Inelastic Production of J/ψ Mesons at HERA

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on behalf of the H1 collaboration

DIS conference, Florence
20.04.2010

HELMHOLTZ GEMEINSCHAFT

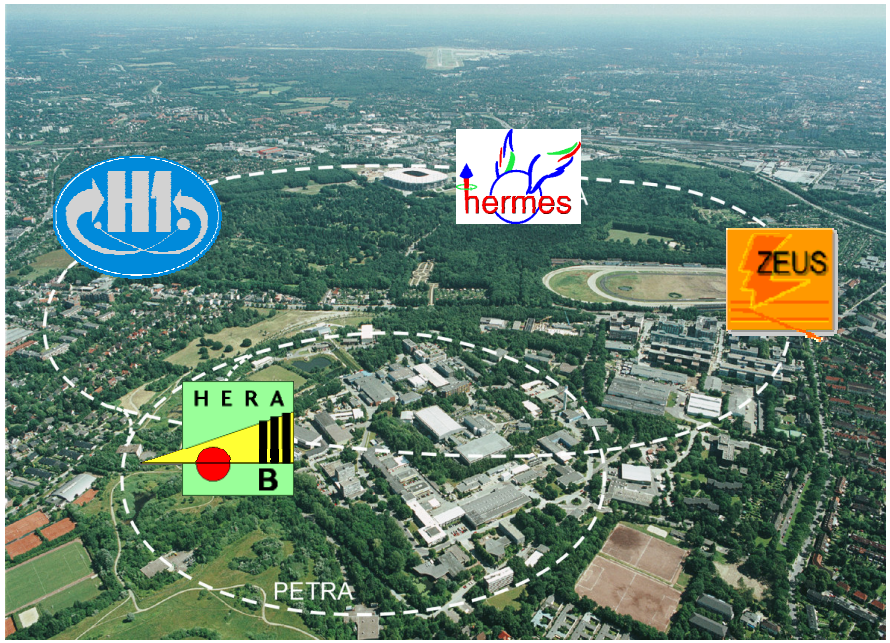
DESY 09-225, arXiv: 1002.0234[hep-ex] (submitted to EPJC)

HERA and H1

- HERA accelerator
  - ep collider

    $\sqrt{s_{ep}} \approx 318\,\mathrm{GeV}$

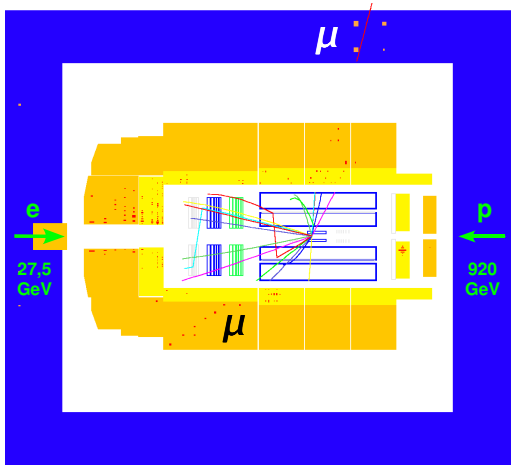
  - data taking : 1991-2007
  - int. luminosity: 1 fb^{-1} (H1 + ZEUS)

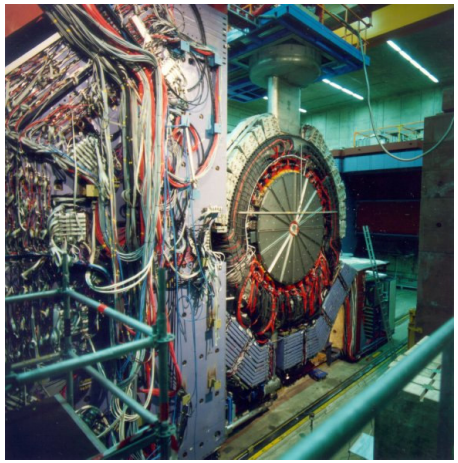


- H1 detector
  - asymmetric instrumentation

    $E_p \gg E_e$

  - 4π multi purpose detector
    - tracking system
    - em. calorimeter
    - had. calorimeter
    - solenoid
    - return yoke / muon detector





Kinematics of ep scattering

- Center of mass energy

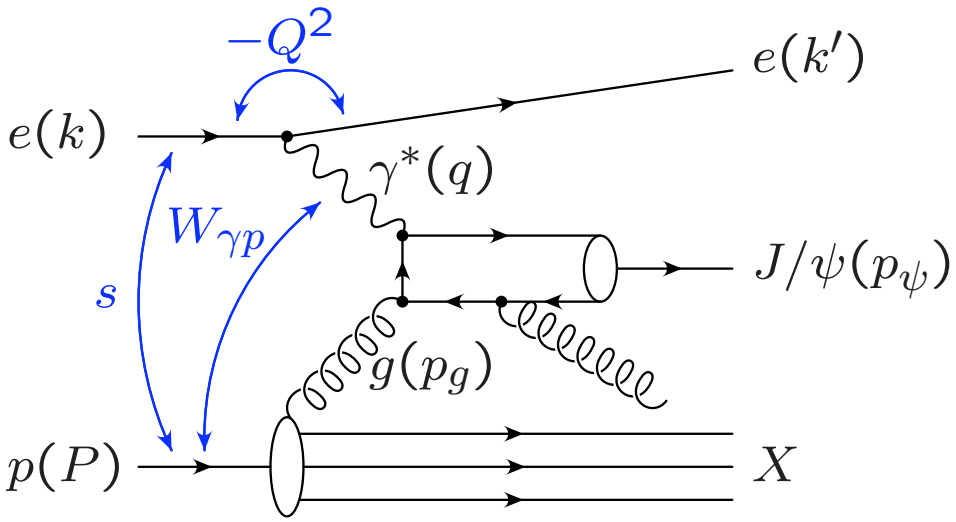
$$s = (P = k)^2$$

- Effective mass in γp system

$$W^2_{\gamma p} = (P + q)^2$$

- Photon virtuality

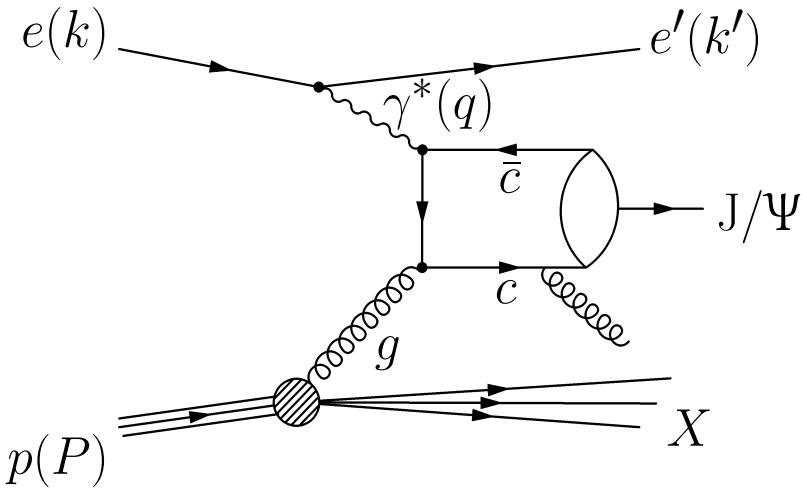
$$Q^2 = -q^2 = 4 \cdot E_e E_{e'} \cdot \cos\left(\frac{\theta_{e'}}{2}\right)$$



