Photoproduction of Heavy Vector Mesons at the LHC

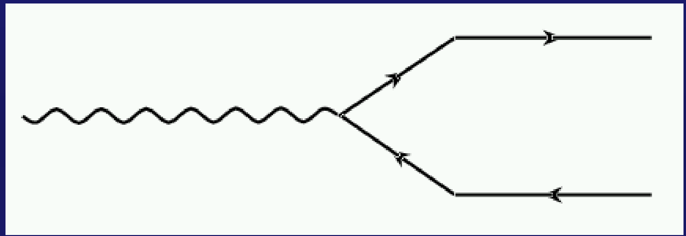
Joakim Nystrand
Department of Physics and Technology,
University of Bergen, Norway

In collaboration with Spencer Klein, LBNL, Berkeley

Photoproduction of heavy Vector Mesons - A probe of the nucleon/nucleus gluon density

The photon wave function can be written as a Fock decomposition:

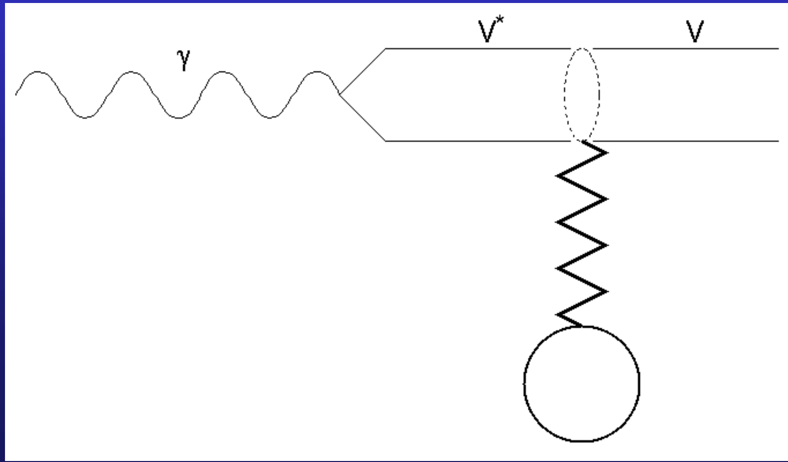
$|\gamma\rangle = C_{bare} \,|\, \gamma_{bare}\rangle + C_\rho \,|\rho\rangle + C_\omega \,|\omega\rangle + C_\phi \,|\phi\rangle + \ldots + C_q \,|qq\rangle$



A photon is not always a photon…
With a certain probability it will appear as a $q\bar{q}$ flucutuation

Conservation of quantum numbers (γ: $J^P = 1^-$) $\Rightarrow$ The photon tend to fluctuate to a vector meson (ρ, ω, ϕ, J/Ψ). Vector Meson Dominance.

A photon in the vector meson state will interact strongly (hadronically). The hadronic component can materialize if the virtual qq-pair is knocked on mass shell.



The probability to find the photon in the vector meson state V:

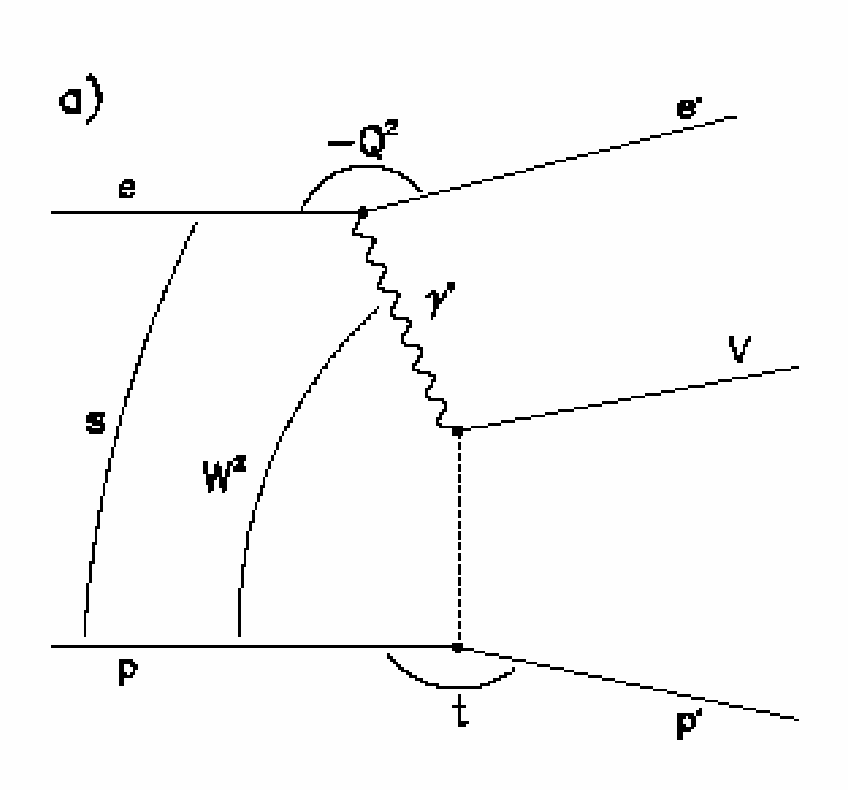
$$C_V = \frac{\sqrt{4\pi\alpha_{em}}}{f_V}$$

f_V – photon-vector-meson coupling

Vector Meson Dominance:

$$\frac{d\sigma}{dt}(\gamma A) = C_V{}^2 \frac{d\sigma}{dt}(VA)$$

Studied at HERA in ep collisions:

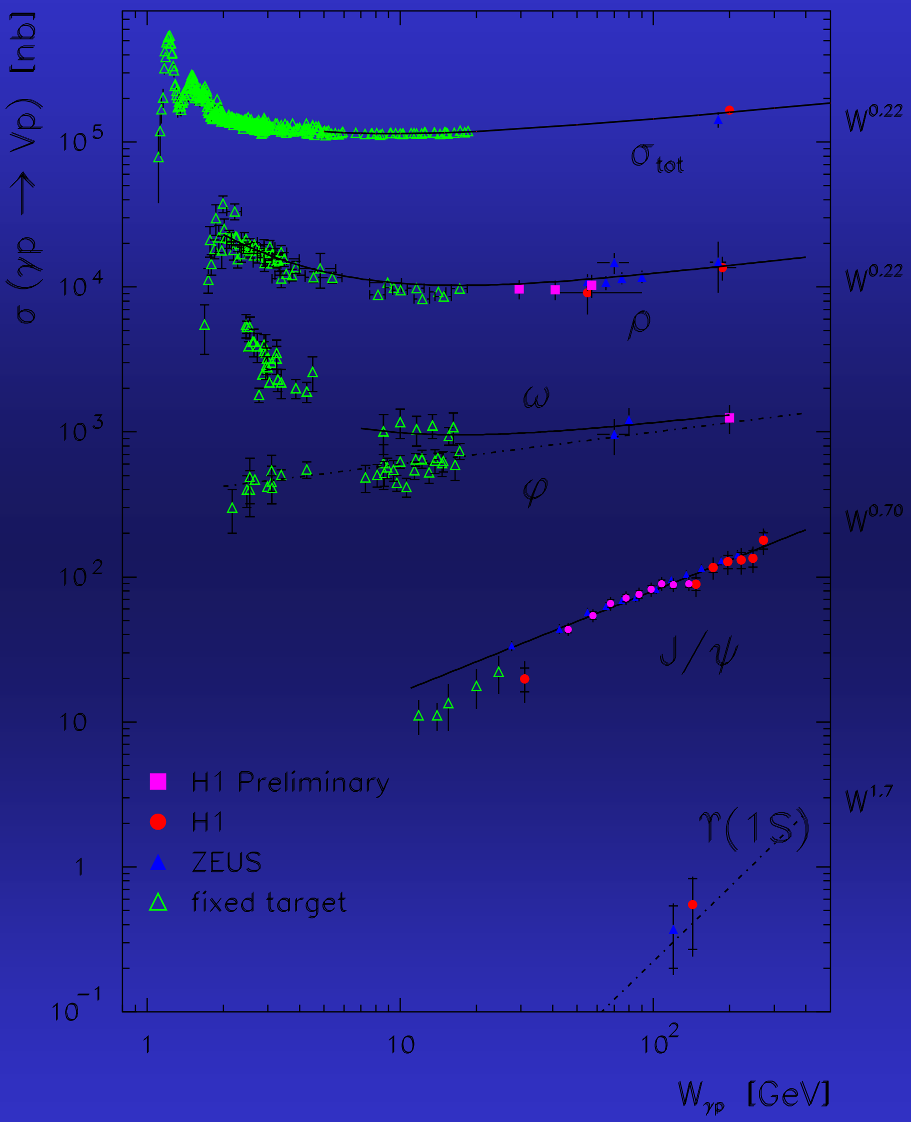


$W_{\gamma p}$: photon-proton CM energy

t: (momentum transfer from proton) ^{2}

$-Q^2$: virtuality of the photon; for protons or nuclei, $Q^2 \approx 0$.

Summary of HERA Results



- $W_{\gamma p}$ up to 200 GeV
- $\rho^0 \leftrightarrow$ 10% of σ_{TOT}
- Light mesons:

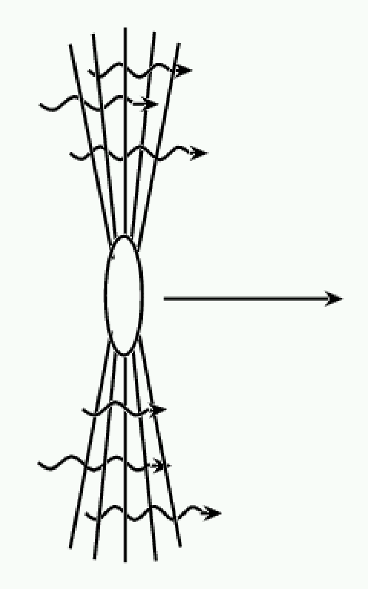
$$\sigma \propto W_{\gamma p}^{\ 0.22}$$

- J/Ψ:

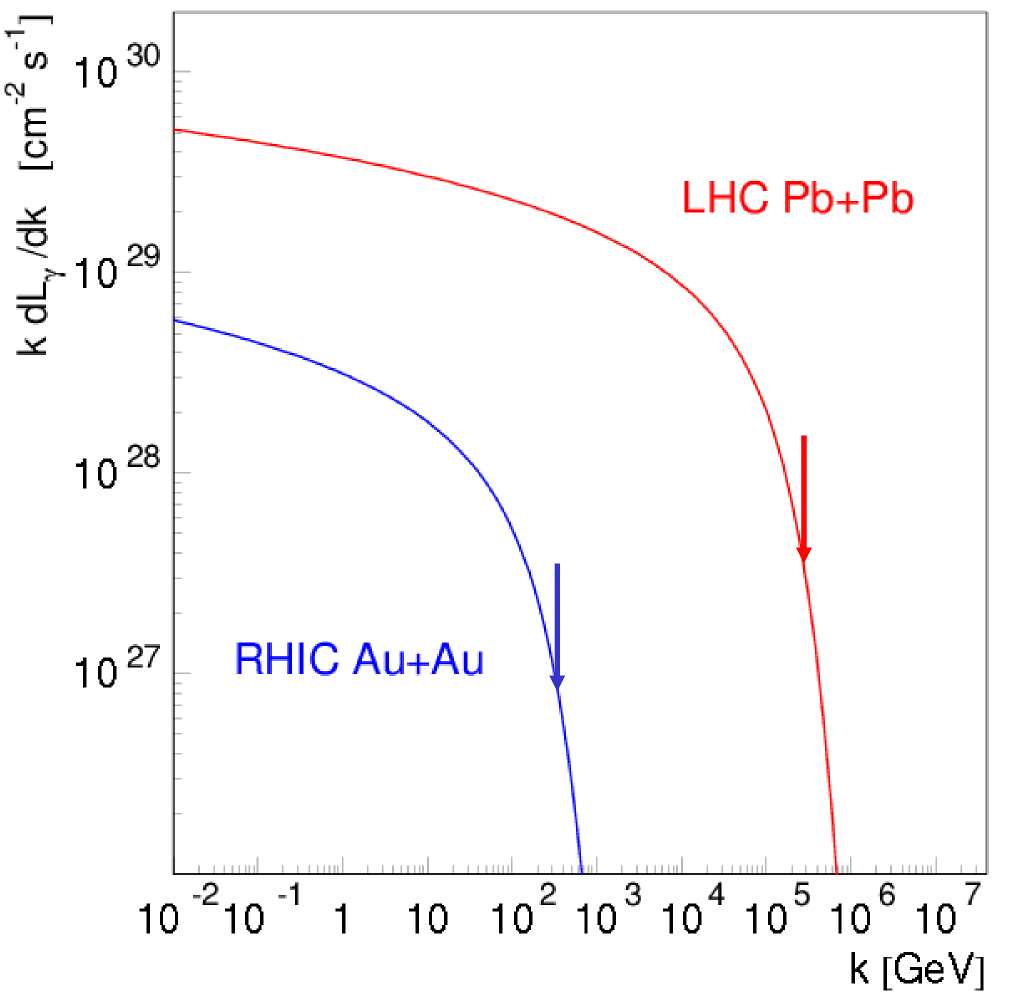
$$\sigma \propto W_{\gamma p}^{\ 0.80}$$

