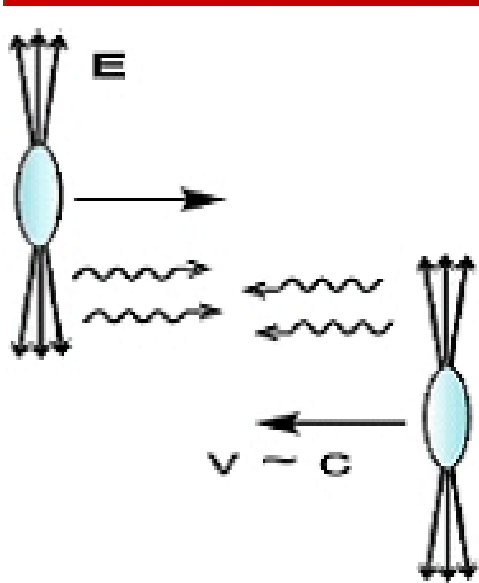


# $J/\Psi$ photo-production in ultra-peripheral collisions

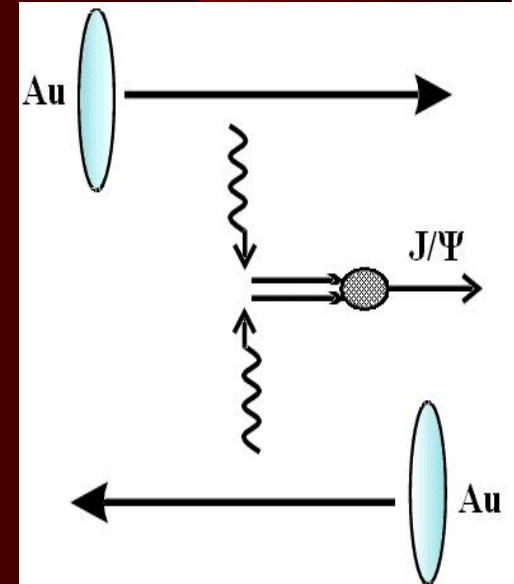
Máté Csanád (Eötvös University, PHENIX)

ADVANCED STUDIES INSTITUTE  
SYMMETRIES AND SPIN (SPIN-Praha-2008)

Prague, July 20 - July 26, 2008



- UPC physics
  - Photon-photon interactions
  - Photon beam in A+A
- Measurements at RHIC
  - Experimental signatures
  - Background
  - Results
- LHC?



# Based on ...

- David d'Enterria for PHENIX QM 2005 nucl-ex/0601001
- David d'Enterria 1<sup>st</sup> Alice Physics Week Erice, Dec 2005
- A lot of thanks ...

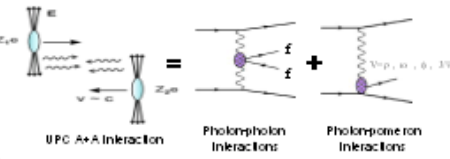
## Coherent photoproduction of $J/\psi$ & high mass $e^+e^-$ pairs in Ultra-Peripheral AuAu Collisions at $\sqrt{s_{NN}} = 200$ GeV

David d'Enterria

for the PHENIX Collaboration

### ULTRAPERIPHERAL COLLISIONS (UPC)

- High-energy ultra-peripheral ( $b > 2R_N \approx 10 - 100$  fm) AA collisions produce strong electromagnetic fields due to the coherent interaction of all nuclear charges.
  - Such strong EM fields constitute a flux of quasi-real photons which can fluctuate into fermion pairs or vector mesons:
- $$|b\rangle = e^+e^- + \sum_{F=photon, \dots} e^+F + \sum_{F=photon, \dots} e^-F + \sum_{F=photon, \dots} e^+F + \sum_{F=photon, \dots} e^-F$$
- and they scatter elastically with the other coherently on nuclei



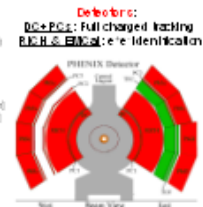
### PHYSICS GOAL

- Measure dielectrons @ mid-rapidity in UPC AuAu - 200 GeV from:
- (1) Coherent  $J/\psi$  production:  $\gamma + A \rightarrow A^* + J/\psi \rightarrow e^+e^-$
  - (2) Dielectron continuum at high  $m_{ee}$ :  $\gamma + \gamma \rightarrow (A^*) + e^+e^-$
- to study: (i) gluon distribution function,  $G(x, Q^2)$ , in nuclei, (ii) Pomeron-exchange factorization, (iii) vector-meson dynamics in nuclear matter.

- High rates expected @ RHIC due to:
  - (i) Large Au charge:  $e_{Au} = Z \cdot Z \cdot e^2 \approx 4 \cdot 10^{-6}$
  - (ii) High  $\gamma$  flux:  $\sim 2 \cdot 10^{14} \text{ cm}^{-2} \text{ s}^{-1}$  @  $R = 6 \text{ GeV}$  for  $\gamma_{cut} = 100$

### LEVEL 1 UPC TRIGGER AuAu RUN-4

- UPC: (ZDCN || ZDCS) && (BBC1L1+V1) && (ERT2x2) (ZDC1L1N || ZDC1L1S) && (BBC1L1S + BBC1L1N) && (ERT2x2)
- Send to  $\gamma + A \rightarrow A^* + J/\psi \rightarrow e^+e^-$ :
- Veto on BBC ( $y = \pm 3.4$ ) (exclude periph. nuclear & beam-gas)
  - Neutron(s) in at least one ZDC (from Au<sup>+</sup> Coulomb dissociation)
  - Large energy (>0.8 GeV) cluster in ZDC (e<sup>+</sup>e<sup>-</sup> decay from J/ $\psi$ )
- Total data size: 1352 PRDFF: ~0.8 GB/ite ~ 1.04 TB
- Total cost (estimated) in months:  $L_{int} = 120 \mu\text{b}^{-1}$



### DATA ANALYSIS

- Global cut:  $|z_{vtx}| < 30$  cm, track multiplicity  $< 15$
- Single-track cut:
- $N_{tr} \geq 2$  (# of RICH phototubes fired by e<sup>+</sup>)
  - $E > 0.8$  GeV ( $E_e > 0.8$  GeV [ERT threshold])
  - No dead-wire lower around assoc. EMCal cluster [CUT-EMC matching, e<sup>+</sup>e<sup>-</sup> candidates]
- Pair cut:  $m_{ee} = m_{ee}$  (back-to-back dielectrons)
- Background subtraction: [like-sign] - [like-sign]
- Full GEANT MC for  $J/\psi$  & high mass e<sup>+</sup>e<sup>-</sup> continuum based on physics input from Stachel model [1-3]

### PRELIMINARY RESULTS

- Invariant mass distribution of unlike-sign and like-sign e<sup>+</sup>e<sup>-</sup> pairs:
- $dN/dm_{ee}$  (backgrounds subtracted w/fit to MC) expected dielectron continuum and  $J/\psi$  signals:
- $J/\psi$  invariant mass distribution (e<sup>+</sup>e<sup>-</sup> pairs minus dielec. continuum)
- $p_T$  distribution of e<sup>+</sup>e<sup>-</sup> pairs: peaked at very low  $p_T$  → coherent production ( $p_T < \sim 2$  GeV/c @  $R = 50$  MeV)

Excellent agreement with  $J/\psi$  peak position & width from full MC.