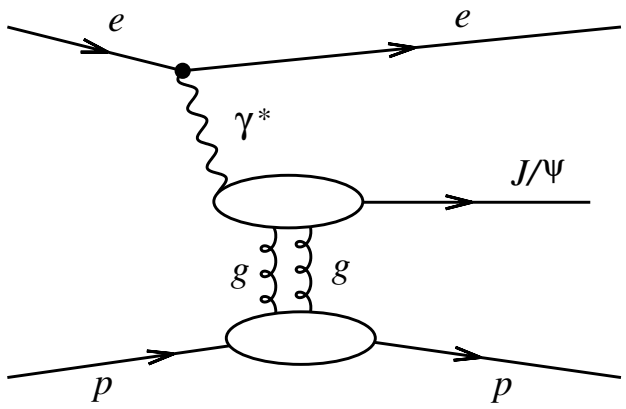
- $Q^2 \approx 0$ GeV^2: Photoproduction (γp)
  - photon quasi real
  - scattered electron escapes undetected
- $Q^2 > 3.6$ GeV^2: Electroproduction (DIS)
  - large scattering angle
  - electron detected in main calorimeters

J/ψ Production at HERA

- Inelastic Production
  - quark pair from boson gluon fusion (BGF)
  - radiation of gluons
    → high track multiplicities



- Diffractive Production
  - much larger cross section
  - no exchange of quantum numbers
  - nothing beside J/ψ meson is produced
    → only decay lepton tracks



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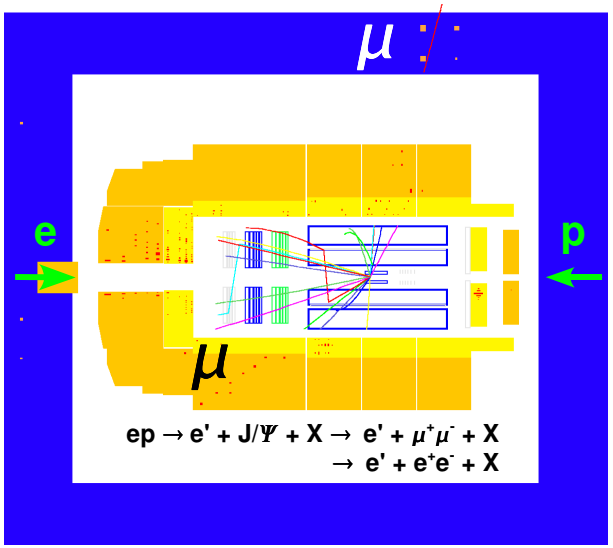

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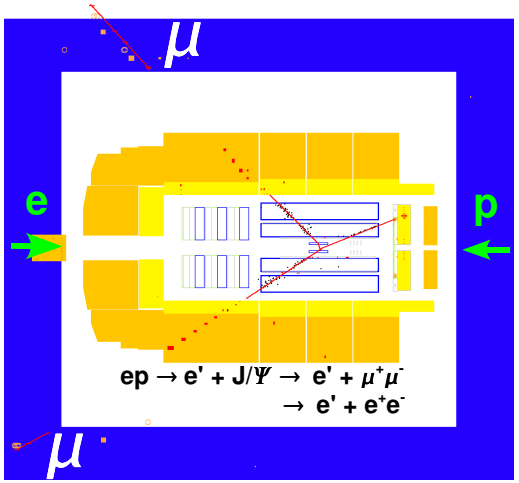
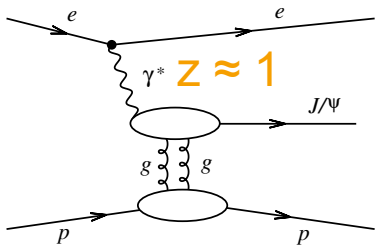


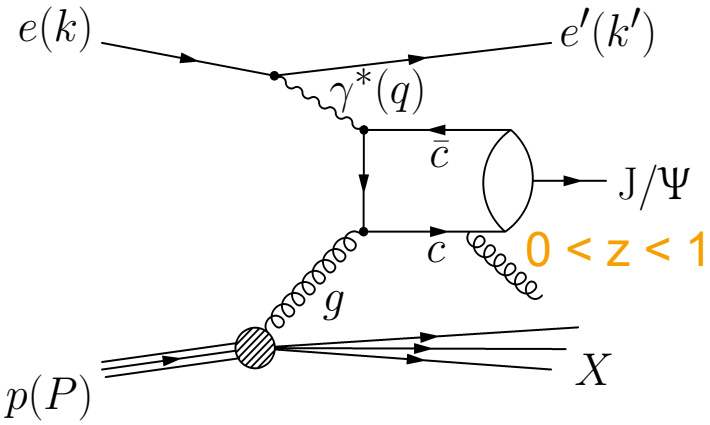
Elasticity of the J/ψ Mesons

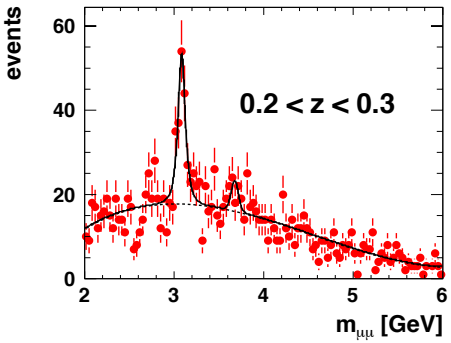
- Used to distinguish production processes

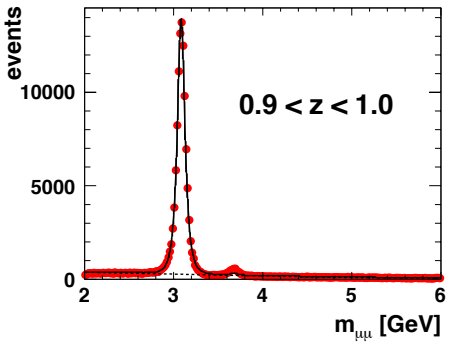
$$z = \frac{P_\psi \cdot P}{q \cdot P} = \frac{E_\psi}{E_\gamma *} \quad \text{(in proton rest frame)}$$