- a few tens of Υ seen

Electromagnetic field ↔An equivalent flux of photons.
(Fermi 1924, Weizsäcker-Williams 1935)



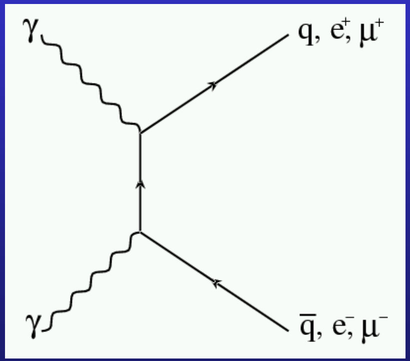
Equivalent photon luminosity



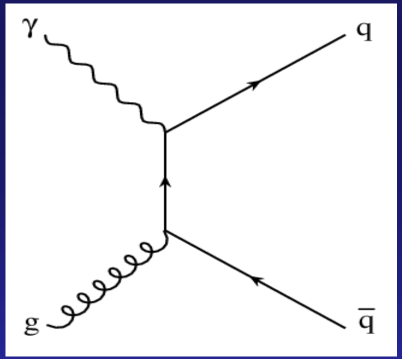
The photon spectrum extends to ~ γ/R
$\Leftrightarrow W_{\gamma p} \approx 1000$ GeV
in Pb+Pb collisions
$(Q^2 \approx 0)$

Ultra-peripheral Interactions Menu

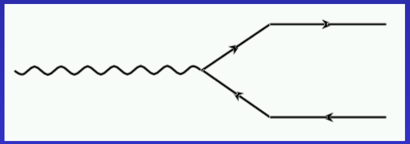
1. Purely electromagnetic, two-photon



2. Photonuclear
   a) direct
      Example: gamma+gluon



   b) resolved
      Vector Meson Dominance



Calculation of Vector Meson cross sections in Heavy-Ion Interactions

Phenomenological model based on scaling data of γp to γA.

J. Nystrand, S. Klein PRC 60(1999)014903

The ingredients:

Photon spectrum:

Weizsäcker-Williams

Input photon-nucleon data:

parameterized from results at HERA and fixed target

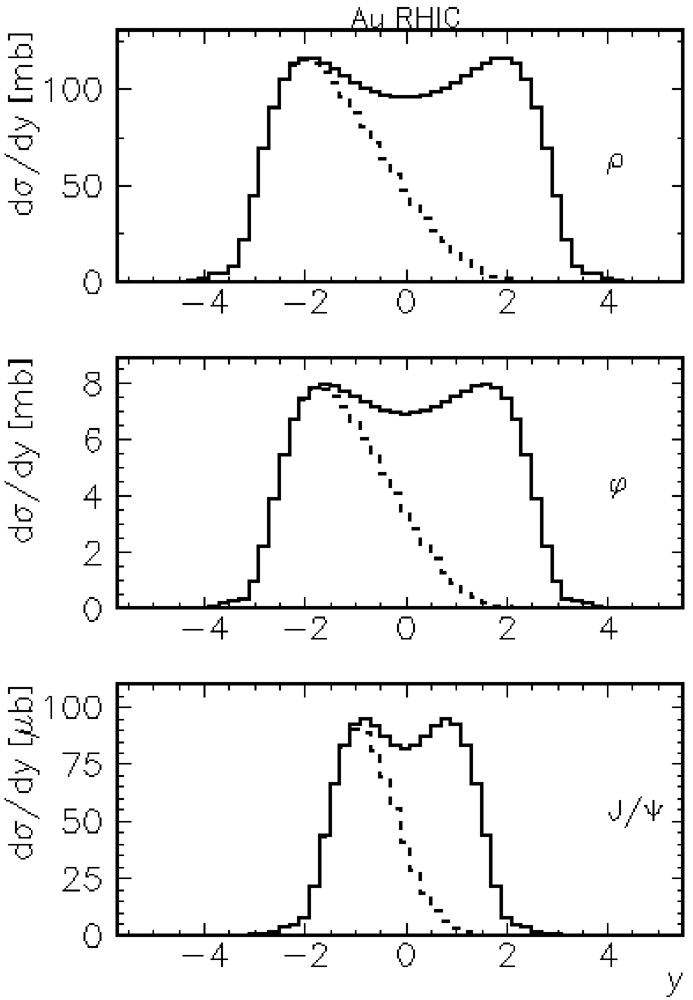
Scaling $\gamma p \rightarrow \gamma A$:

1) Neglecting cross terms - γ fluctuates into V which scatters elastically

2) Shadowing through a Glauber model

3) nuclear momentum transfer from Form factor

The model predicts cross sections, rapidity and p_T distributions of vector mesons at RHIC and LHC. For Au+Au 200 GeV at RHIC:

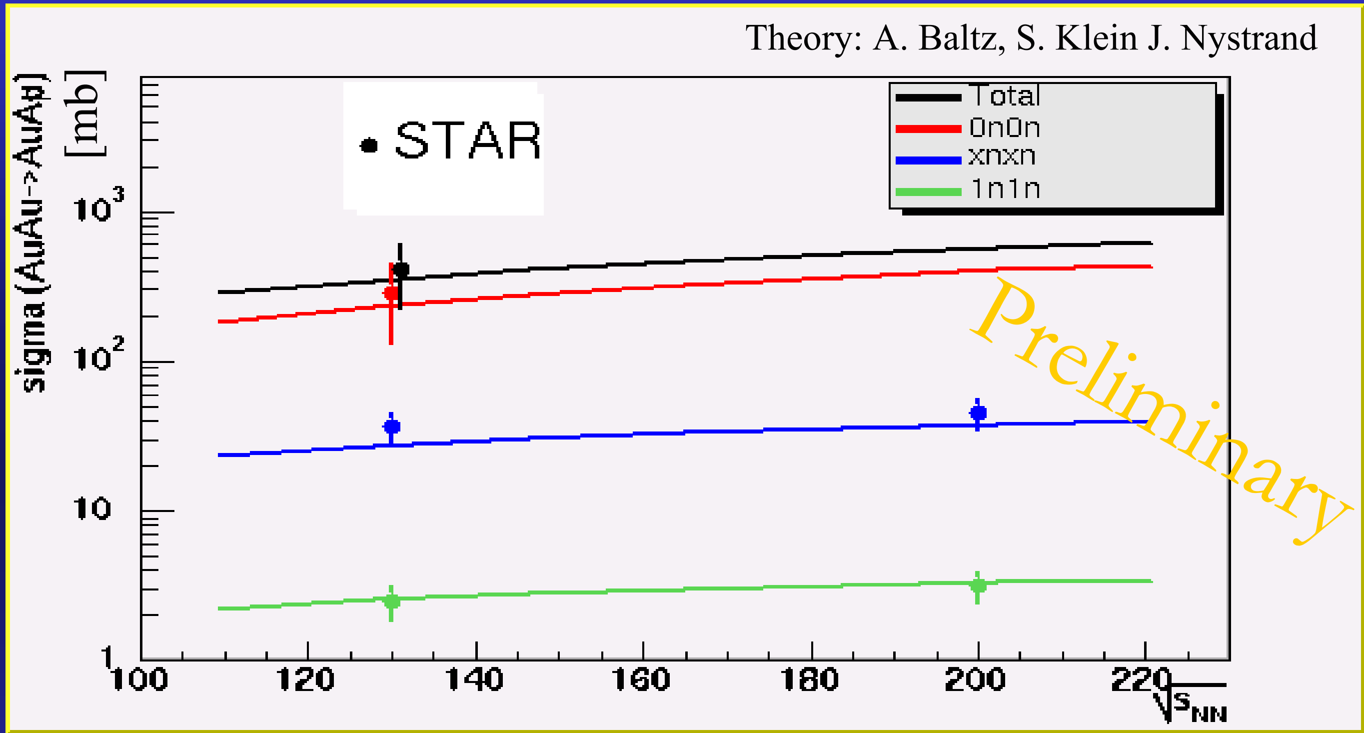


	σ [mb]	(prod. rate)
ρ	590	(120 Hz)
ω	59	(12 Hz)
φ	39	(7.9 Hz)
J/ψ	0.29	(0.058 Hz)

Cross sections in the 1-600 mb range!

The p_T distribution determined by the nuclear Form Factor,
$p_T \sim 1/R \sim 50$ MeV/c

Data on Au+Au→Au+Au+ρ^0 at RHIC in good agreement with calculations



STAR Collaboration, Quark Matter 2002

⇒ Triggering + Analysis techniques work; photon spectrum and basic photonuclear cross sections well understood.

γp data from HERA

J/Ψ: $\sigma = 1.5\ W_{\gamma p}^{\ 0.80}$ [nb, W in GeV]

$\Rightarrow$ Extrapolate this to LHC energies

Too little data on Υ, QCD predicts

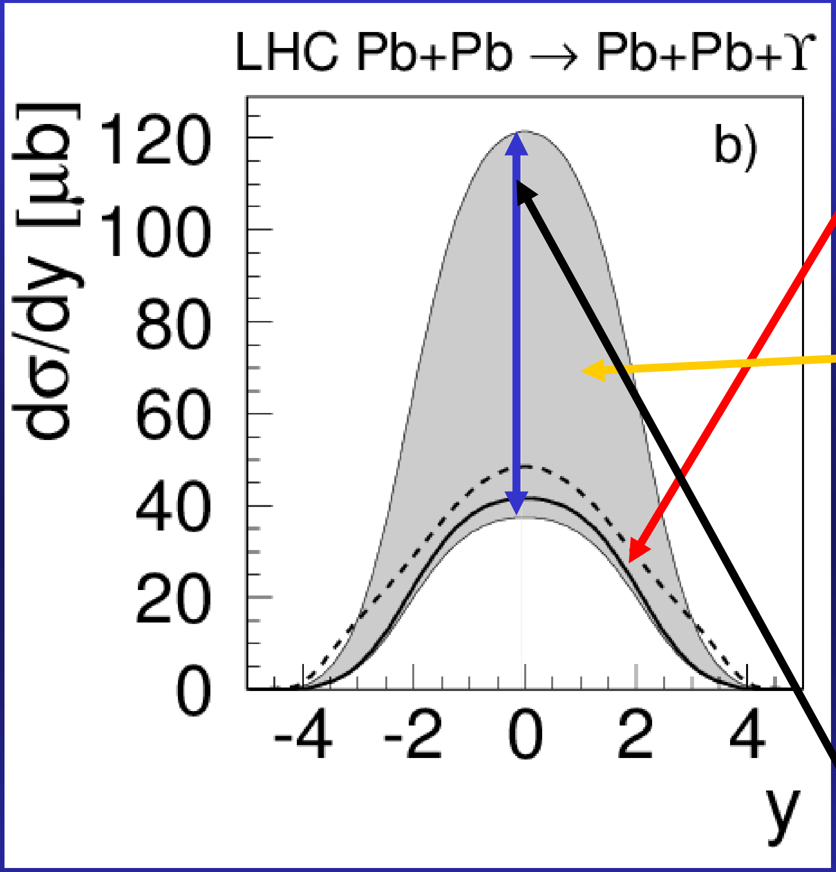
$$\frac{d\sigma}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xg(x, \frac{M_V^2}{4})]^2$$ Ryskin 1993

Further developments: Martin,Ryskin,Tubner Phys. Lett B 454 (1999)339 and Frankfurt,McDermott,Strikman JHEP 02(1999)002.

$\Rightarrow$ Can be parameterized as

Υ: $\sigma = 0.06\ W_{\gamma p}^{\ 1.7}$ [pb, W in GeV]

Υ in ultra-peripheral Pb+Pb collisions at the LHC



A^2 scaling of QCD prediction

A^2 scaling of exp. data from HERA.

Uncertainty in measured cross section (mainly poor statistics).

Mid-rapidity y=0 ⇔
γp CM energy $W_{\gamma p}$ = 230 GeV,
$x=2\cdot10^{-3}$

What can one expect in pp/$\bar{p}$p ?

