J/Ψ photo-production in ultra-peripheral collisions

Máté Csanád (Eötvös University, PHENIX)

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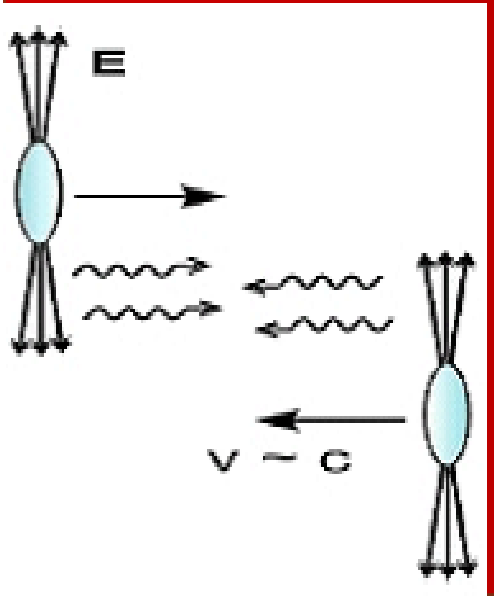
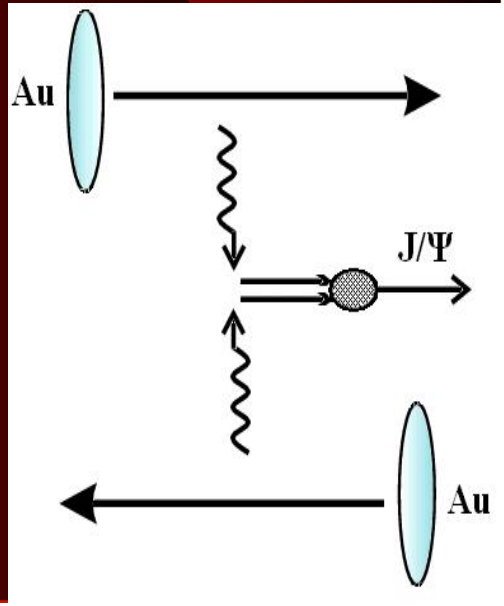
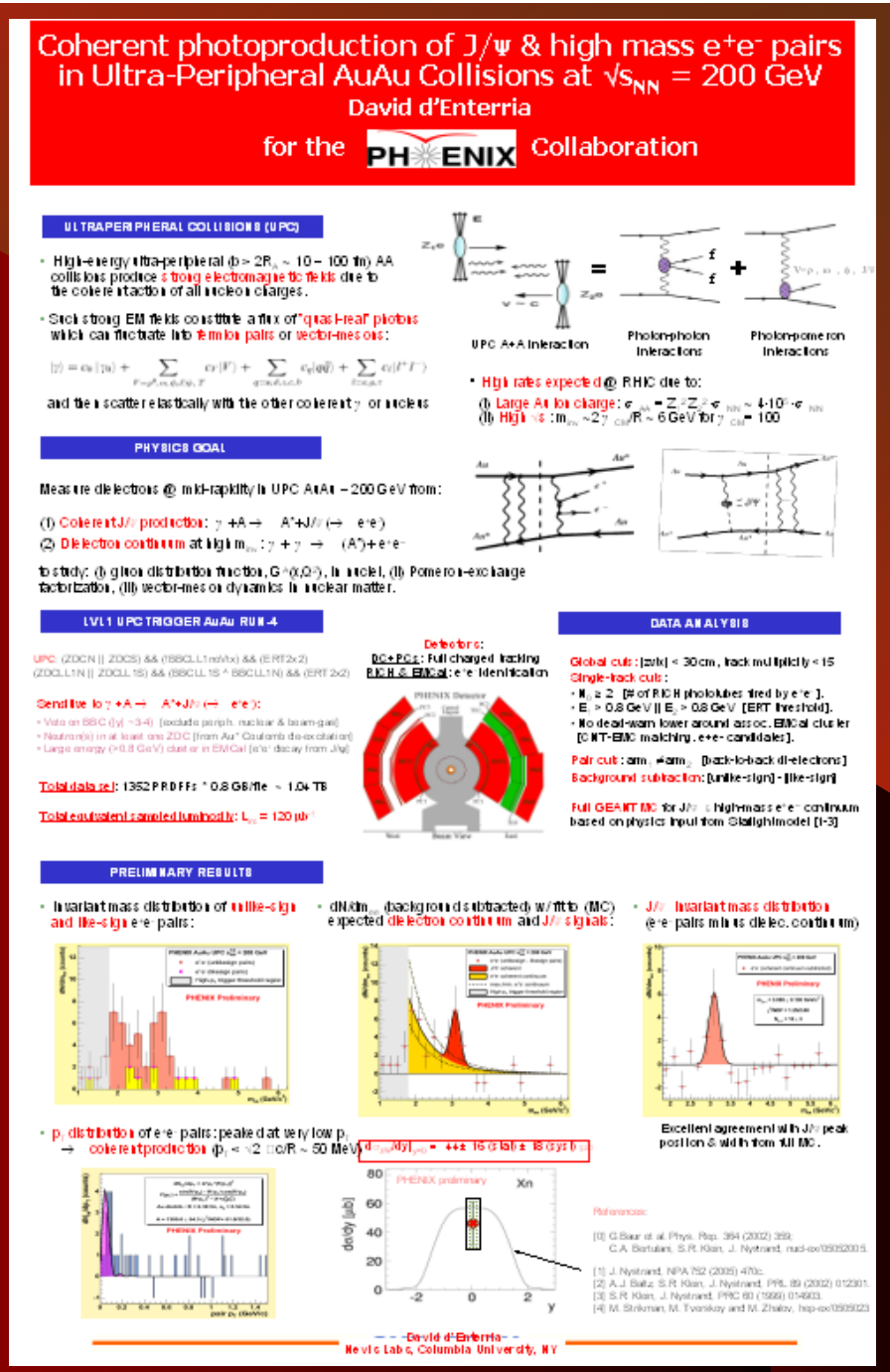


