)$
  - $\rightarrow$ J2003 set 2 unintegrated gluon density

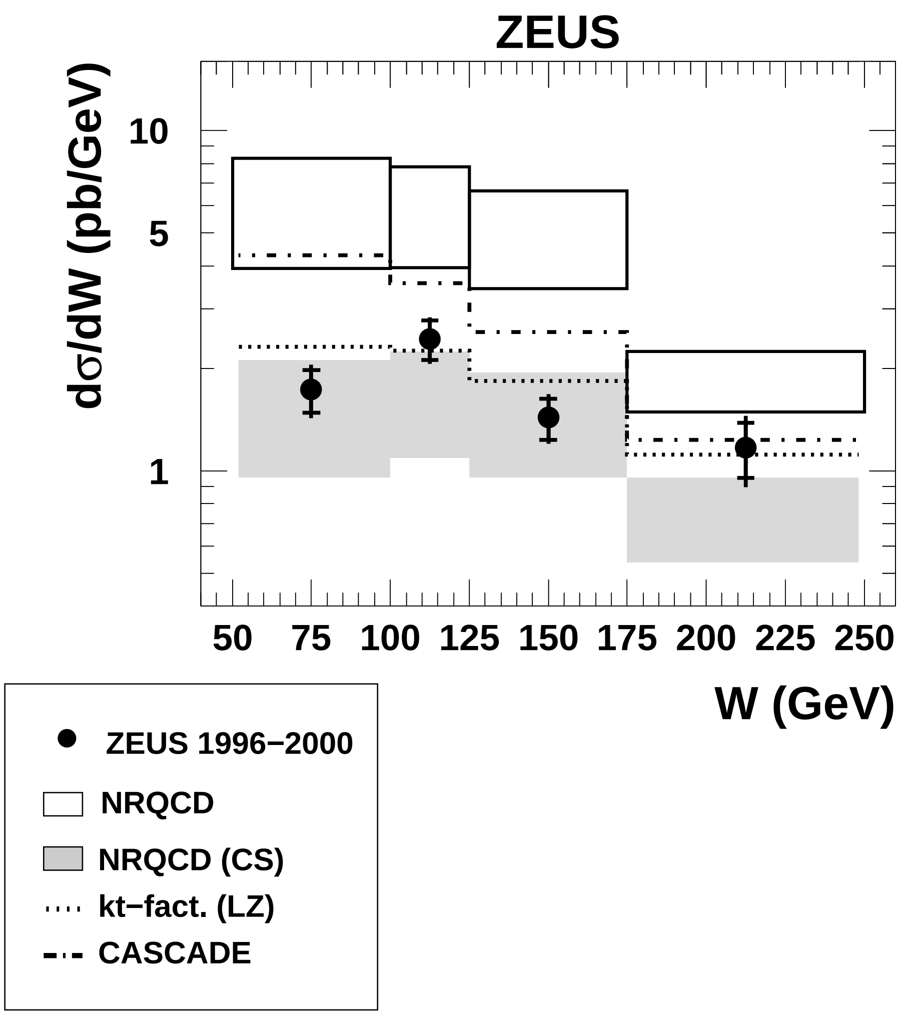
Measurements of $d\sigma/dz$ and $1/\sigma d\sigma/dz$