- Fraction of γ energy transferred to J/ψ
  - in proton rest frame
- Diffraction
  - full photon energy to J/ψ
    → z ≈ 1
- Inelastic Production
  - whole elasticity range
  - increasing track multiplicity towards low z
    → larger combinatorial background







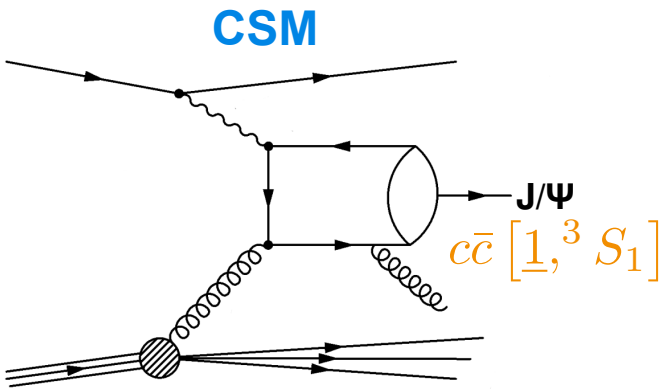


Inelastic Production of Heavy Quarkonia

Color Singlet Model (CSM)

LO: Berger et al, Baier et al., 1981
NLO (direct): Krämer, Zerwas et al., 1995

- radiation of a 'hard' gluon

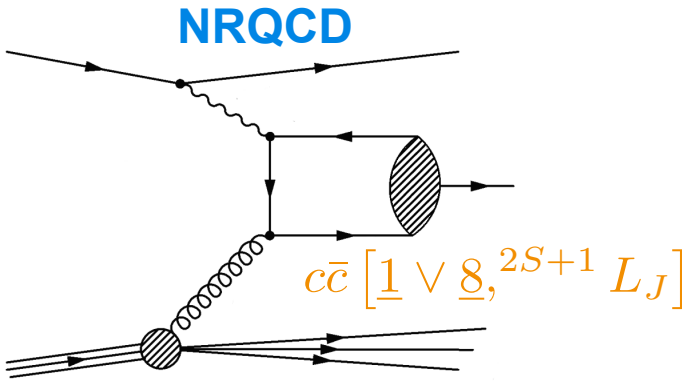


Color Octet Model (NRQCD)

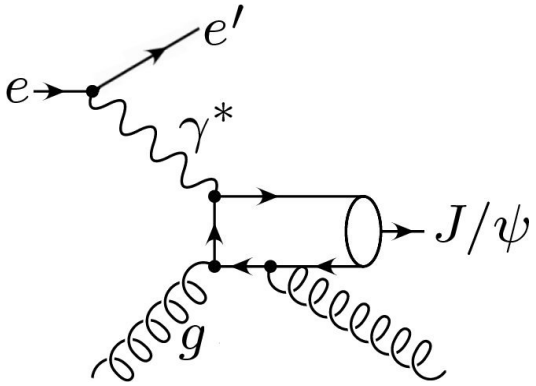
LO: Bodwin, Braaten, Lepage, 1995
NLO (γp): Butenschön, Kniehl, 2009

$$\sigma\left(\mathbf{J}/\Psi + \mathbf{X}\right) = \sum_{\mathbf{n}} \hat{\sigma}\left(\mathbf{c\bar{c}}\left[\mathbf{n}\right] + \mathbf{X}\right) \times \mathbf{LDME}[\mathbf{n}]$$

- radiation of 'soft' gluons
- contains CSM
- LDME obtained from fit to Tevatron data
  → expected to be universal

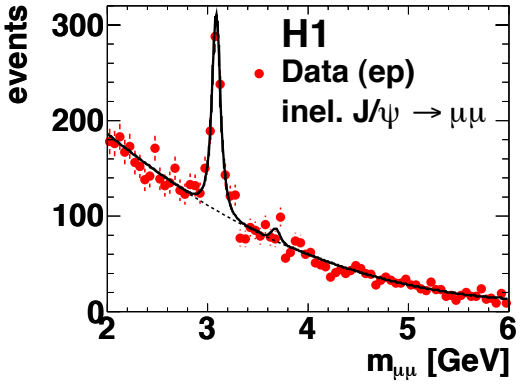


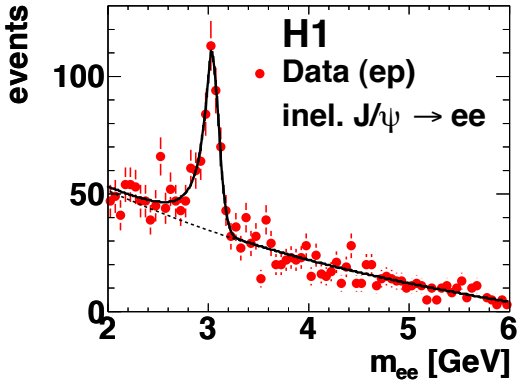
Kinematic Selection

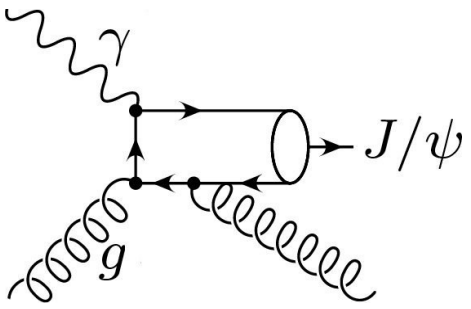


Electroproduction

- $\mathscr{L}$ = 315 pb^{-1}
- 3.6 < Q^2 < 100 GeV^2
- $P_{T,\psi}$* > 1 GeV ($P_{T,\psi}$ in γp rest system)
- 60 < $W_{\gamma p}$ < 240 GeV
- 0.3 < z < 0.9
- syst. uncertainty: 9.0%