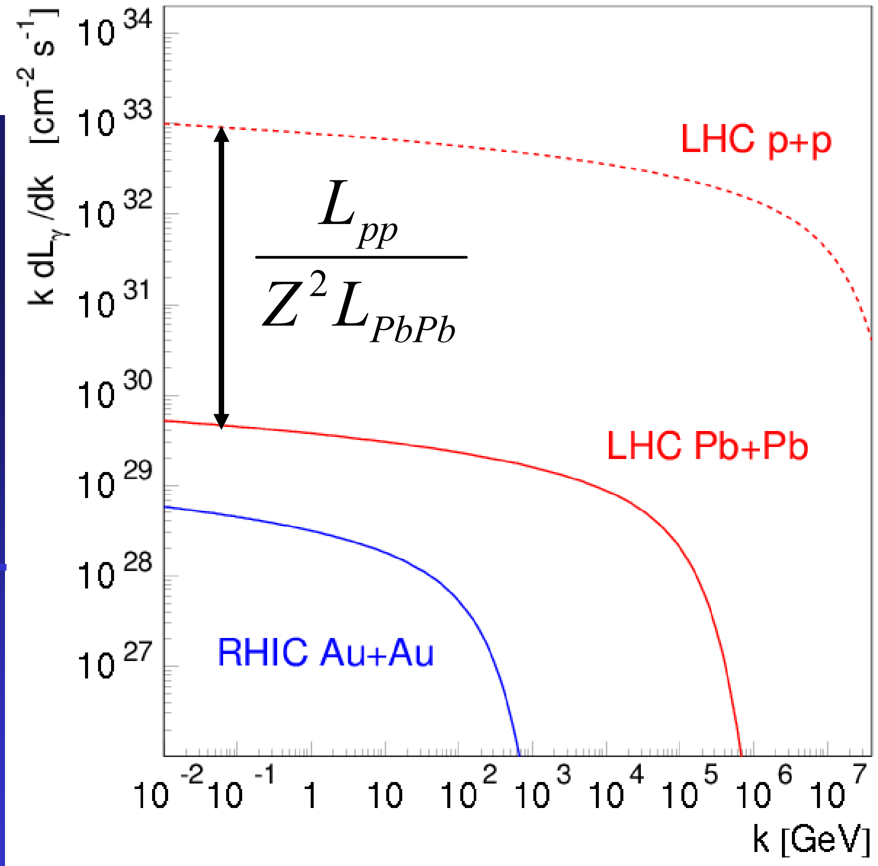
Equivalent photon spectrum of a proton:

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

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

Drees and Zeppenfeld (1989)

Point charge, b>0.7 fm



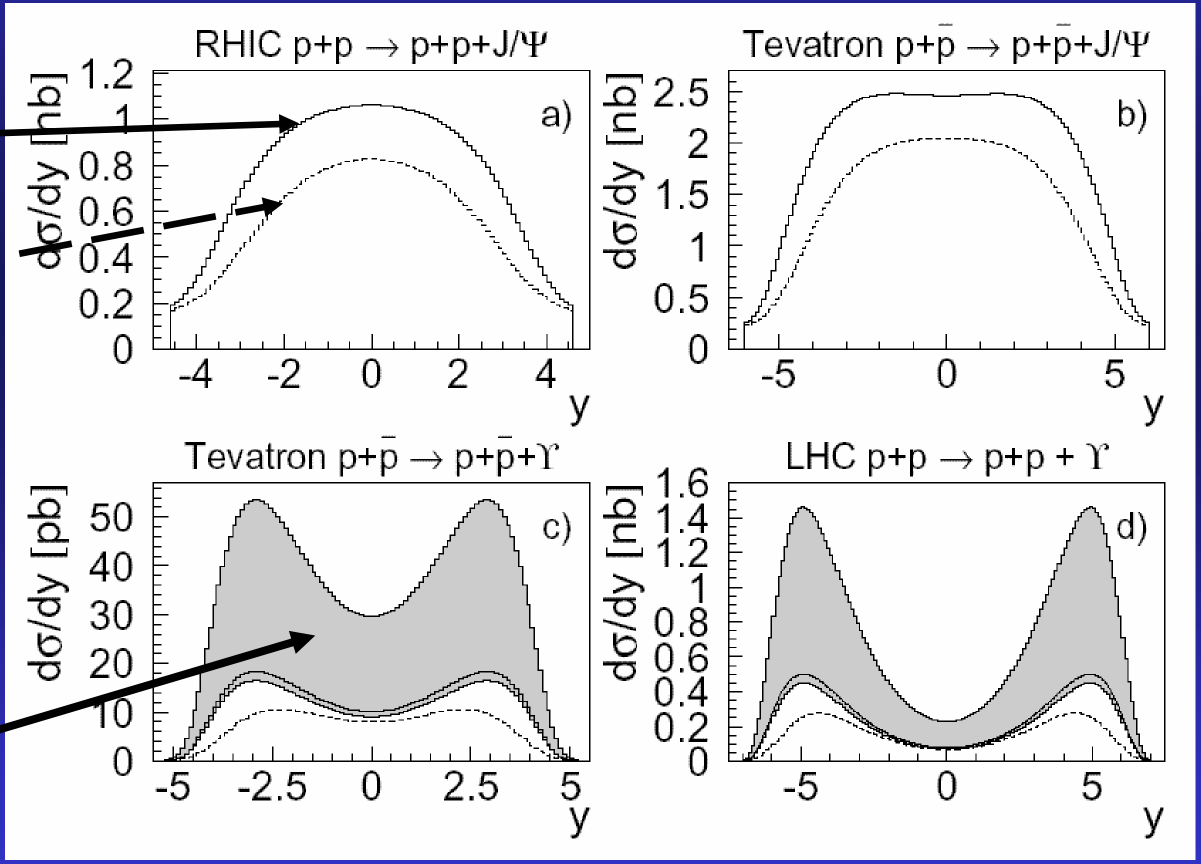
σ(pp→pp+V)

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

Drees&Zeppenfeld photon spectrum

point charge, b>1fm

Uncertainty in experimental cross section (mainly poor statistics).



$\sigma(pp \to pp+V)$

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

Kinematics at mid-rapidity (y=0)