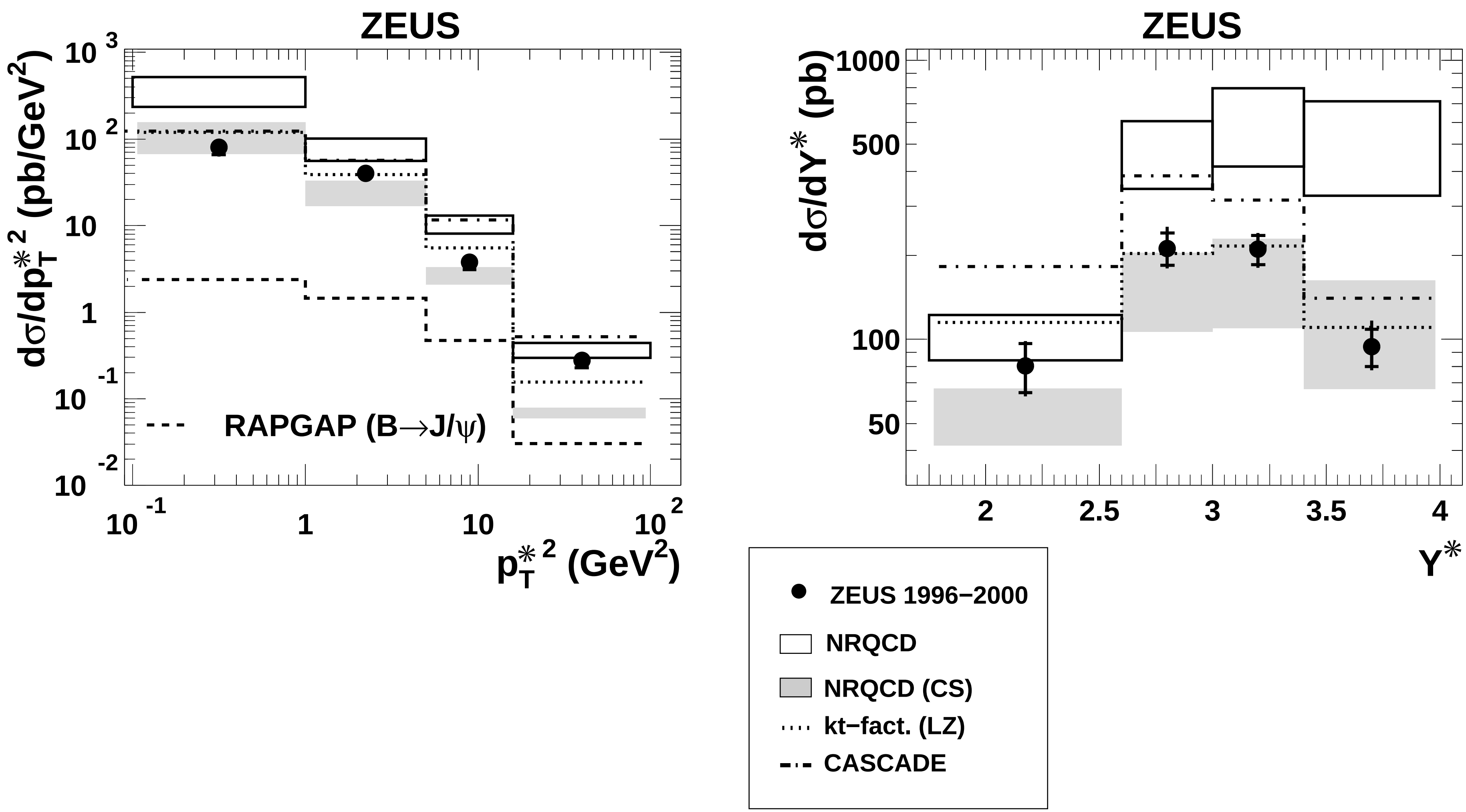
- NRQCD CS generally agree.
- CS + CO: resummation needed? higher order corrections?
- k_T-factorisation gives good description;
- CASCADE (J2003 set 2): absolute prediction overshoots data; shape reasonable.