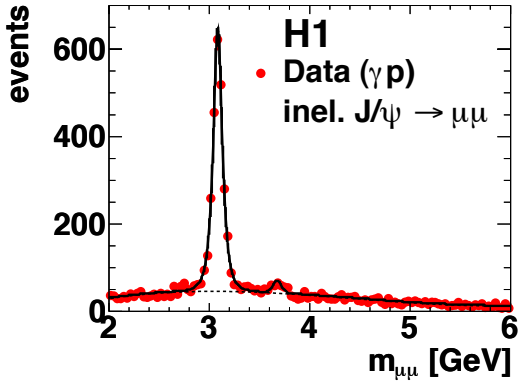






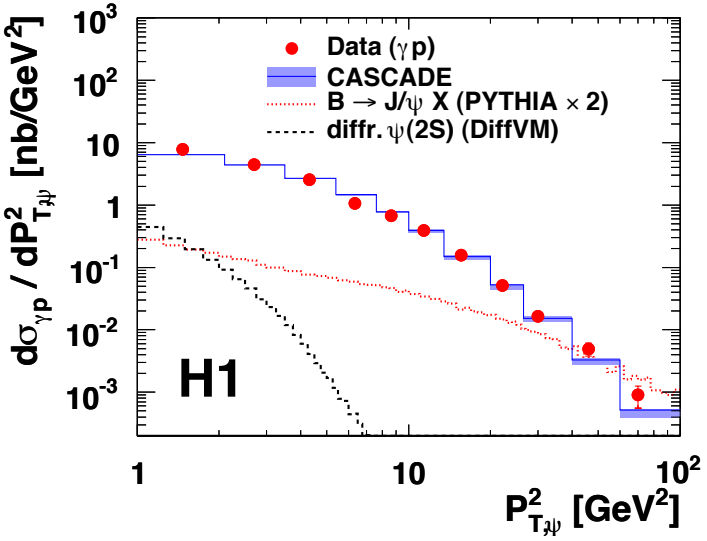
Photoproduction

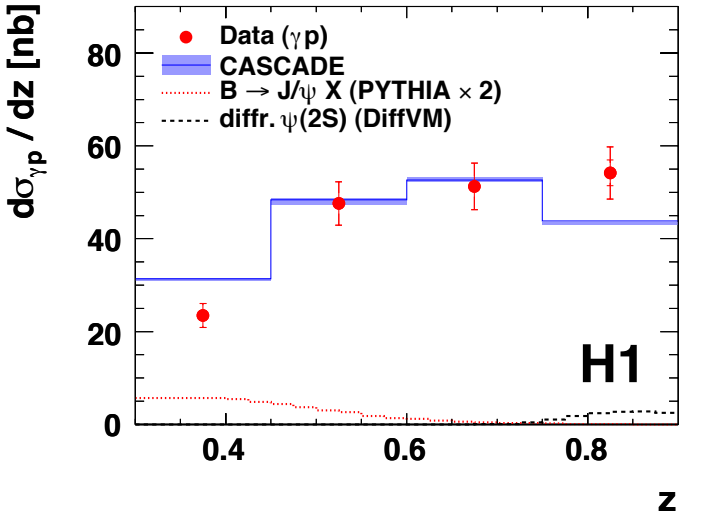
- $\mathscr{L}$ = 165 pb^{-1}
- Q^2 < 2 GeV^2
- $P_{T,\psi}$ > 1 GeV
- 60 < $W_{\gamma p}$ < 240 GeV
- 0.3 < z < 0.9
- syst. uncertainty: 8.5%



Feed-down from non-prompt J/ψ mesons

- Inelastic ψ(2S) mesons: 15-20%
  - equally distributed in all bins
  - not shown
- B hadrons: 3.6%
  - lowest z bin: 20%
- Diffractive ψ(2S) mesons: 1.3%
  - highest z bin: 5%
- Cross sections are **not** corrected for these contributions

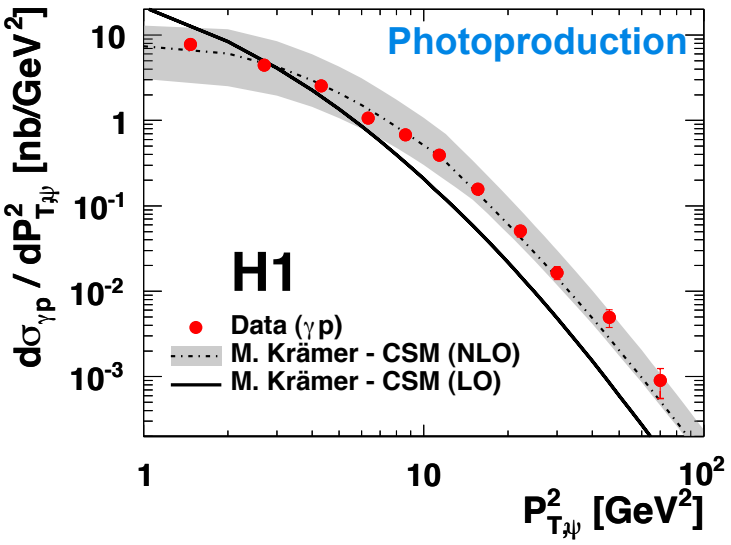




Inelastic J/ψ Meson Production at HERA

- CSM NLO calculation exists since 1995
  - direct photoproduction only
  - very large NLO corrections
  - good description of HERA data

Krämer et al., 1995



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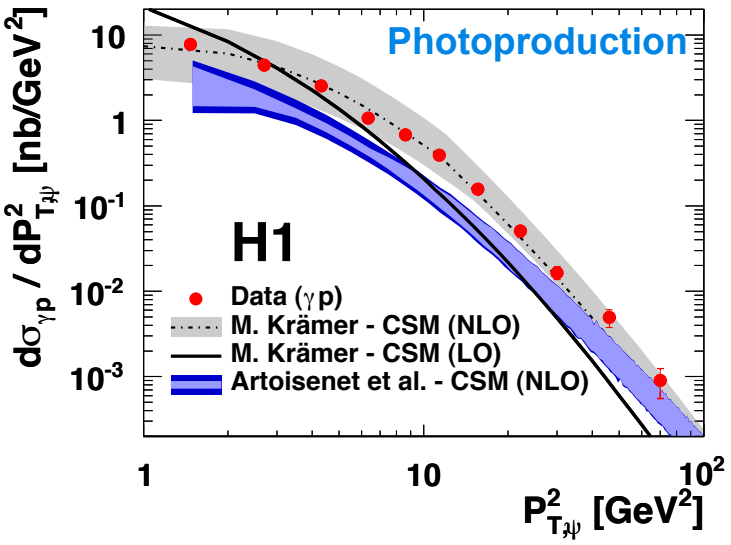


- Recently recalculated
  - up to date set of parameters:

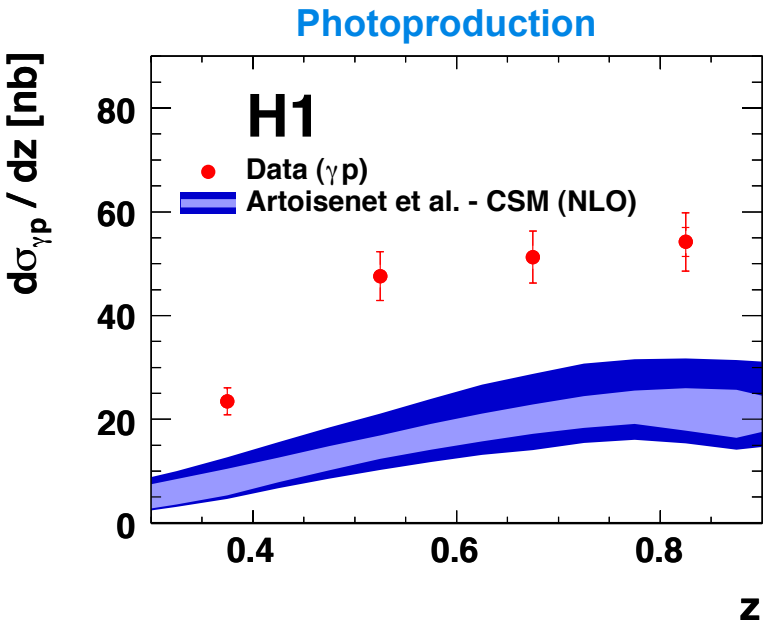
Krämer, 1995

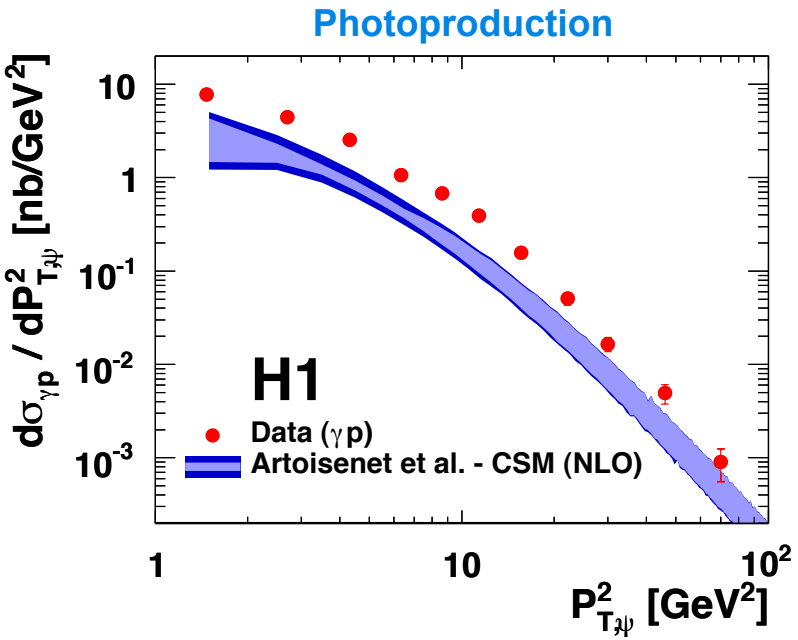
- m_c = 1.3 GeV
- MRST
- $\mu_r = \mu_f = \frac{1}{2}\sqrt{m_c^2 + P_{T,\psi}^2}$

Artoisenet, Maltoni, 2009

- m_c = 1.5 GeV
- CTEQ6M
- $\mu_r = \mu_f = 4m_c$

Cross Section Measurement





- Shapes well described by CSM NLO
- Too low in normalisation

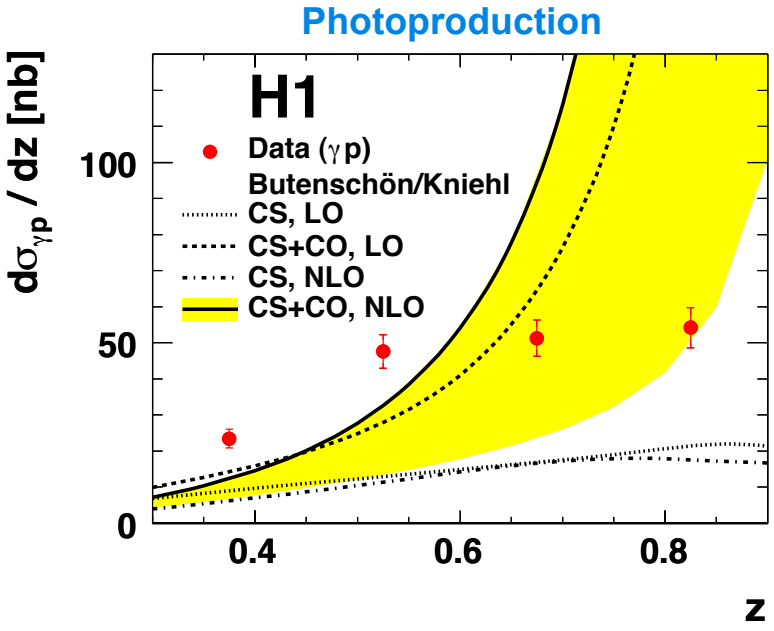
- Huge uncertainties arising from choice of scales and parameters

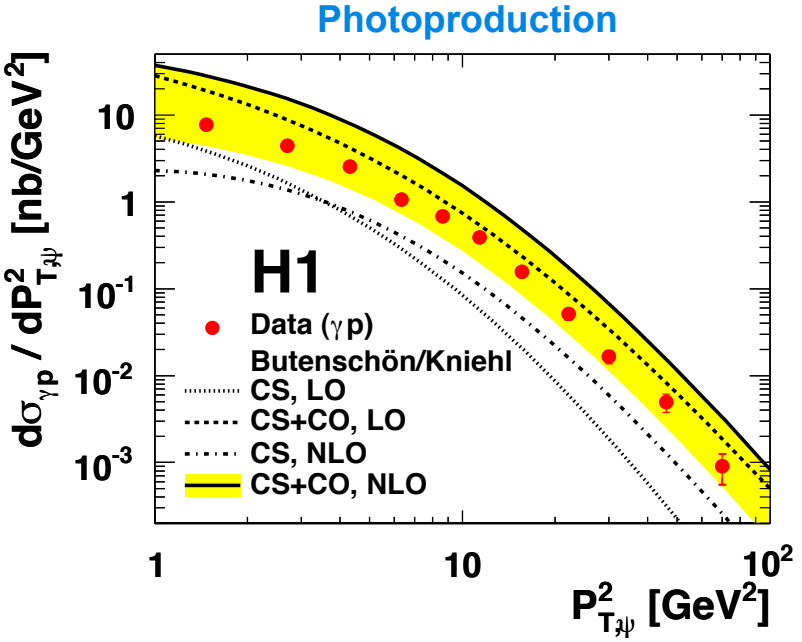
- We need to recover normalisation
  - color octet contributions ?
  - N^nNLO corrections ?