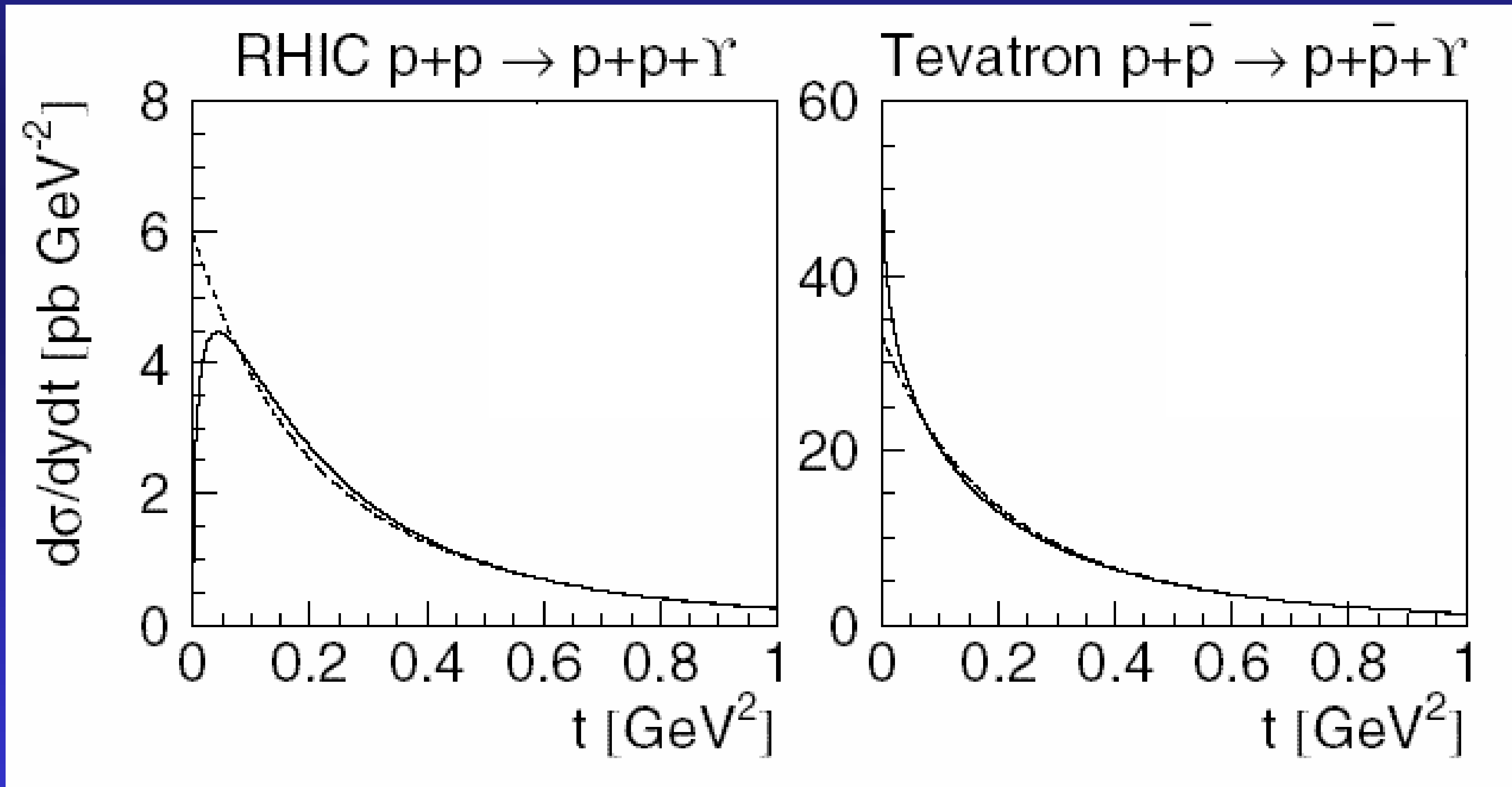
	J/ψ	Υ
Tevatron	$W_{\gamma p}$ = 80 GeV $x \approx 1 \cdot 10^{-3}$	$W_{\gamma p}$ = 130 GeV $x \approx 5 \cdot 10^{-3}$
LHC	$W_{\gamma p}$ = 210 GeV $x \approx 2 \cdot 10^{-4}$	$W_{\gamma p}$ = 350 GeV $x \approx 6 \cdot 10^{-4}$

Lower x can be reached away from y=0, but separation of photon-emitter and photon-target non-trivial.