References:

- [1] J. Nystrand, NPA 792 (2005) 470c;
- [2] A. J. Baltz, S. R. Klein, J. Nystrand, PRL 89 (2002) 012301;
- [3] S. R. Klein, J. Nystrand, PRC 60 (1999) 014603;
- [4] M. Shkhanov, M. Tsvetkov and M. Zhabov, hep-ex/0509023

— David d'Enterria —  
Physics Labs, Columbia University, NY

# Introduction

- **Nonlinear QCD dynamics at small  $x$  and  $Q^2$  is one of the focal points of theoretical activity**
  - $Q^2$  for coupling quarks even smaller,  $\sim 1 \text{ GeV}^2$ , black disk limit
  - Mixing of perturbative and nonperturbative effects at small  $x$  and  $Q^2$
  - Interested in gluon distributions  $G(x, Q^2)$

- **Photon to vectormeson processes: sensitivity to gluon distribution at small  $x$ , cross-section (with  $Q^2=M_V^2/4$ ,  $x=M_V^2/W_{\gamma N}^2$ ):**

$$\left. \frac{d\sigma(\gamma N \rightarrow VN)}{dt} \right|_{t=0} \approx \frac{\alpha_s \Gamma_{ee}}{3\alpha_e M_V^5} 16\pi^3 \left( xG(x, Q^2) \right)^2$$

- **Photon-photon processes: tested in  $e^+e^-$  or  $ep$  (HERA)**
- **Possible new directions:**
  - higher energies
  - nuclear beams

# Photon-photon interactions

- High-energy  $\gamma\gamma$ : complementary to "conventional"  $e^+e^-$ , ep (DIS), or pp collisions (to study QCD/QED, or even beyond-SM)
- High energy photon: point-like interaction or quantum-fluctuation into a vector meson or quark-pair

$$|\gamma\rangle = c_0 |\gamma_0\rangle + \sum_{V=\rho^0, \omega, \Phi, J/\Psi, \Upsilon} c_V |V\rangle + \sum_{q=u, d, s, c, b} c_q |q\bar{q}\rangle + \sum_{l=e, \mu, \tau} c_l |l\bar{l}\rangle$$

- $\gamma_0$  dominates, but  $\gamma \rightarrow V, qq$  fluctuations interact strongly and give largest contribution to  $\gamma\gamma$  cross-sections

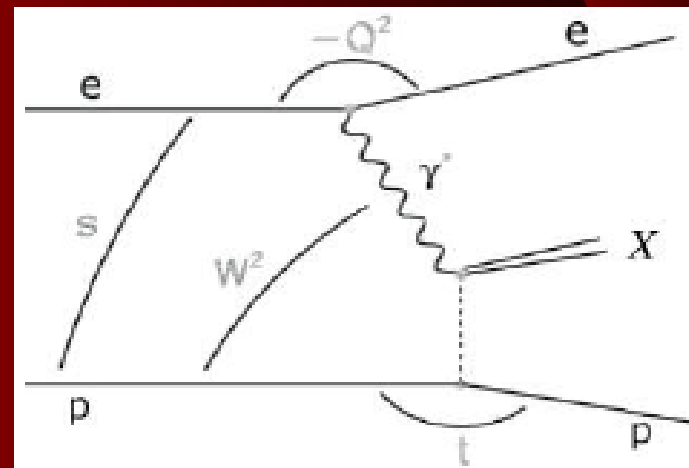
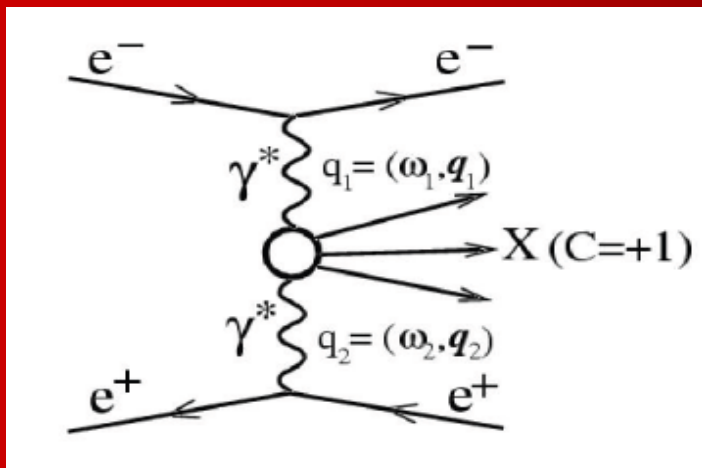
# How to make $\gamma\gamma$ collisions?

- EM field of relativistic charged particle = flux of “equivalent” photons.

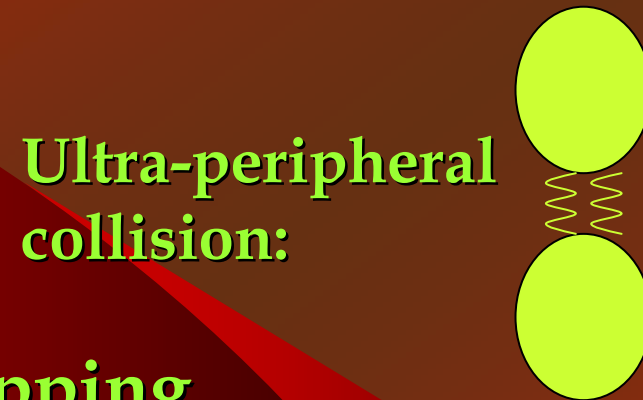
- Weizsacker-Williams formula for  $\gamma$ -spectrum in an  $e^\pm$  beam (with  $z=E_\gamma/E_e$ ):

$$\frac{dN}{dz} \approx \frac{\alpha_{em}}{2\pi} \frac{1}{z} \left( 1 + (1-z)^2 \right) \ln \frac{Q_{max}^2}{Q_{min}^2} \quad Q_{min}^2 = \frac{m_e^2 z^2}{1-z} \quad Q_{max}^2 = m_V^2 \text{ (e.g.)}$$

- Scattered beam close to parent beam (kinematics)  
 $\Rightarrow$  low  $p_t$  products & quasi-real photons ( $Q^2 \sim 0$ )



# $\gamma\gamma$ in nucleon-nucleon collisions



- Two heavy nuclei not overlapping
  - $b > b_{\min} \approx 2R$
  - Ultra-Peripheral Collision (UPC)
- Emitting a quasi-real photon
  - $z = E_\gamma / E_A$ ,  $x = z m_A b_{\min} / K \dots$  Bessel functions
  - flux: 
$$\frac{dN_\gamma}{dz} \approx \frac{\alpha_{\text{em}} Z^2}{2\pi} \frac{1}{z} \left( 2xK_0(x) - x^2 \left( K_1^2(x) - K_0^2(x) \right) \right)$$
- Interacts with the other nucleus
- Large photon cross-sections ( $\sim Z^4$ )