Color Octet Contributions (NRQCD)

- HERA matrix elements calculated very recently to NLO
  - see talk by B. Kniehl (talk ID 87)
- LDME taken from Tevatron data
  - yet only available in LO
  - error band: difference between "*LDME (LO)*" and "*LDME (LO higher order improved)*"

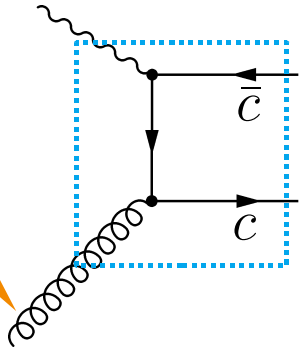
- CO states recover normalisation
  - within huge uncertainties arising from LDME uncertainties
- Problems to describe shape as function of z
  - LDME@NLO urgently needed





k_T Factorisation Approach

- Initial partons may be off-shell
  - contains implicitly higher order corrections

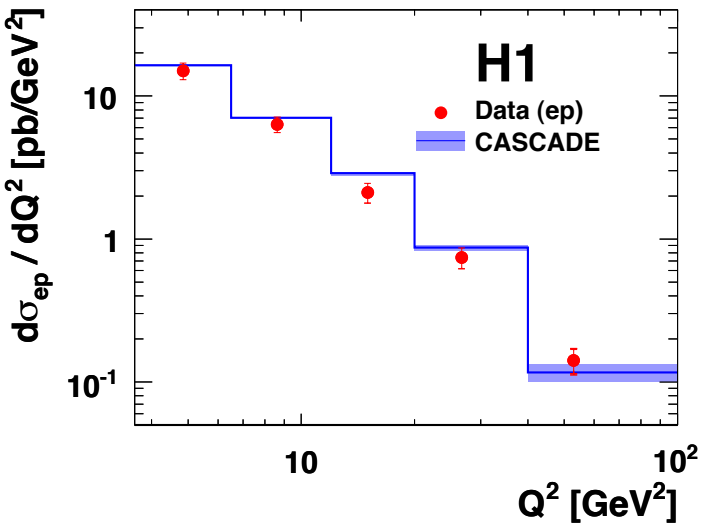


Jung, 2001

- CCFM evolution equations
  - as implemented in CASCADE
- Provides best description of the data
  - in shape and normalisation

Text

Electroproduction



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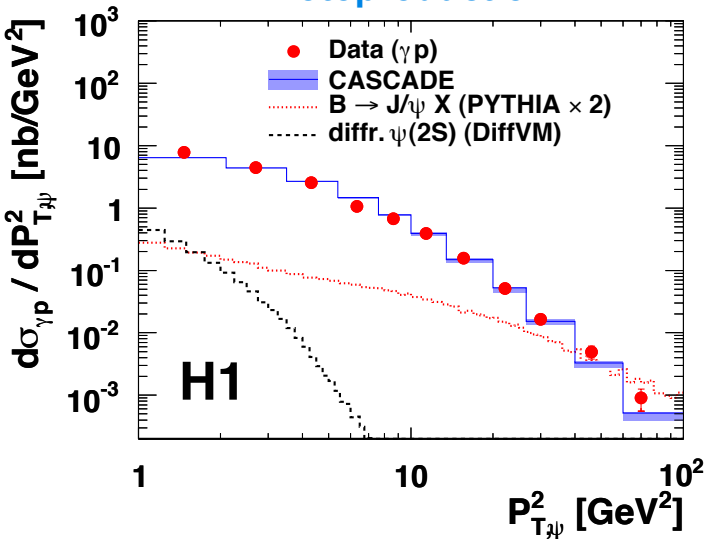

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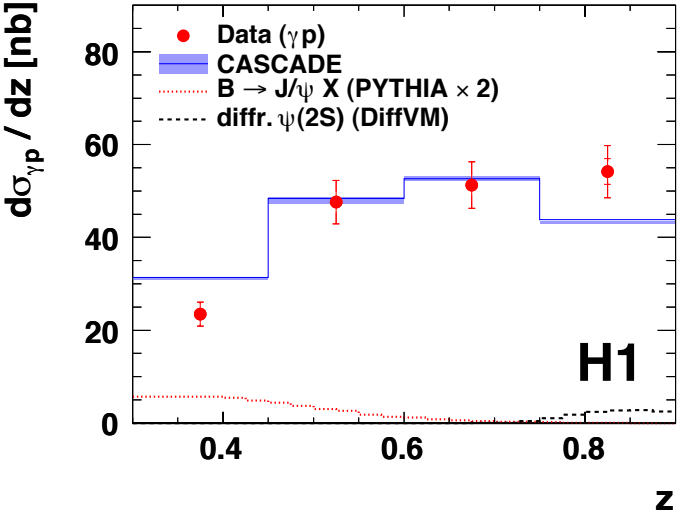


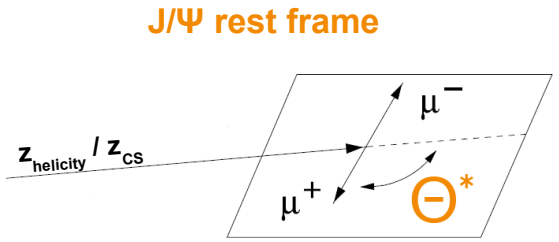
Polarisation Variables

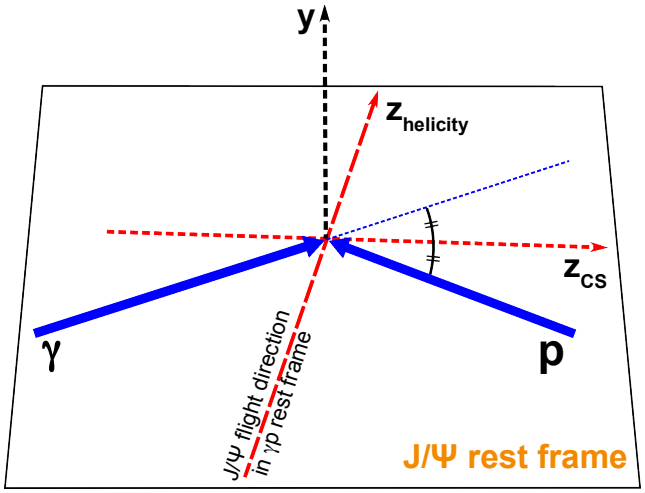
- Additional test of production models
- Polarisation parameters α and ν
  - taken from parametrisation of angular distributions

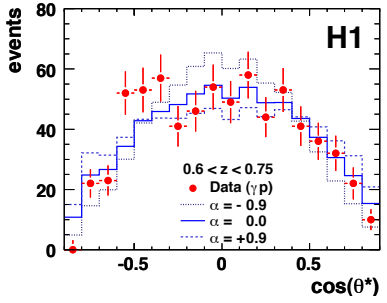
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos(\theta^*)} \propto 1+\alpha\cos^2(\theta^*)$$

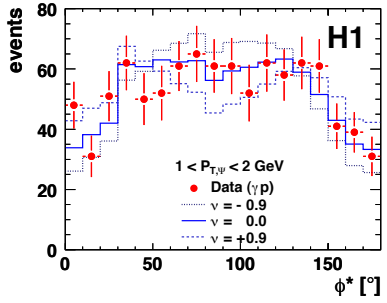
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*} \propto 1+\frac{\alpha}{3}+\frac{\nu}{3}\cos(2\phi^*)$$

- Two complementary frames used
  - Helicity: z axis ≙ J/ψ direction in γp rest frame
  - Collins-Soper: z axis ≙ bisector of γ and -p in J/ψ rest frame
- Projecting μ⁺ vector onto axis yields
  - x ~ cos(θ*)
  - y ~ sin(θ*) sin(ϕ*)
  - z ~ sin(θ*) cos(ϕ*)
- Minimise χ^2 by varying polarisation variables on generator level