Measurements of $d\sigma/dQ^2$ and $d\sigma/dW$

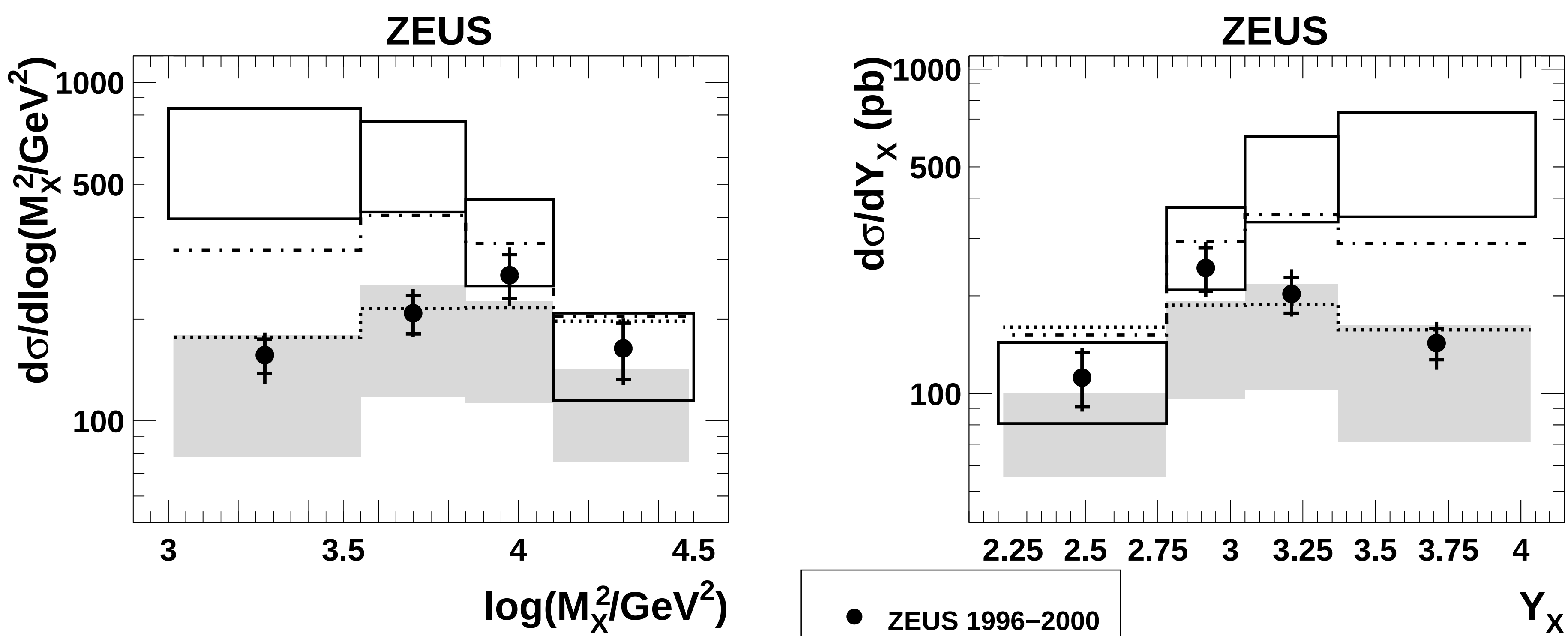


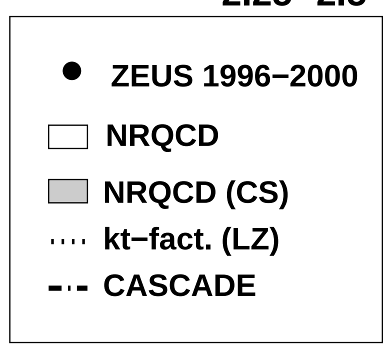


Measurements of $d\sigma/dp_T^{*2}$ and $d\sigma/dY^*$ in γp



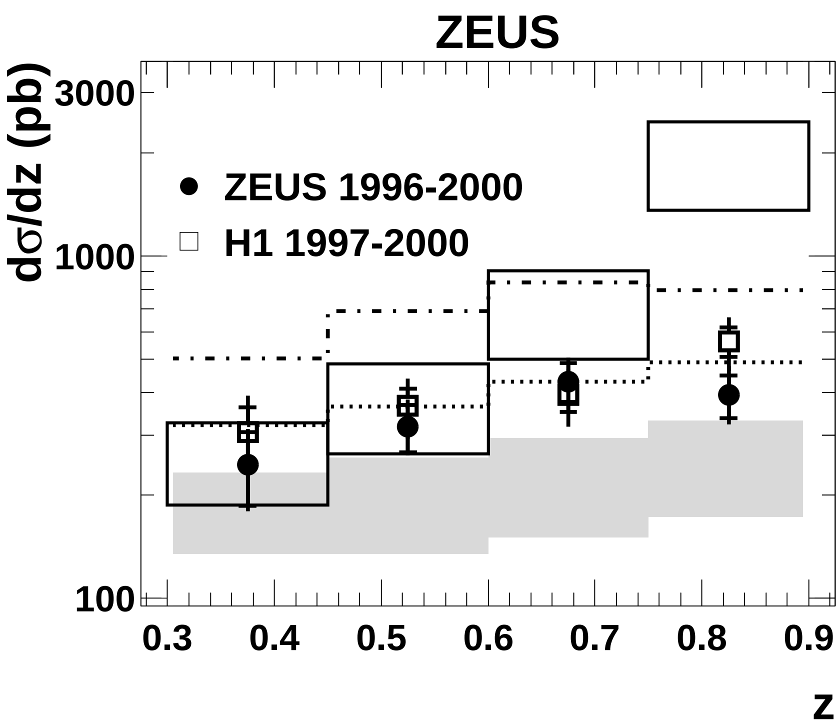
