Exclusive Production of Heavy Quark Mesons in pp and $p\bar{p}$ collisions

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Photoproduction of heavy vector mesons in pp/$p\bar{p}$ collisions

Rates and rapidity distributions

Interference and p_T spectra

Backgrounds

Conclusions

Photoproduction

- A photon from the electromagnetic field of one nucleus interacts with the other nucleus, producing a vector meson
  - Either nucleus can be photon source
  - The photon flux extends up to 0.1 E_p or higher

	E_{cm}	k_{max} (target)	W_{gpmax}
RHIC	500 GeV	12.5 TeV	158 GeV
Tevatron	2.0 TeV	50 TeV	316 GeV
LHC	14 TeV	1 PeV!	4.4 TeV

- These photons can probe low-x gluons

	Gluon x Y (y=0)	Gluon x J/Ψ (y=0)
RHIC	0.02	0.006
Tevatron	0.005	0.0015
LHC	0.0007	0.0002

Photon Flux

- From Weizsacker-Williams
- $b > 2R_p$;
  - no hadronic interactions
    - Clean event signatures
  - Take b_{min} ~ 0.7 fm
    - Change to b_{min} = 1.0 fm is error estimate
- Sensitive to proton form factor
  - $Q_{min}^2 = k/\gamma$

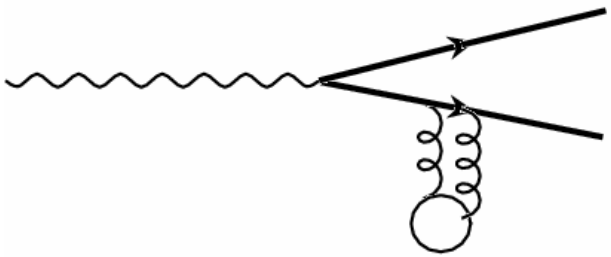
$$\frac{dN}{dk} = \frac{\alpha}{2\pi k}\left[1+(1-\frac{2k}{\sqrt{s}})^2\right]\left(\ln(A) - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right)$$

$$A = \frac{(1+0.71GeV^2)}{Q_{min}^2}$$

Drees and Zeppenfield, 1989

Vector Meson production I Theory

- γg collision at lowest order
  - Need another gluon to conserve color
- Refinements
  - Relativistic wave functions
  - Off diagonal parton dists.
  - NLO contributions
- Sensitive to gluon distributions
  - $Q^2=M_V^2/4$



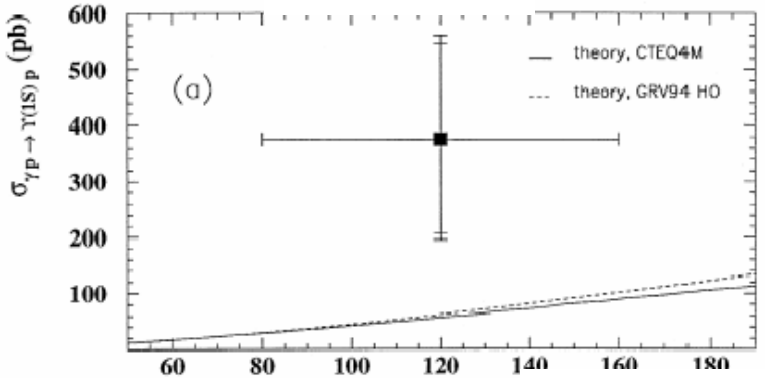
$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xg(x, \frac{M_V^2}{4})]^2$$

Ryskin, 1993

Vector Meson production II Experiment

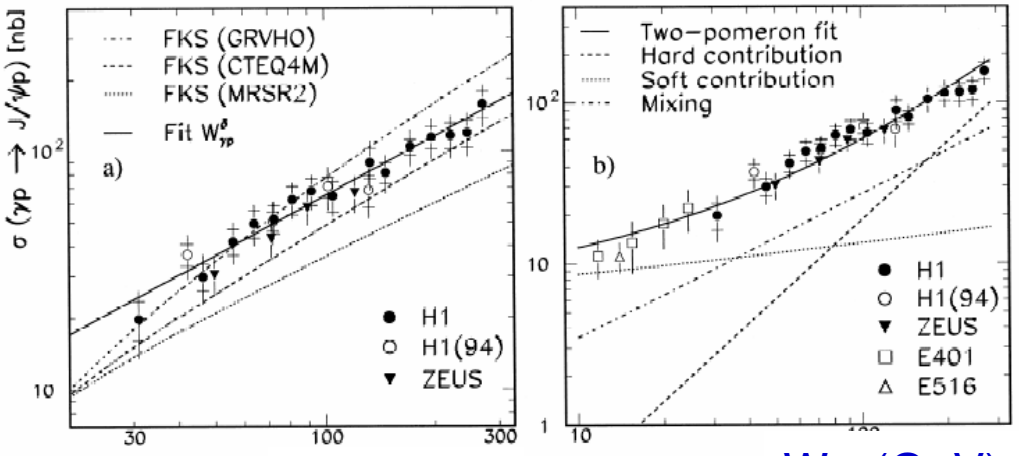
- HERA data
  - J/Ψ: $\sigma \sim W^{0.8}$
    - agreement with theory
  - Υ: $\sigma \sim W^{1.7}$
    - limited statistics
    - Υ(1), Υ(2), Υ(3) not separated
    - Estimate 80% Υ(1)
      - Alternately, use $\sigma \sim W^{0.8}$
    - So-so match with theory
- Tevatron reaches slightly higher $W\gamma p$
  - Lower gluon x