# Where all this is done: BNL@RHIC

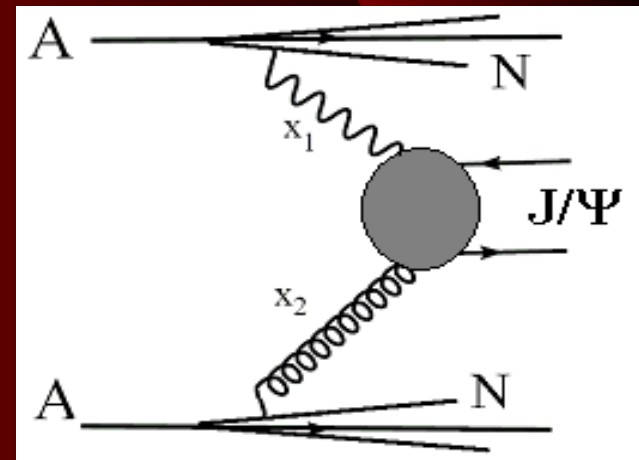
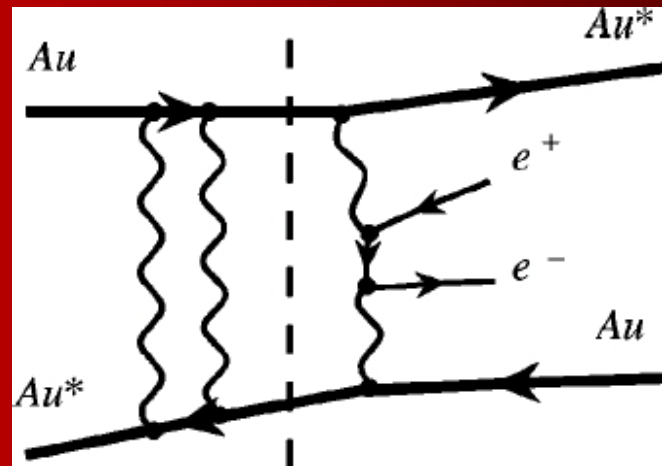
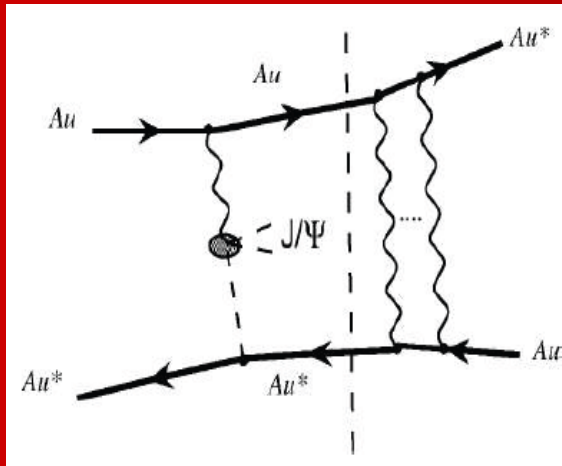
- **RHIC: Au+Au @  $E_{\text{cms}} = 200$  GeV/nucleon**
  - Au+Au, Cu+Cu, pp+pp, d+Au collisions
  - 4 experimental collaborations:  
BRAHMS, PHENIX, PHOBOS, STAR
- **PHENIX: several hundred scientist, a lot of topics**
- **See earlier talks of Rachid Nouicer, David Kawall and Atsushi Taketani**



# J/Ψ production in UPC's

- Different type of processes

- Dielectron continuum:  $A + \gamma + \gamma \rightarrow A^* + e^+ e^-$
- Coherent J/Ψ production:  $\gamma + A \rightarrow A^* + J/\Psi (\rightarrow e^+ e^-)$
- Incoherent production (Coulomb-breakup):  
 $A + A \rightarrow A' + A'' + xN + \gamma + g \rightarrow A' + A'' + xN + J/\Psi (\rightarrow e^+ e^-)$





# Experimental signatures

- **Central rapidities:**

- Low multiplicities:  $N < 15$  (well below 15)
- Low total  $p_t$  (large wavelength, “coherence condition”):  $E_{\text{photon,max}} \sim \gamma/R \sim 3\text{GeV}$  (80GeV at LHC)
- Zero net charge
- Narrow  $dN/dy$  peaked at  $y=0$  (tagging/triggering)

- **Forward rapidities:**

- Coulomb-excited  $A^*$  dissociation via (forward) neutron ( $Xn$ ) emission

# Measured processes in Au+Au UPC

## STAR:

- PRL 89 272302 (02), Coherent  $\rho$  production,  $\gamma+A \rightarrow A^*+\rho(\rightarrow\pi^+\pi^-)$
- PRC 70 031902 (04), Dielectron continuum at low  $m_{inv}$ ,  $\gamma+\gamma \rightarrow e^+e^-$
- PHENIX (nucl-ex/0601001, QM proc):
  - Coherent  $J/\Psi$  production:  $\gamma+A \rightarrow A^*+J/\Psi(\rightarrow e^+e^-)$
  - Dielectron continuum at high  $m_{inv}$ :  $\gamma+\gamma \rightarrow e^+e^-$
  - Incoherent production: work in progress

# Eliminating background sources

- **“Non-physical”:**

- Cosmic rays: no ZDC, no good vtx.
- Beam-gas collision: no good vertex, large multiplicity, asymmetric  $dN/dy$

- **Physical processes:**

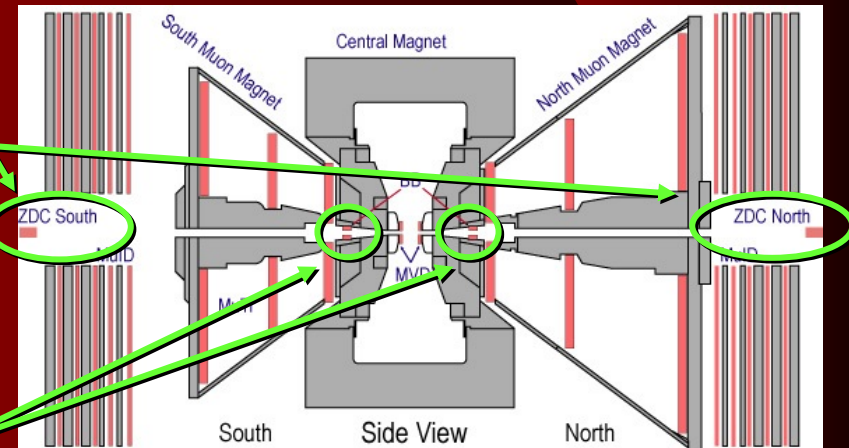
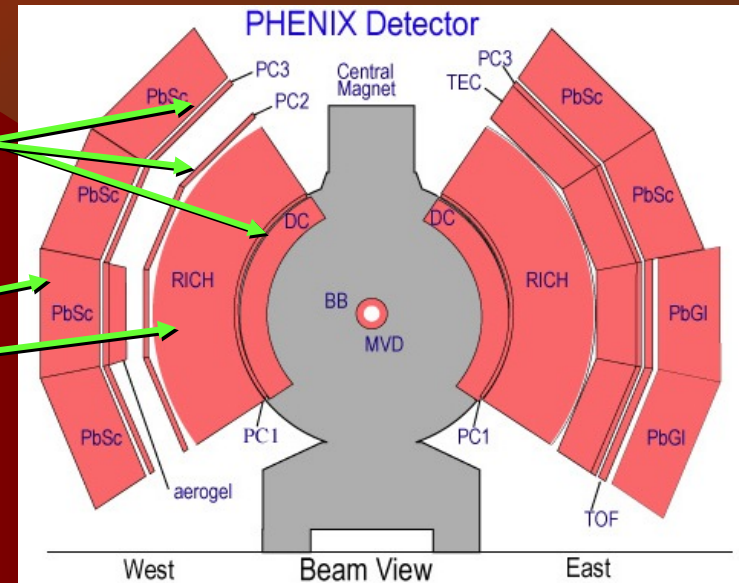
- Peripheral nuclear A+A: “large” multiplicity, large  $p_t$
- Hadronic diffractive (Pomeron-Pomeron): forward proton emission, larger  $p_t$ :  $p_t(\gamma\gamma) < p_t(PP)$ , like-sign pairs. Hard-diffractive  $J/\Psi$  production.
- Incoherent UPC  $\gamma+n \rightarrow n+J/\Psi$  :  $p_t(\gamma\gamma) < p_t(\gamma P)$ , wider & asymm.  $dN/dy$ ,  $\geq 2$  neutrons (induced nuclear break-up) with same direction as  $J/\Psi$ .
- Other coherent UPC processes:  $\gamma\gamma \rightarrow e^+e^-$  (important),  $\gamma A \rightarrow \text{jet}+A$  (lower cross-sections)