- **UPC physics**
  - Photon-photon interactions
  - Photon beam in A+A
- **Measurements at RHIC**
  - Experimental signatures
  - Background
  - Results
- **LHC?**



Based on …

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



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, ~ 1 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 $Q^2=M_V^2/4$, $x=M_V^2/W_{\gamma N}^2$):**

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

- **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

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

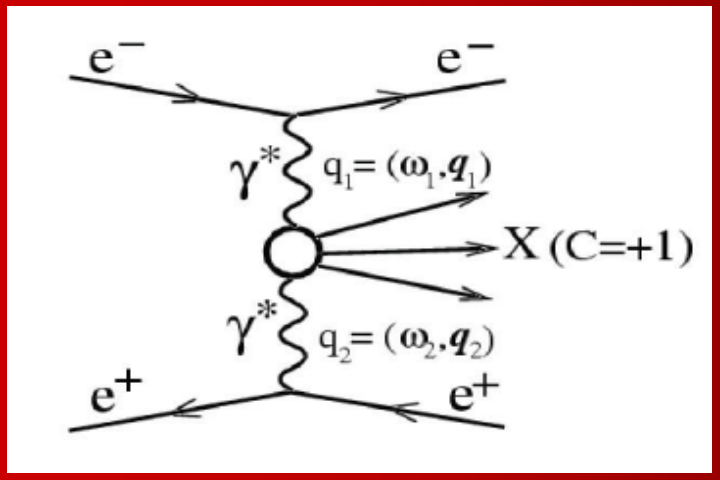
- γ_0 dominates, but $\gamma \to V,qq$ fluctuations interact strongly and give largest contribution to $\gamma\gamma$ cross-sections