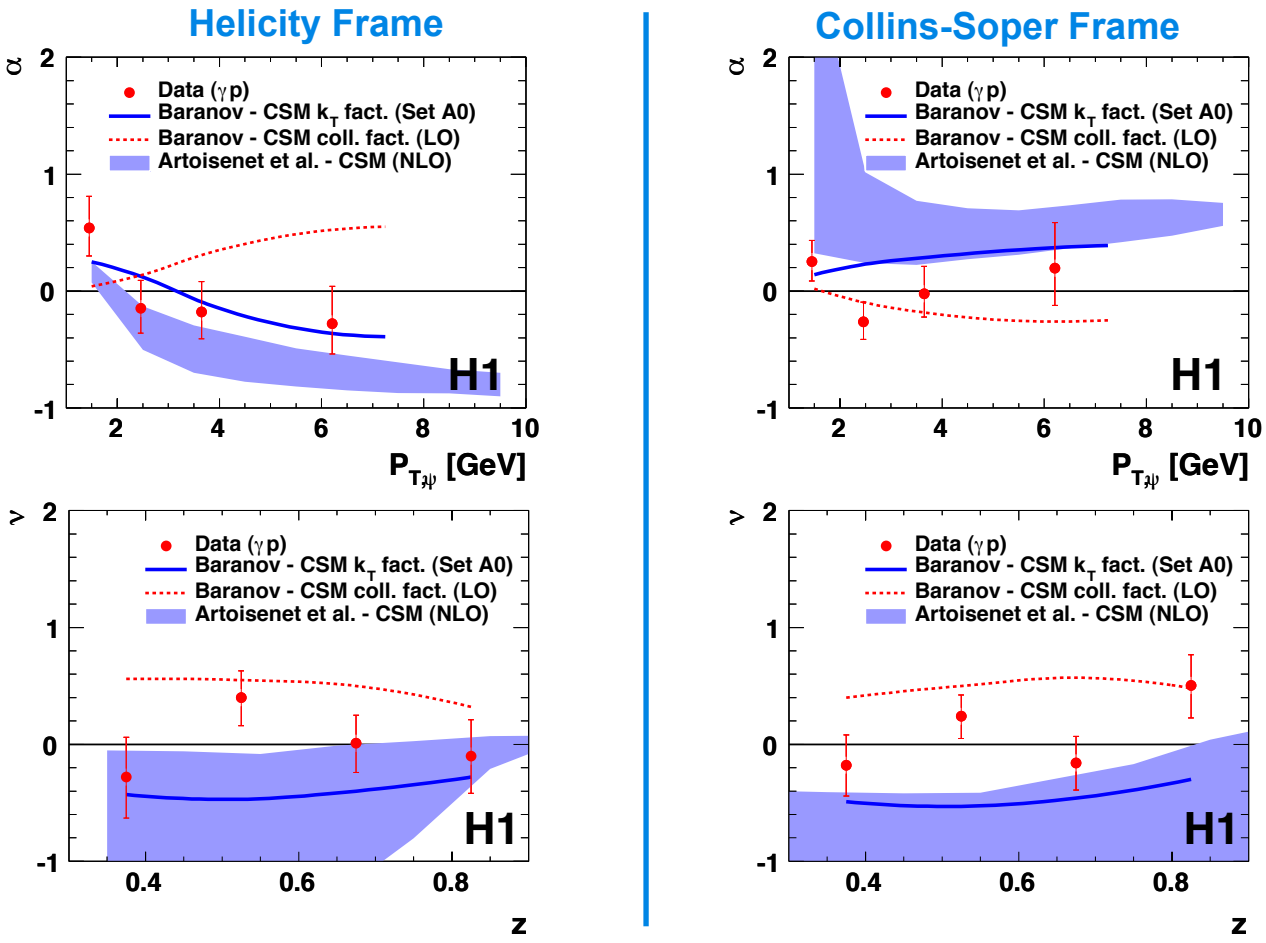








Polarisation Measurement



- New calculations in CSM NLO and k_T factorisation
  - Both show correct trend within large uncertainties
- Large impact of NLO corrections
  - Sign of α changes

Baranov, 2009
Artoisenet, Maltoni et al. 2009

Summary

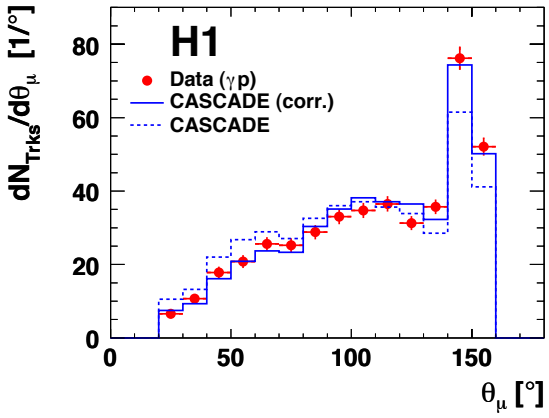
- Final H1 result on inelastic J/ψ cross section and polarisation measurements
  DESY 09-225, arXiv: 1002.0234[hep-ex] (submitted to EPJ C)
  - Photoproduction and DIS using full HERA-II statistics
  - Improved statistical/systematic uncertainties and detector understanding

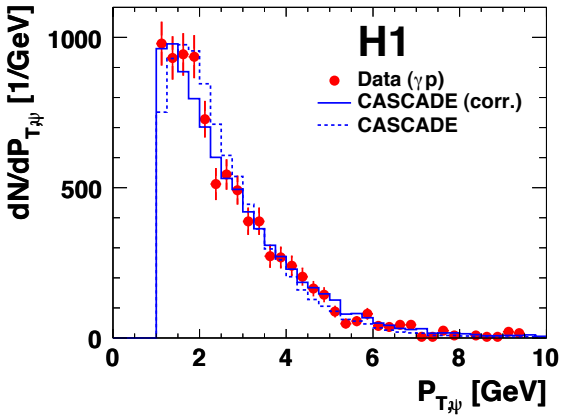
- Comparison to recent calculations
  - k_T factorisation approach (CSM)
    - CASCADE describes shapes and normalisation quite well
    - Analytical calculation models the measured polarsation parameters
  - CSM NLO
    - 'State of the art' set of parameters
    - Describes shape of cross sections and polarisation measurement
    - Too low in normalisation
    - Consistent with recent calculations for Tevatron
  - NRQCD ('color octet model')
    - First calculation to NLO available for HERA
    - Able to recover normalisation
    - Problems to describe shape as function of elasticity