trigger level

final signal

# PHENIX detectors for UPC

- DC + PC's: Full central-arm charged tracking ( $e^\pm$  momentum)
- EMCal + RHIC:  $e^\pm$  identification in central rapidity.
- ZDC: Forward neutron detection ( $Au^*$  dissociation):
- BBC: charged tracks



# Triggering on UPC's

- **PHENIX Run-4 AuAu UPC level-1 trigger:**

- Sensitive to  $\gamma + \text{Au} \rightarrow \text{Au}^* + \text{J}/\Psi (\rightarrow e^+e^-)$

- **Veto on coincident BBC ( $|\eta| \sim 3-4$ ):**

- avoid periph. nuclear, beam-gas colls.

- **Neutron in ZDC ( $E > 30 \text{ GeV}$ )**

- sensitive to  $\text{Au}^*$  Coulomb dissociation

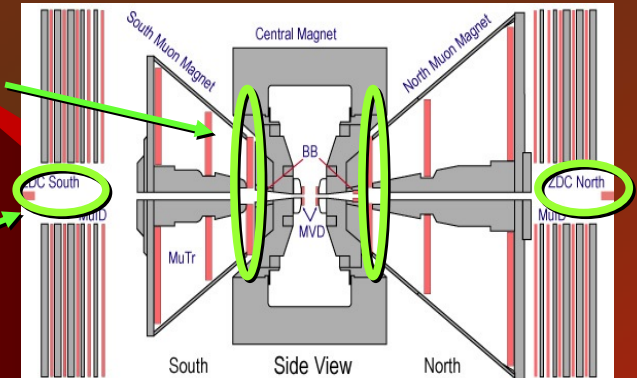
- **Large energy ( $E > 0.8 \text{ GeV}$ ) cluster in EMCAL:**

- $e^+e^-$  decay from  $\text{J}/\Psi$

- **Trigger definition based on the above**

- **Events collected ( $\sim 0.4\%$  of MB trigger):**

- UPC AuAu: 8.5 M
- MinBias AuAu (BBCLL1): 1122 M ( $\int L = 120 \mu\text{b}^{-1}$ )

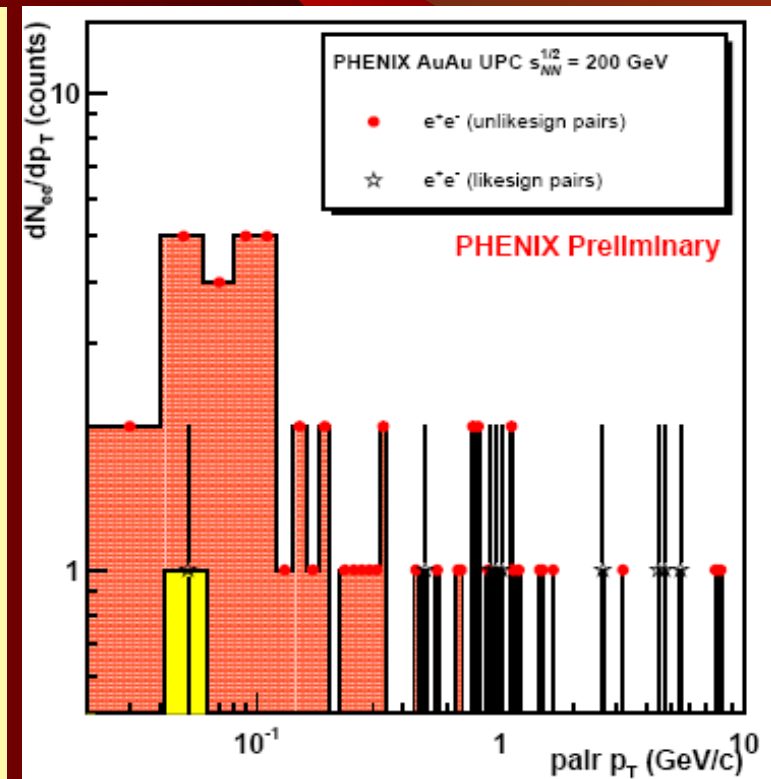
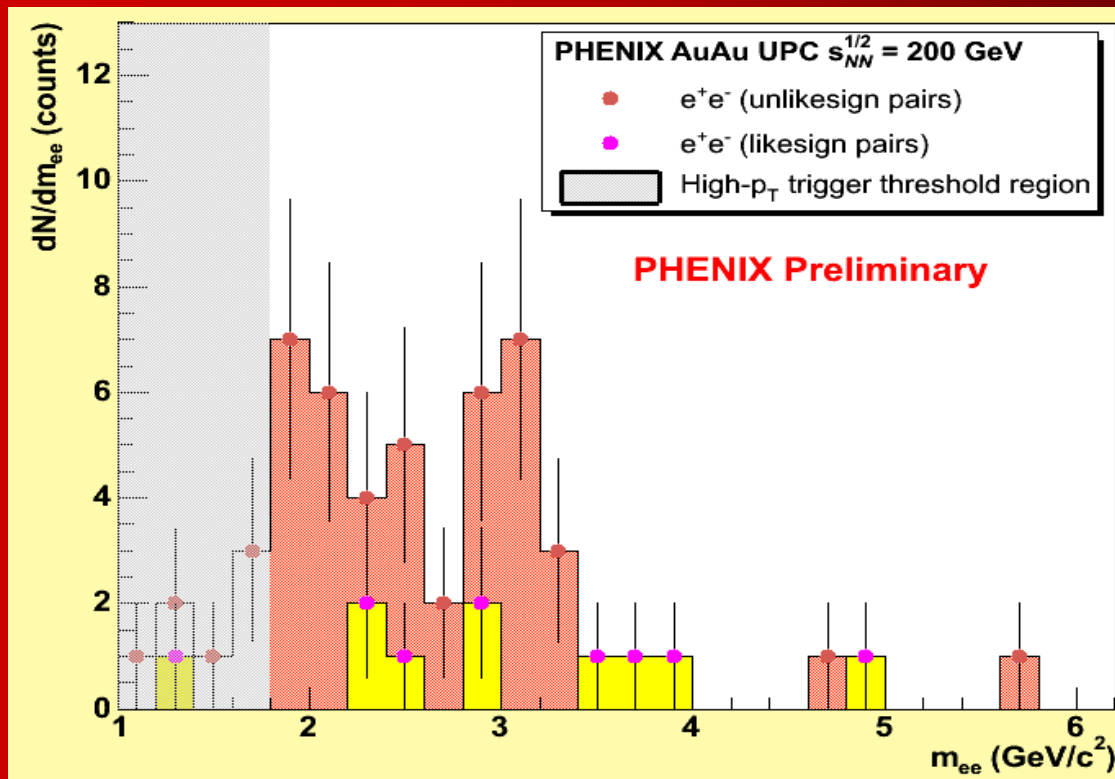