ZEUS Υ



$W_{\gamma p}$ (GeV)

H1/ZEUS J/ψ



$W_{\gamma p}$ (GeV)

$W_{\gamma p}$ (GeV)

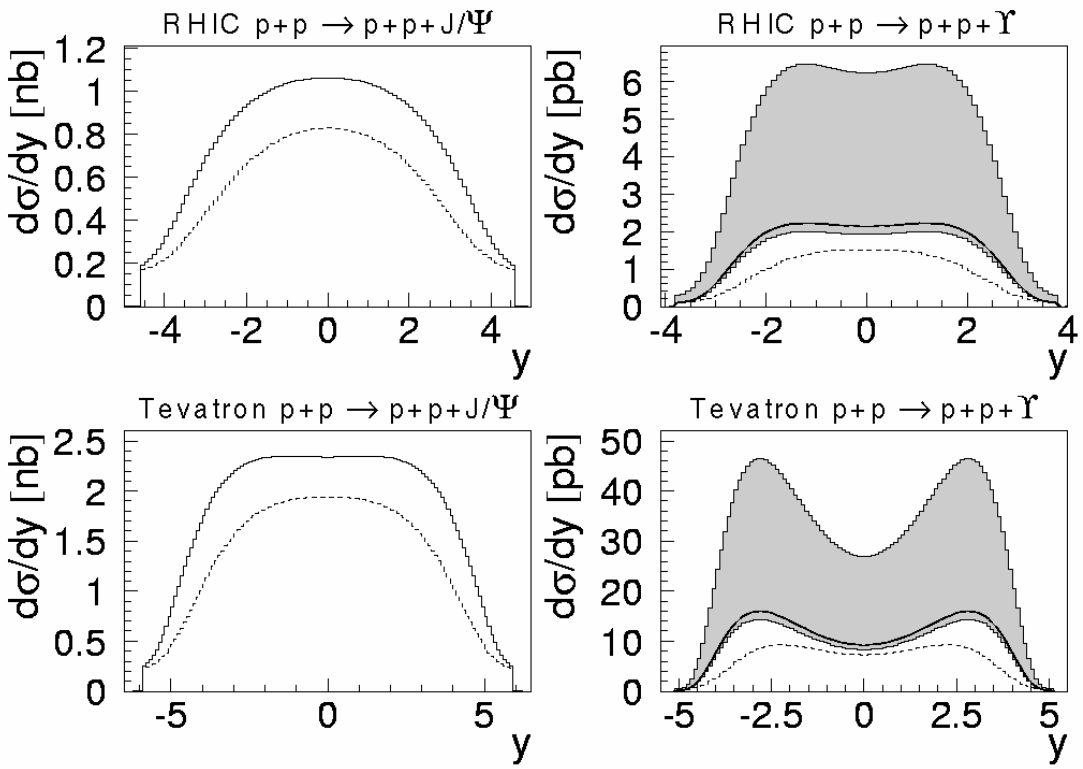
Cross Sections, Rates and dσ/dy

- Photon energy -> rapidity
  - Y = ½ ln (2k/M_V)

$$\frac{d\sigma}{dy} = k\frac{dn_\gamma}{dk}\sigma(\gamma p \to Vp)$$

- The Υ @ RHIC (500 GeV, 10^{31}cm^{-2} s^{-1})
  - 0.4/hr
  - difficult
- The Υ @ the Tevatron (1.8 TeV, 2*10^{32}cm^{-2}s^{-1})
  - 76/hr
  - Easy
- J/Ψ rates are high

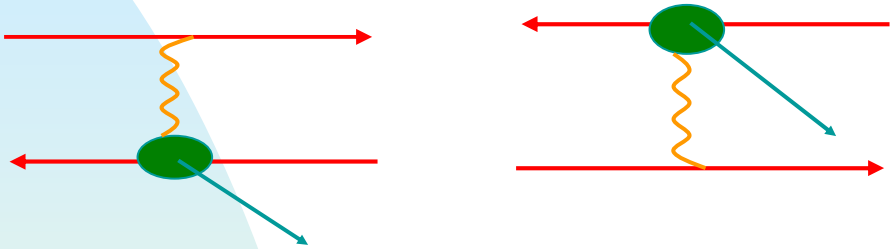
RHIC @ 500 GeV (top)



The Tevatron (bottom)