Transverse momentum spectrum

Dominated by proton form factor

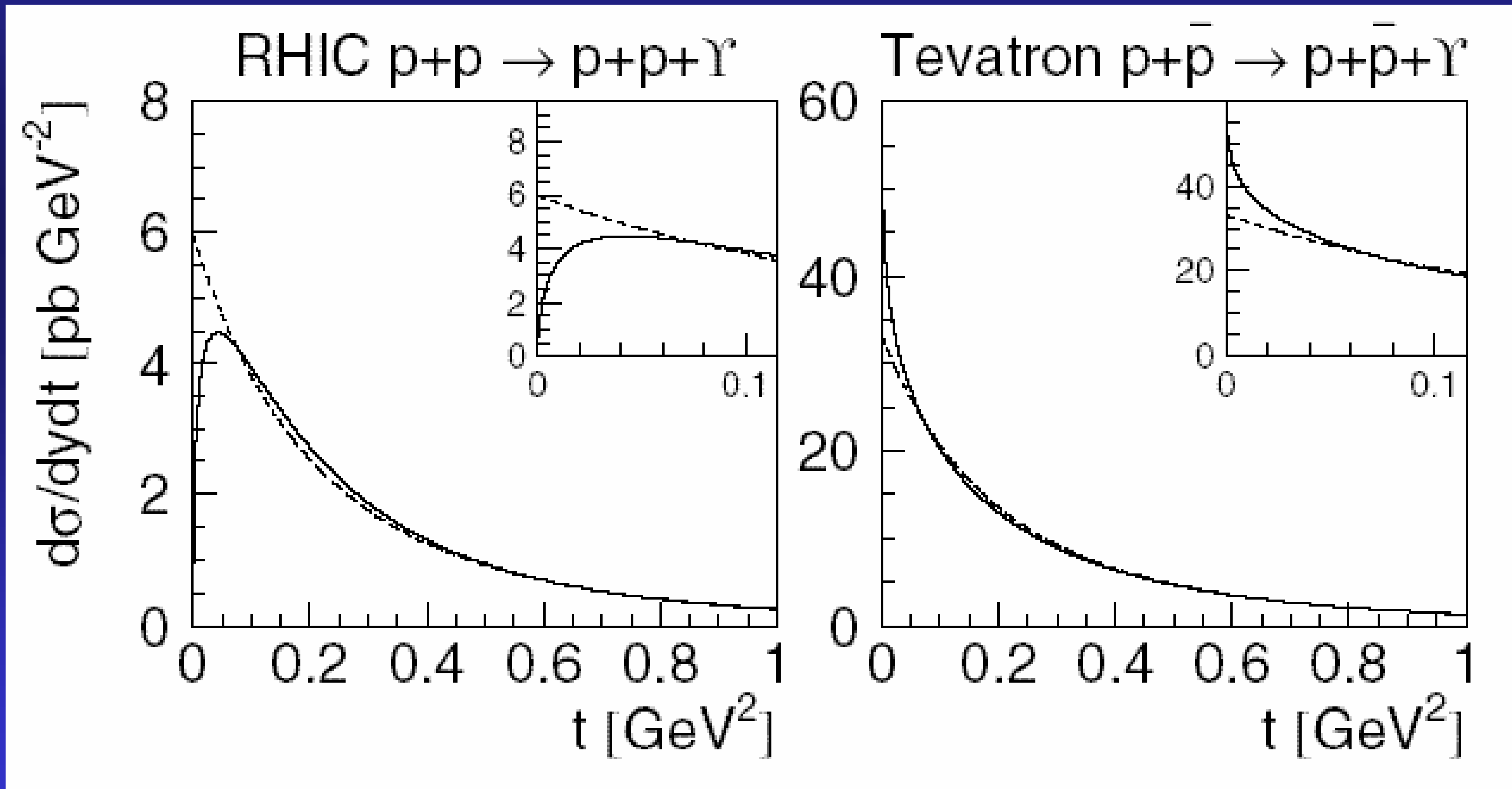
Low $p_T < \sim 1$ GeV/c



Transverse momentum spectrum

Dominated by proton form factor

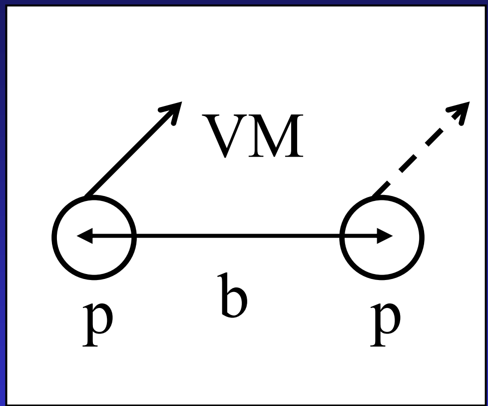
Low $p_T < \sim 1$ GeV/c



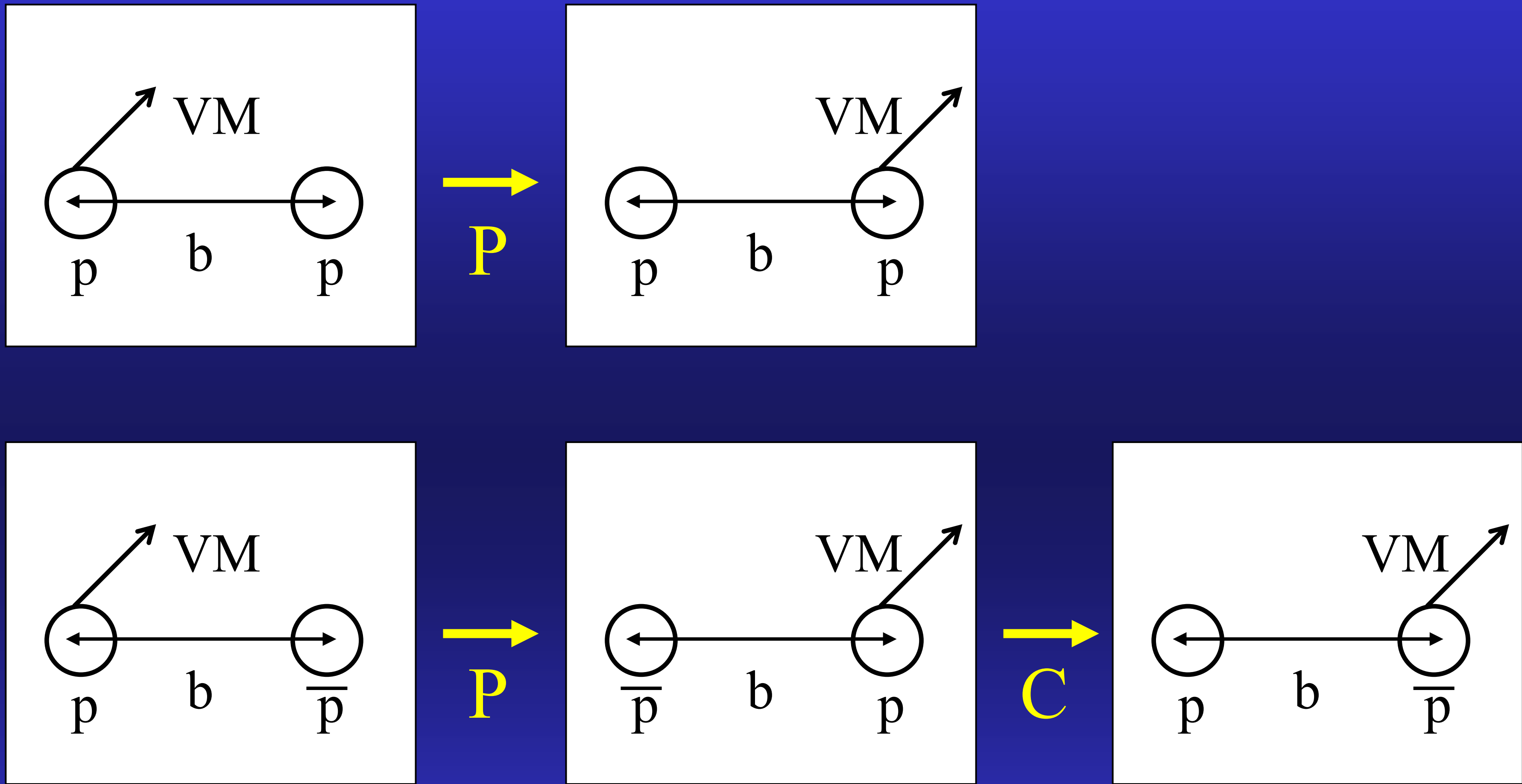
Transverse momentum spectrum

At very low p_T (p_T << 1/<b>), not possible to distinguish photon-emitter and photon-target.

$\Rightarrow$ Add amplitudes (not cross sections) with correct sign.



Exchanging photon-emitter and photon-target



$J^{PC} = 1^{--}$ $\Rightarrow$ Destructive interferenc in pp (AA), constructive interference in $p\bar{p}$.

Comparisons with hadronic production mode (pp)