# PHENIX UPC analysis cuts

- **Cuts made on the 8.5M UPC triggered events**
- **Global cuts:**
  - Standard vertex cut:  $|z_{\text{vtx}}| < 30$  cm
  - Multiplicity (number of tracks)  $< 15$ , removes non-UPC
- **Electron ID cuts:**
  - RICH: # of photo-tubes within nominal ring radius  $> 2$
  - Electrons:  $E_1 > 1$  GeV or  $E_2 > 1$  GeV, high- $p_t$  trigger threshold
- **Pair cuts:**
  - Dielectrons back-to-back (low sum  $p_t$ )
- **Residual background subtraction:**
  - unlike-sign pairs – like-sign pairs

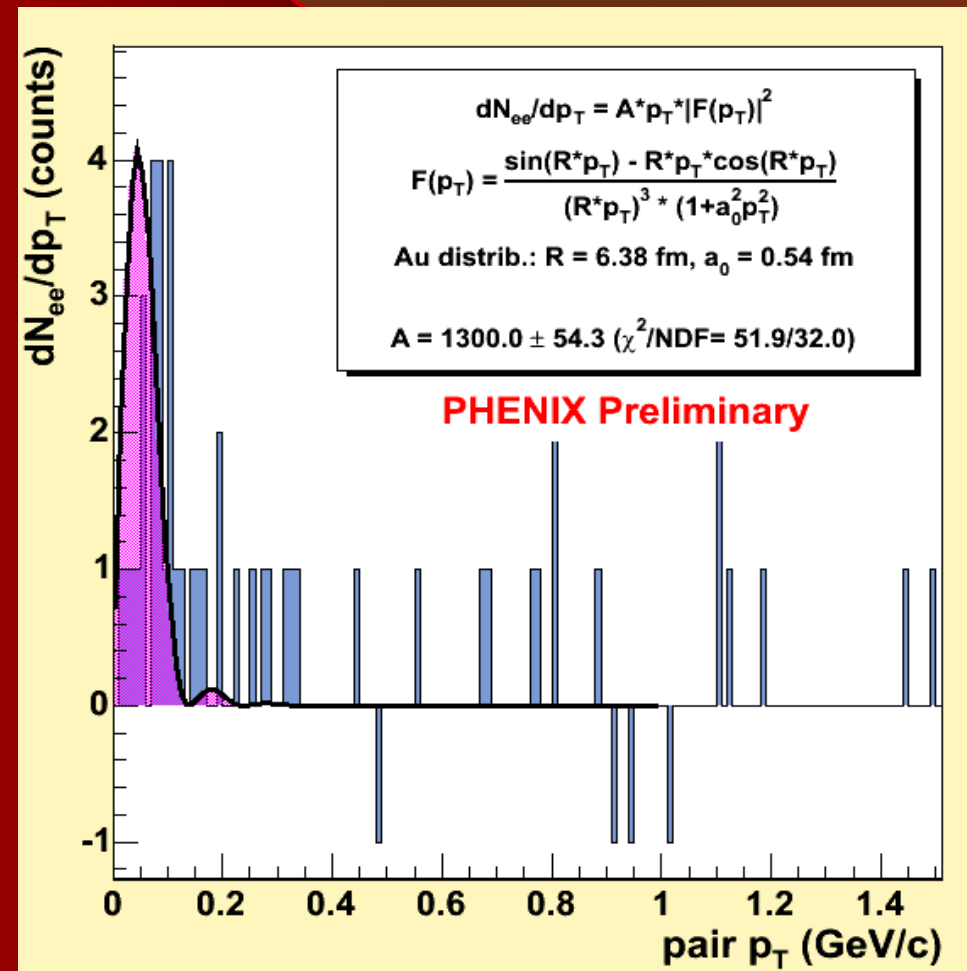
# Resulting distributions

- Invariant mass distribution with continuum background
- Pair transverse momentum distribution
- Unlike-sign (red) and like-sign (yellow) pairs



# Transverse momentum distribution

- Nuclear form factor fit (J.Nystrand, nucl-th/0112055)
- Unlike minus like sign pairs
- $dN/dp_t$  peak at  $p_t \sim 90$  MeV/c
- Shape in accordance with simulation