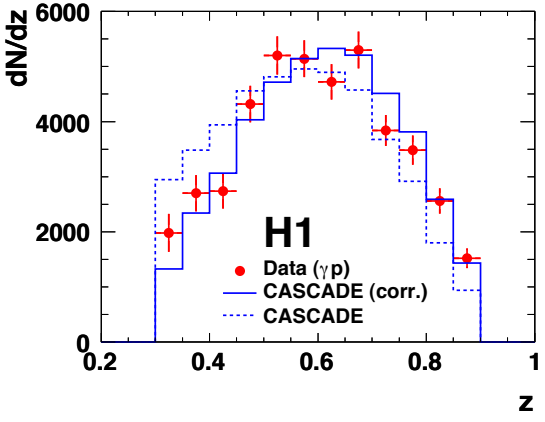
- Final conclusion needs LDME@NLO and N^nNLO calculations

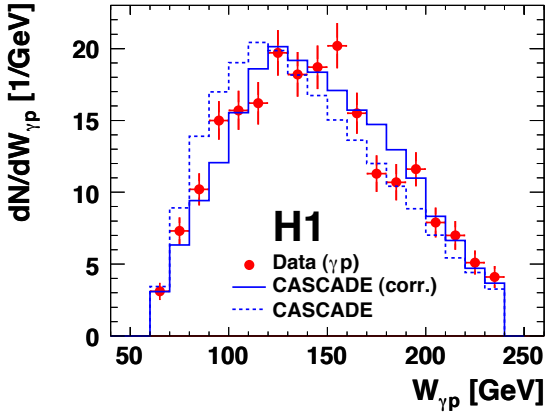
BACKUP

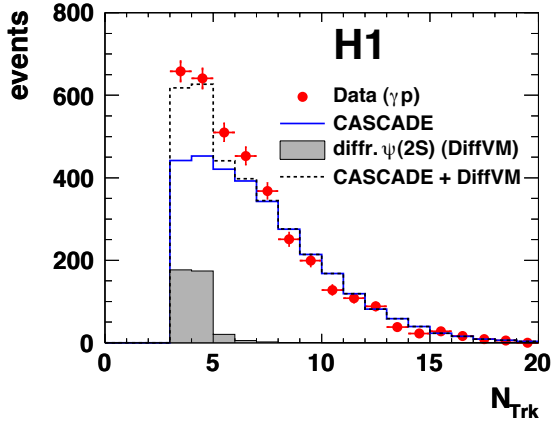
Control Plots

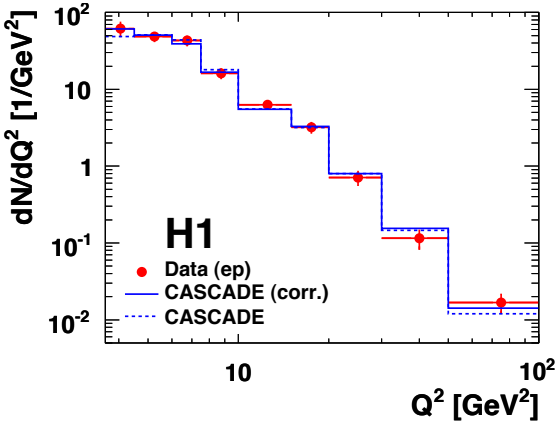






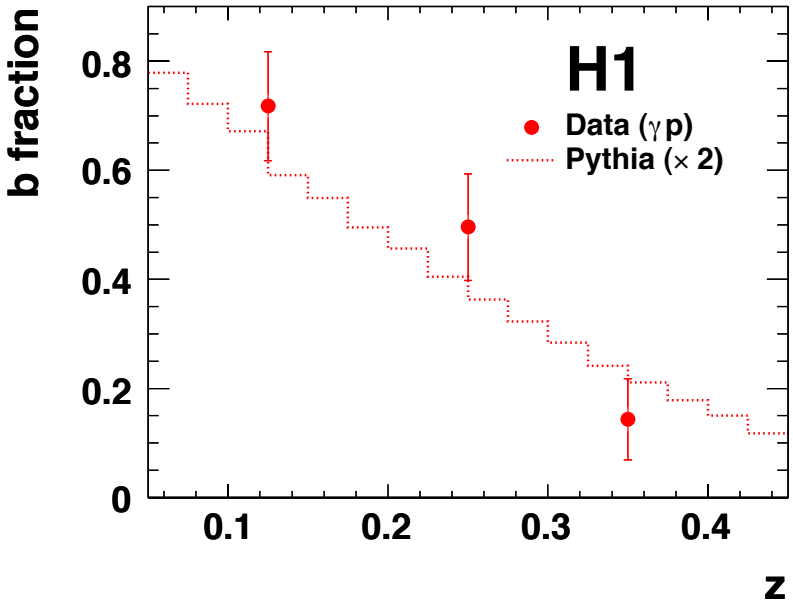


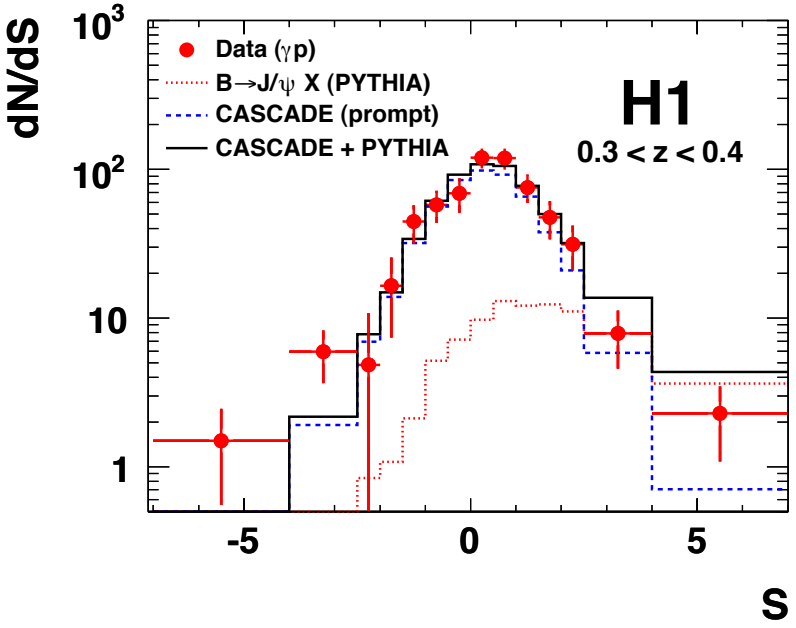




Beauty contribution to J/ψ production at low z

- B hadrons
  - directly measures using life time tag method
    0.05 < z < 0.4
  - very good agreement with Pythia prediction
    total contribution (0.3 < z < 0.9): 3.6%
    lowest analysed z bin (0.3 < z < 0.45): 20.0%





J/ψ Production at HERA and at Tevatron

- new calculation consistent with Tevatron results
  - shape described, lower in normalisation
  - CSM NLO produced by same authors
  - NNLO contribution still large