Measurements of $d\sigma/d\log(M_X^2/\mathrm{GeV}^2)$ and $d\sigma/dY_X$

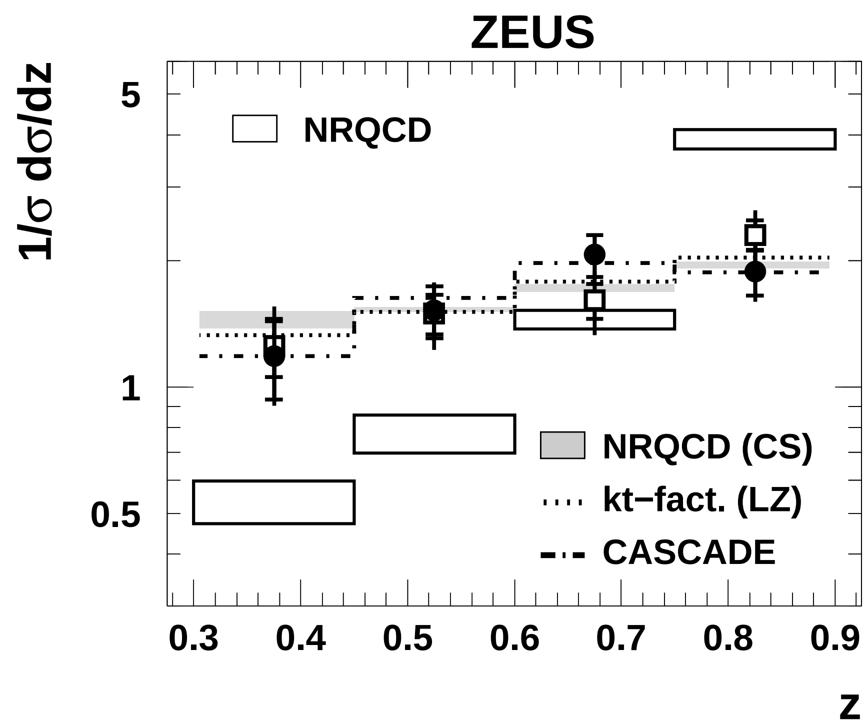




where M_X is the invariant mass of the hadronic final state

Comparison to H1 results $d\sigma/dz$ and $1/\sigma d\sigma/dz$





H1 kinematic range:

$2 < Q^2 < 100$ GeV^2

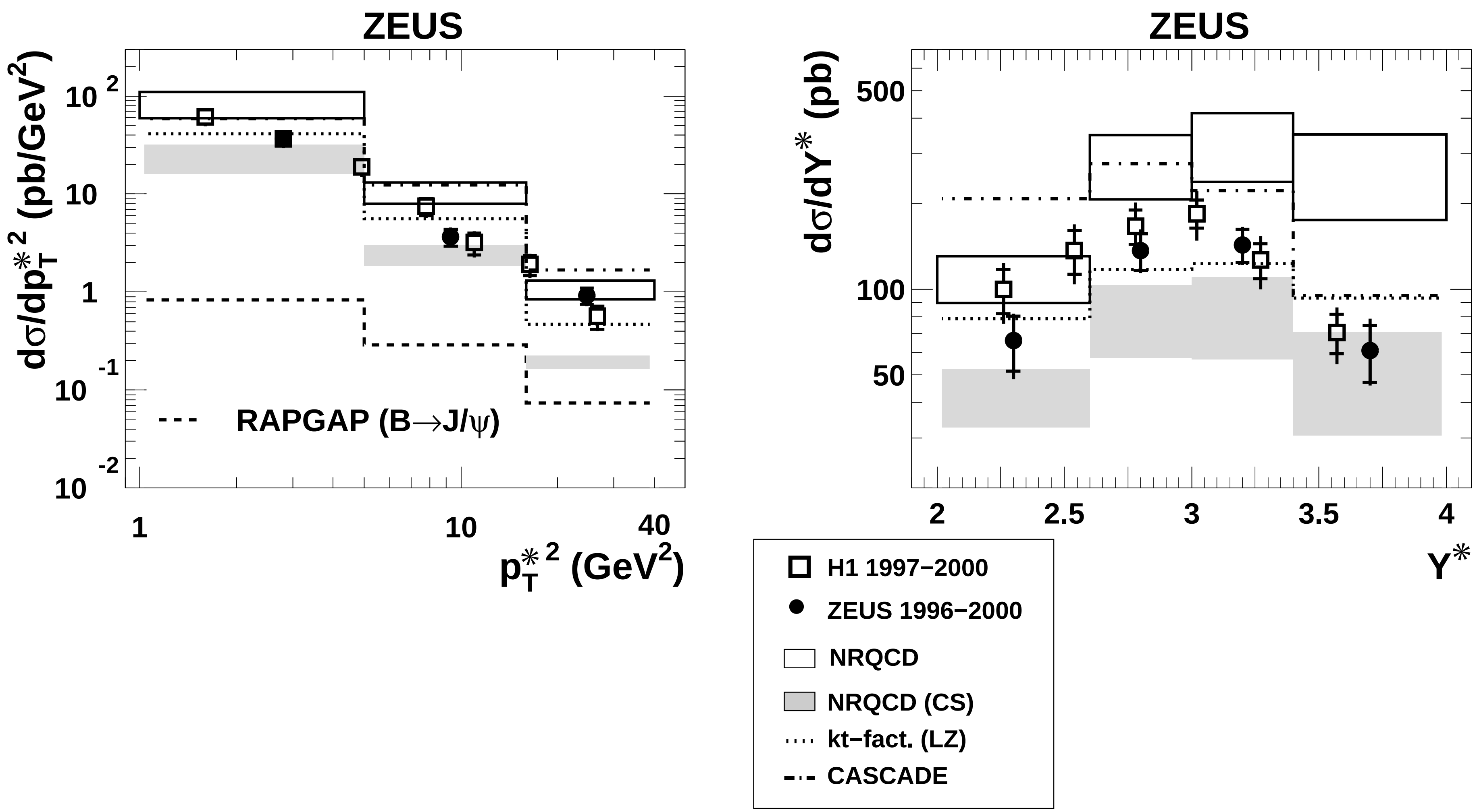
$50 < W < 225$ GeV

$0.3 < z < 0.9$

$p_T^{*2} > 1$ GeV^2

The ZEUS data are in agreement with the H1 results.

Comparison to H1 results $d\sigma/dp_T^{*2}$ and $d\sigma/dY^*$ in γp



Summary and conclusions

- New ZEUS measurement of inelastic J/ψ in DIS using complete data sample available at HERA I
- The data are in agreement with the H1 results.
- The data are compared with LO NRQCD predictions, including both CS and CO contributions, and k_T–factorisation calculations (BFKL and CCFM).
- Calculations of the CS process only generally agree with the data whereas inclusion of CO terms spoils this agreement. Also the k_T–factorisation calculations generally agree with the data. CASCADE (J2003 set 2) is above data, shapes of distributions are reasonably described except for W.
- Calculations with higher order corrections and soft gluon emission treatment needed.