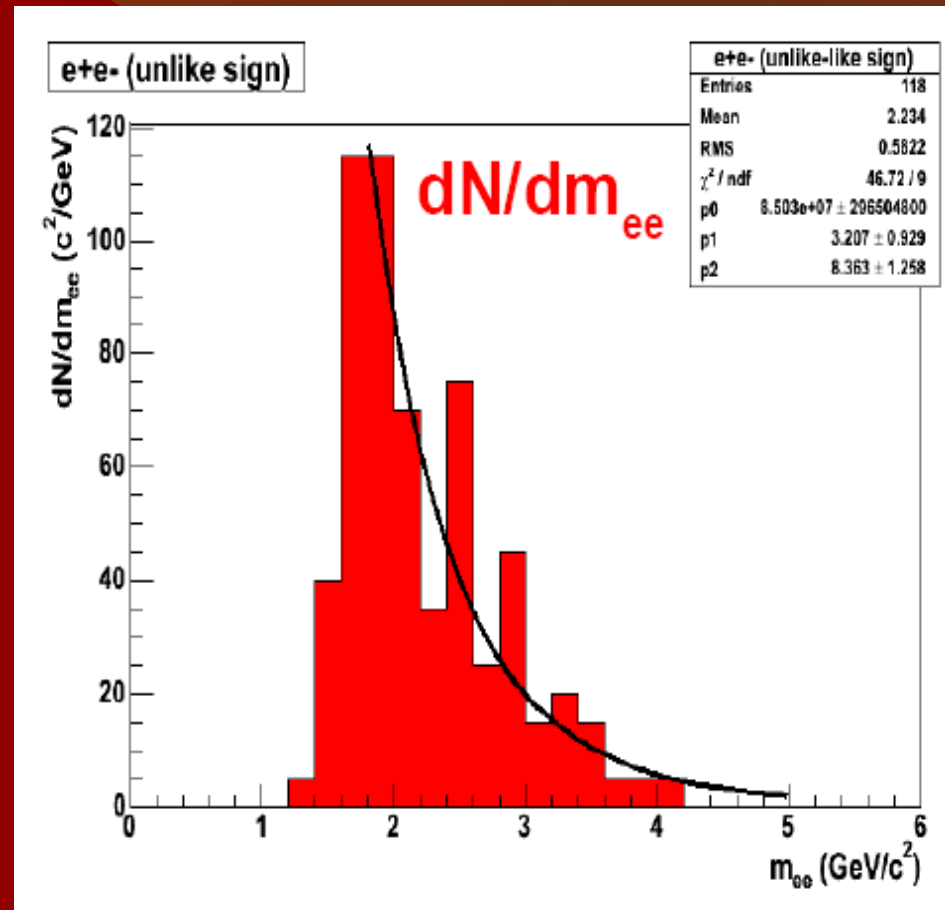




# Background subtraction

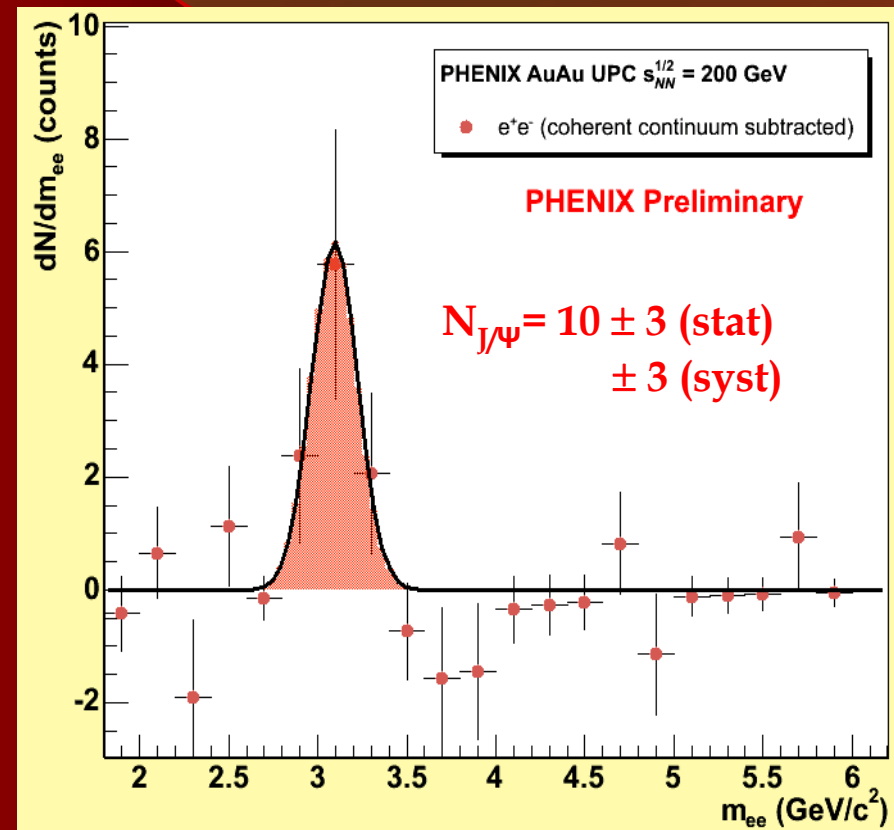
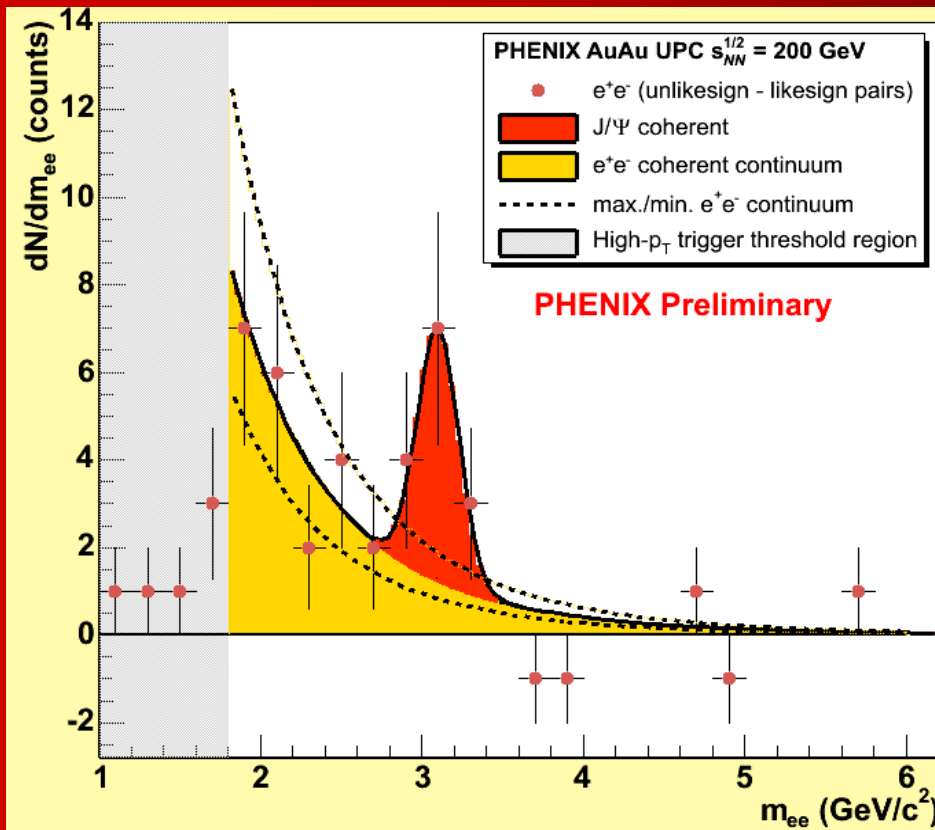
- Starlight Monte Carlo simulation
- Determine continuum shape
- 700k  $e^+e^-$  pairs with  $m_{inv} > 1.5$  GeV,  $500 \mu\text{b}^{-1}$
- Fit:  $A/(m_0+m)^b$
- $m_0=3.2, b=8.36$

J. Nystrand, hep-ph/0412096, NPA752(2005)470



# Background subtraction

- $dN/dm_{inv}$  with continuum fit from MC (see above):  $A/(m_0+m)^b$
- Normalized at  $m_{inv} = 1.8 - 2.2 \text{ GeV}/c^2$



- Continuum in good agreement with theoretical input
- J/ $\Psi$  peak & width also (theoretical input + full MC resp.+reco)