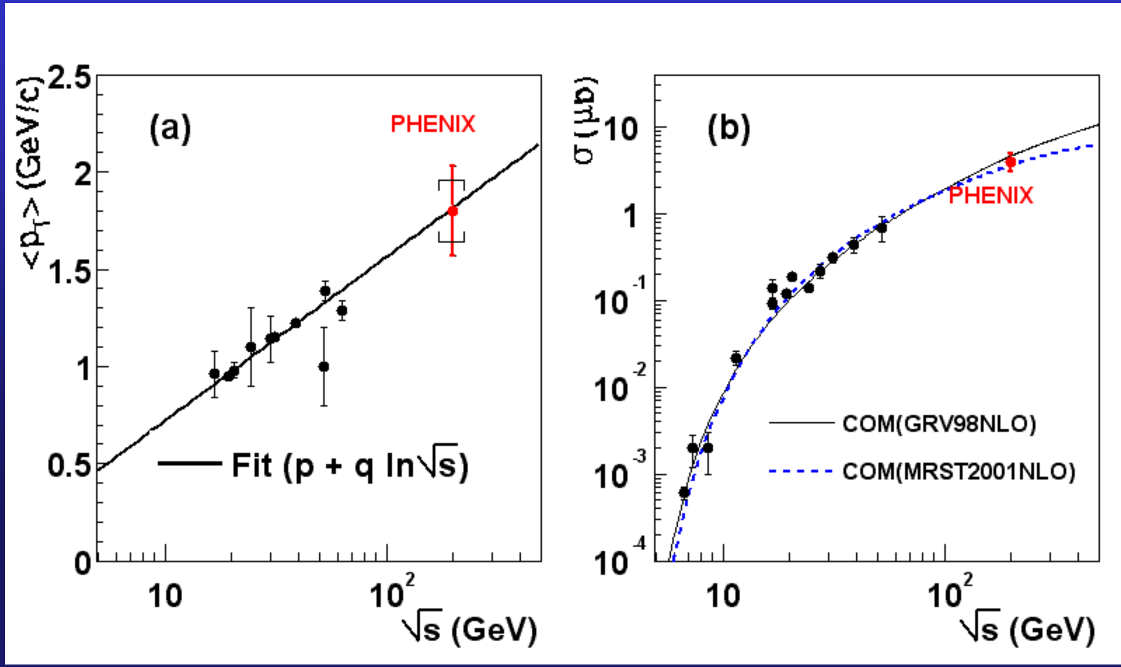
J/Ψ

RHIC, √s=200 GeV:

$\sigma = 2.70 \pm 0.40\ \mu b$

Photoproduction:

$\sigma \approx 7$ nb



S.S. Adler et al. (PHENIX Collaboration) PRL 92(2004)051802, $p+p \rightarrow J/\psi + X$

Υ

Tevatron, √s=1.96 TeV:

$d\sigma/dy|_{y=0} = 30.4 \pm 3.1$ nb

Photoproduction:

$d\sigma/dy|_{y=0} = 10\text{-}25$ pb

Comparisons with hadronic production mode at LHC

$pp \to \Upsilon$:

hadronic: 0.15–0.28 μb*   photo: 3.5 nb

ratio: $\sim 2 \cdot 10^{-2}$

*ALICE PPR / R. Vogt

$PbPb \to \Upsilon$:

Total hadronic (all centralities) $\sigma_{AA} \approx A^2 \sigma_{pp}$

hadronic: 6.5–12.1 mb   photo: 170 μb

ratio: $\sim 2 \cdot 10^{-2}$

Much better background rejection in PbPb:

a) Higher multiplicities (hadronic interactions)

b) Coherence $\Rightarrow$ photoproduced Υ w/ very low p_T

In pp, hadronic 'background' must be suppressed by a factor 10^3!

Rapidity gaps:

$<dn_{ch}/dy> \approx 4 - 6$ in pp at Tevatron/LHC

Probability of having a gap of width Δy:

$$\exp(- <dn_{ch}/dy> \cdot \Delta y)$$

$\Rightarrow \Delta y \approx 2$ will be sufficient

Further rejection from p_T distribution, $p_T < 1$ GeV/c

Some indication of J/ψ at the Tevatron

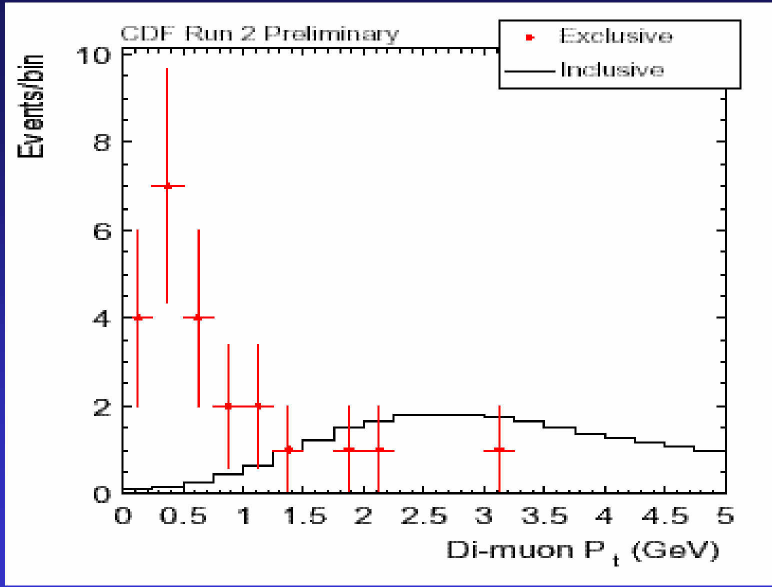
Presented at ”Small-x and Diffraction”, Fermilab, September 2003 (CDF Collaboration, Angela Wyatt)

Searched for $p\bar{p} \rightarrow p\bar{p}+\chi_c$ via Pomeron-Pomeron,

$$\chi_c \rightarrow J/\psi + \gamma$$

Found also a sample of J/ ψ ’s without γ’s !

p_T distribution of exclusive J/ ψ:s:



Kinematics at mid-rapidity - pp vs. PbPb

$W_{\gamma p}$ – photon-proton CM energy

x - Bjorken-x of gluon

y=0	J/ψ	Υ
Tevatron	$W_{\gamma p} = 80$ GeV $x \approx 1 \cdot 10^{-3}$	$W_{\gamma p} = 130$ GeV $x \approx 5 \cdot 10^{-3}$
LHC pp	$W_{\gamma p} = 210$ GeV $x \approx 2 \cdot 10^{-4}$	$W_{\gamma p} = 350$ GeV $x \approx 6 \cdot 10^{-4}$
LHC PbPb	$W_{\gamma p} = 130$ GeV $x \approx 6 \cdot 10^{-4}$	$W_{\gamma p} = 230$ GeV $x \approx 2 \cdot 10^{-3}$

Note: AA and pp competitive for selected reaction channels/final states.

Not suitable for measuring $\sigma_{tot}(\gamma\gamma)$ or $\sigma_{tot}(\gamma p)$, for example.

- Tagging of beam-nuclei not possible.
- $Q^2 \approx \hbar/R \approx 0$.
- The corresponding QCD processes must suppressed.

Summary

- Some more details in PRL 92(2004)142003 (hep-ph/0311164).
- Interesting possibility to study exclusive production of heavy vector mesons in pp and p$\bar{p}$ collisions, and in Ultra-peripheral AA collisions.
- A probe of the nucleon/nucleus gluon density at low Bjorken-x.
- Extends the energy range studied at HERA.