Interference

- Either proton can act as emitter or target
  - Can't differentiate between

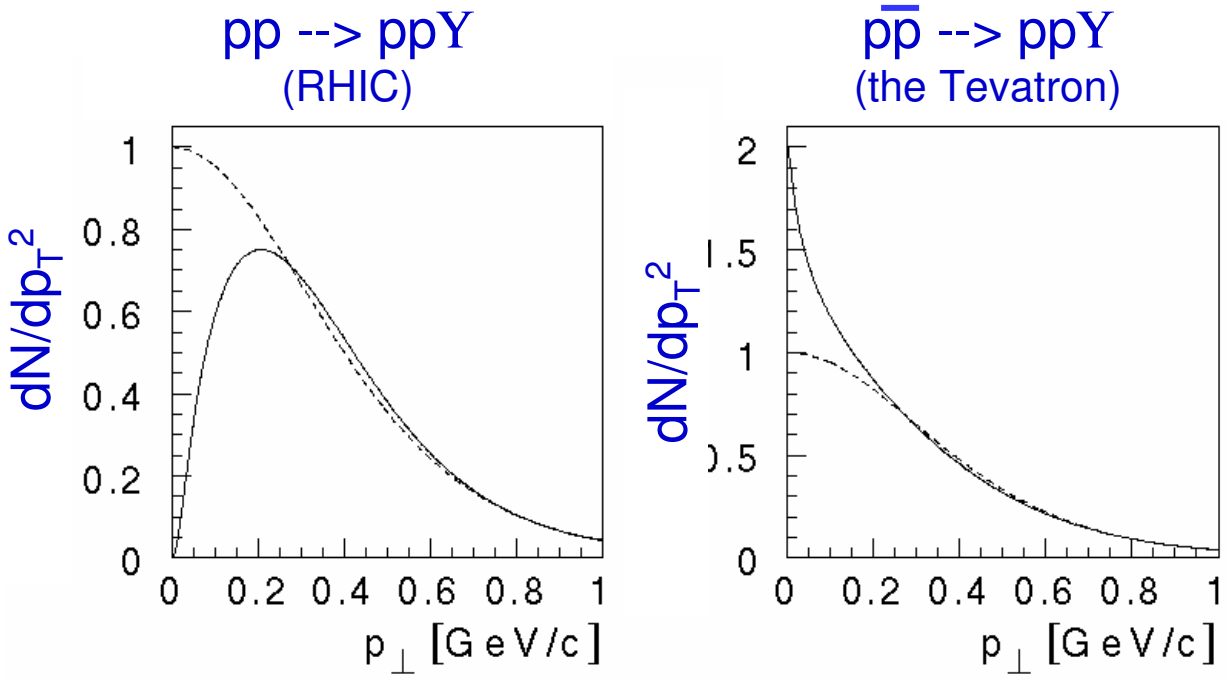


- How to transform diagram 1 into 2?
  - For pp -> parity transform
  - For $p\bar{p}$ -> CP transform
- Υ and J/ψ are $J^{PC} = 1^{--}$
  - pp: subtract amplitudes
  - $p\bar{p}$ add amplitudes

$$\sigma = A_0^2[1 \pm \cos(p_T \cdot b)]$$

p_T spectra

- pp & $p\bar{p}$ are very different!
- <b> ~ few r_p
- $p_{TP} >> p_{T\gamma}$
  - Different from AA
- Interference is relevant for most of production p_T range



Solid – interference
Dashed – no interference

Interference or no interference?

- Interference occurs when we can't tell which nucleus emitted the photon
  - What if scattered proton is detected in a Roman pot?
    - Most of the VM p_T comes from the target proton, so a measurement of the proton p_T can determine where the photon came from.
    - But, what about timing?
      - What if the J/Ψ or Υ is detected before the proton hits the Roman pot?
  - If detection in a Roman pot destroys the interference, then this can be used to remove the 2-fold ambiguity and study gluons at very low x values

Backgrounds

- $\sigma(p(\gamma)p \rightarrow (J/\Psi \text{ or } \Upsilon)pp) \sim 10^{-3}\, \sigma(pp \rightarrow (J/\Psi \text{ or } \Upsilon)X)$.
  - Is the signal visible?
- Cutting on $p_T < 1$ GeV/c eliminates 94% of the hadroproduction.
- Rapidity gaps eliminate the rest.
  - At the Tevatron $dn_{ch}/dy \sim 3.9$.
    - 3 units of rapidity gap --> $\exp(-3*3.9) \sim 10^{-5}$.
    - There are gaps on both sides.
      - The 3 units can be split between both sides.
      - 3 units of coverage is easy.
      - Similar numerology at RHIC; even easier at the LHC.
- Quantum numbers wrong for Pomeron-Pomeron.

Conclusions

- Photoproduction of heavy vector mesons is substantial in pp and $p\bar{p}$ colliders.
  - The rates are sensitive to the gluon distribution in the proton.
- Production at the two sources can interfere. The sign of this interference is different for $p\bar{p}$ and pp collisions.
  - The p_T spectrum of produced mesons is very different for pp and $p\bar{p}$ collisions.