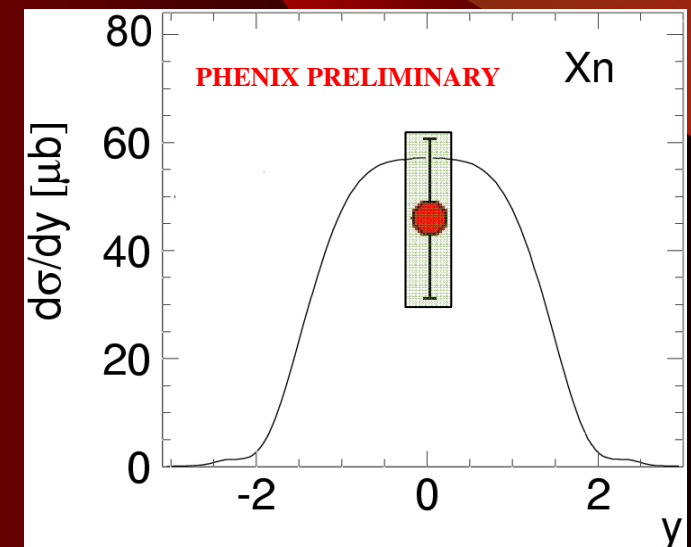
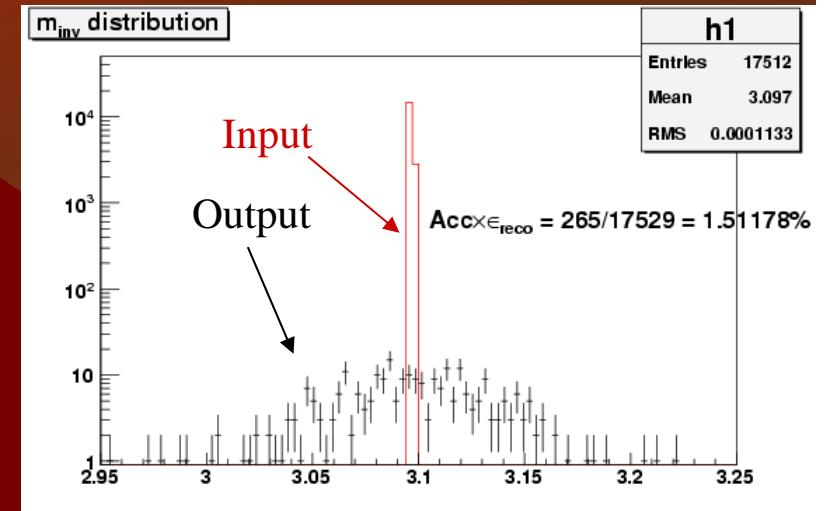
# Cross-section extraction

- Result:  $N_{J/\Psi} = 10 \pm 3 \pm 3$

- Efficiency corrections:

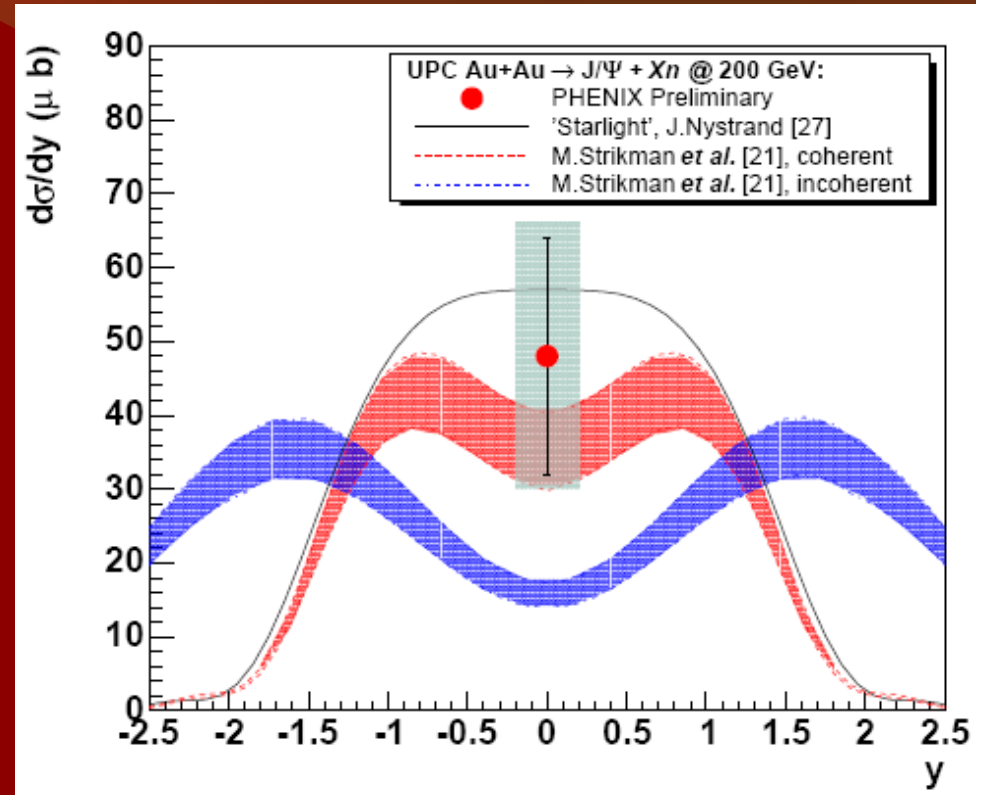
$$\left. \frac{d\sigma_{J/\Psi}}{dy} \right|_{|y| < 0.5} = \frac{1}{BR \cdot Acc \cdot \epsilon_{reco} \cdot \epsilon_{trigg} \cdot L \cdot \Delta y} N_{J/\Psi}$$

- Branching ratio: 5.9%
- Acceptance: 5.7%
- Reco. efficiency: 56.4%
- Trigger efficiency: 90%
- $L = 120 \mu\text{b}^{-1}$
- $\sigma_{J/\Psi} = 48 \pm 16 \pm 18 \mu\text{b}$
- Agreement with theoretical results ☺



# Cross-section results

- Agreement with theoretical results
  - Starlight: J.Nystrand, S. Klein NPA 752(2005)470
  - Strikman et al., hep-ph/0505023
- Main systematic error: coherent continuum
- Statistical errors: larger luminosity
- Present status: detailed study of  $G_A(x, Q^2)$ ,  $J/\Psi$  absorption in cold nuclear matter not possible
- Final data on the way



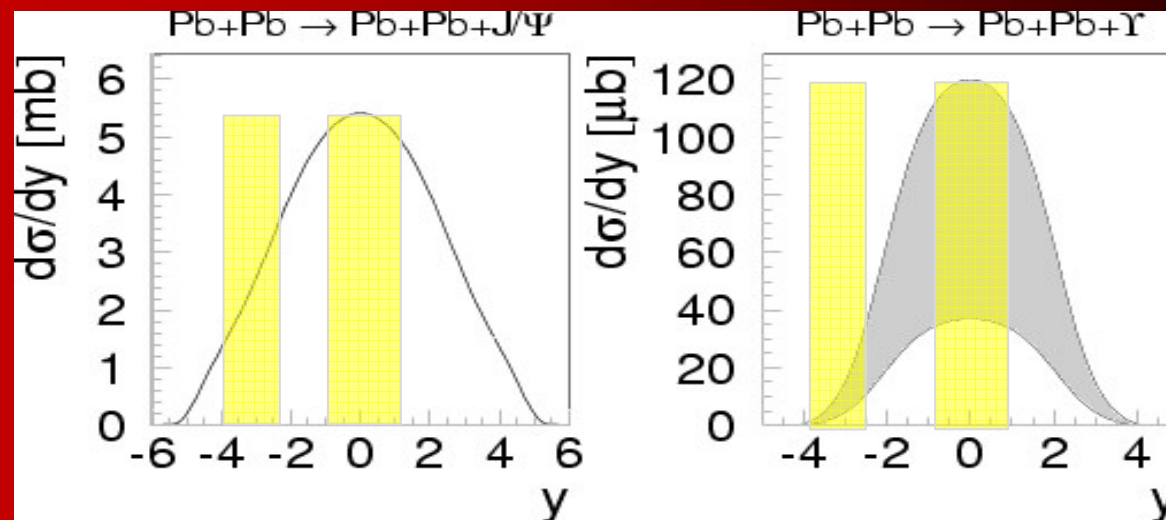
# LHC prospects

Cross-sections from J. Nystrand, hep-ph/0412096, NPA752(2005)470

Accelerator	Hadroproduction $p + p \rightarrow V + X$	Photoproduction $p + p \rightarrow p + p + V$
RHIC $\sqrt{s} = 0.2$ TeV, $V = J/\Psi$	$4.0 \pm 0.9 \mu\text{b}$	3.0 nb
LHC $\sqrt{s} = 5.5$ TeV, $V = J/\Psi$	19-48 $\mu\text{b}$	54 nb
LHC $\sqrt{s} = 5.5$ TeV, $V = \Upsilon(1S)$	190-280 nb	720 pb

Accelerator	Hadroproduction $A + A \rightarrow V + X$	Photoproduction $A + A \rightarrow A + A + V$
RHIC $\sqrt{s_{nn}} = 0.2$ TeV, $V = J/\Psi$	160 mb	290 $\mu\text{b}$
LHC $\sqrt{s_{nn}} = 5.5$ TeV, $V = J/\Psi$	820-2100 mb	32 mb
LHC $\sqrt{s_{nn}} = 5.5$ TeV, $V = \Upsilon(1S)$	8-12 mb	170 $\mu\text{b}$



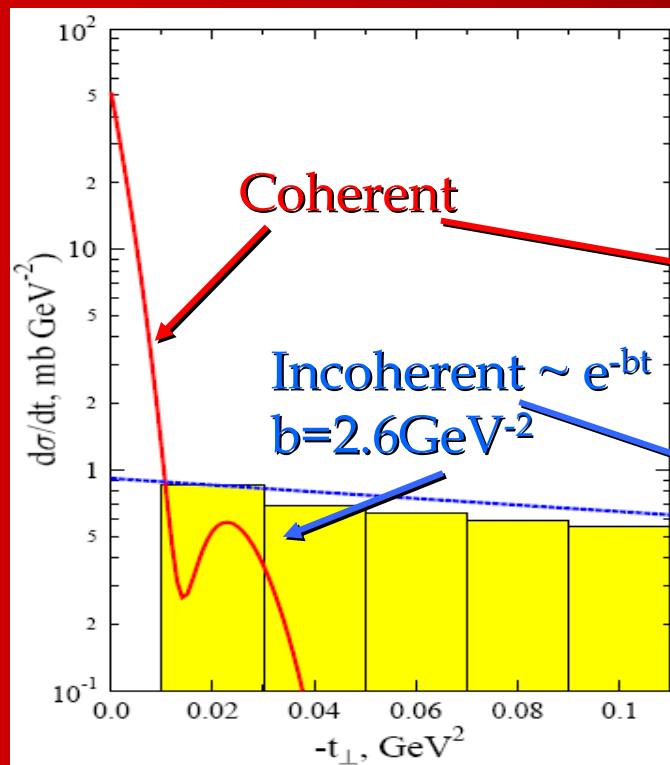
# Summary

- **UPC collisions: high energy photon beam**
- **Precision QCD**
  - Low background, simple initial state
  - Complimentary to conventional  $e^+e^-$  or  $ep$
- **First results from RHIC**
  - Efficient trigger, simple analysis
  - Good theoretical description
  - Main systematic uncertainty: dielectrons
  - No strong constraint on model ingredients yet
- **To be continued at LHC**
  - Incoherent processes, continuum cross-section
  - Higher rates and energies

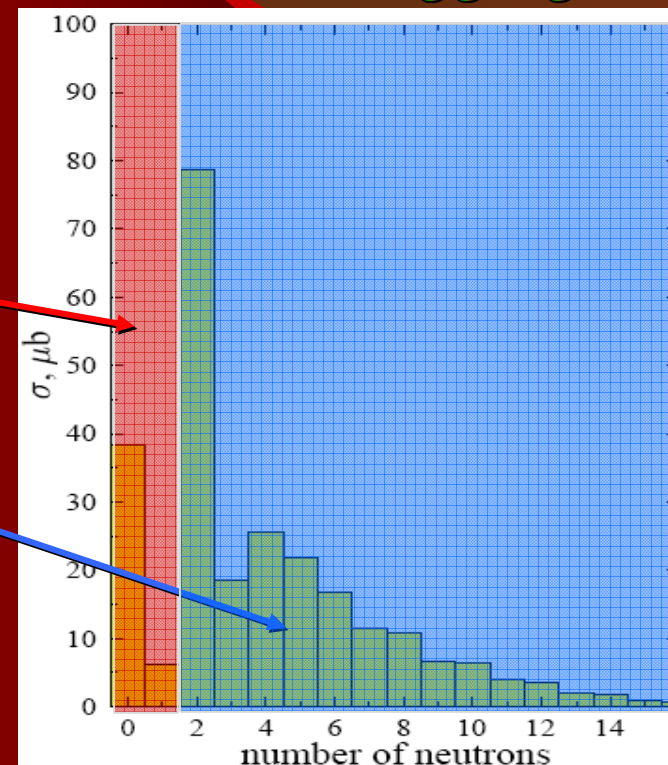
# Incoherent $J/\Psi$ production

- Via Coulomb-breakup
- How to separate from the coherent? Strikman:

Via  $t$  distribution



Via neutron tagging



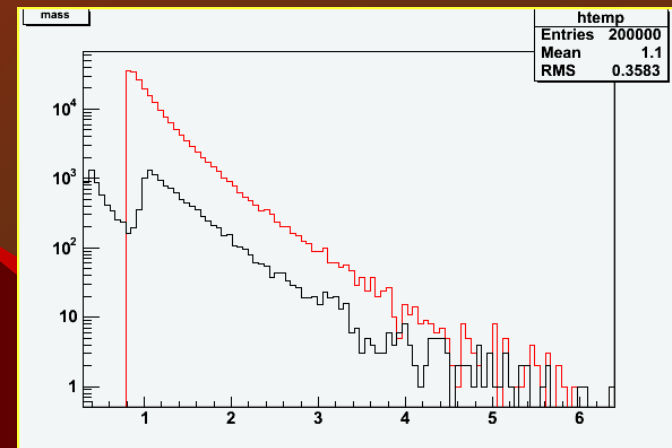
Strikman et al., hep-ph/0505023

- Approved results yet to come

# Continuum cross-sections

- **Efficiency, correction:**
  - No branching ratio, efficiencies have to be determined

$$\left. \frac{d\sigma_{\text{cont}}}{dy} \right|_{|y| < 0.5} = \frac{N_{\text{cont}}}{Acc \cdot \epsilon_{\text{reco}} \cdot \epsilon_{\text{trigg}} \cdot L_{\text{int}}}$$



- **Results: approved data yet to come**
  - E.g. two  $m_{\text{inv}}$  bins,  $d\sigma/dy |_{|y| < 0.5}$  to calculate
  - Results soon
- **Systematic errors:**
  - Acceptance correction: 10%
  - dep cut: 5% vs 10%