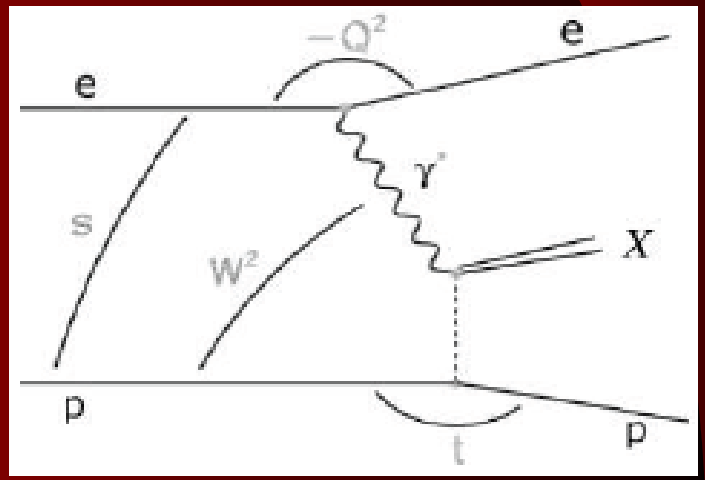
How to make γγ collisions?

- **EM field of relativistic charged particle = flux of "equivalent" photons.**
- **Weizsacker-Williams formula for γ-spectrum in an $e^{\pm}$ beam (with $z=E_\gamma/E_e$):**

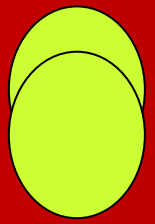
$$\frac{dN}{dz} \approx \frac{\alpha_{em}}{2\pi}\frac{1}{z}\left(1+(1-z)^2\right)\ln\frac{Q^2_{max}}{Q^2_{min}} \qquad Q^2_{min}=\frac{m_e^2 z^2}{1-z} \qquad Q^2_{max}=m_V^2\,(\text{e.g.})$$

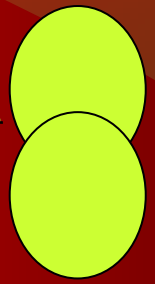
- **Scattered beam close to parent beam (kinematics) ⇒ low p_t products & quasi-real photons ($Q^2\sim 0$)**

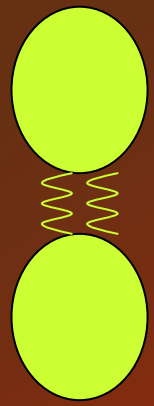




$\gamma\gamma$ in nucleon-nucleon collisions

Central collision: 

Peripheral collision: 

Ultra-peripheral collision: 

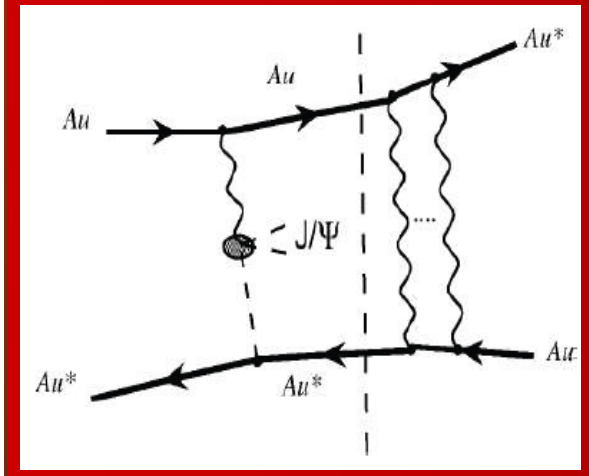
- **Two heavy nuclei not overlapping**
  - $b > b_{min} \approx 2R$
  - Ultra-Peripheral Collision (UPC)
- **Emitting a quasi-real photon**
  - $z = E_\gamma / E_A$, $x = z m_A b_{min}$, K … Bessel functions
  - flux: $$\frac{dN_\gamma}{dz} \approx \frac{\alpha_{em} Z^2}{2\pi} \frac{1}{z} \left(2xK_0(x)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

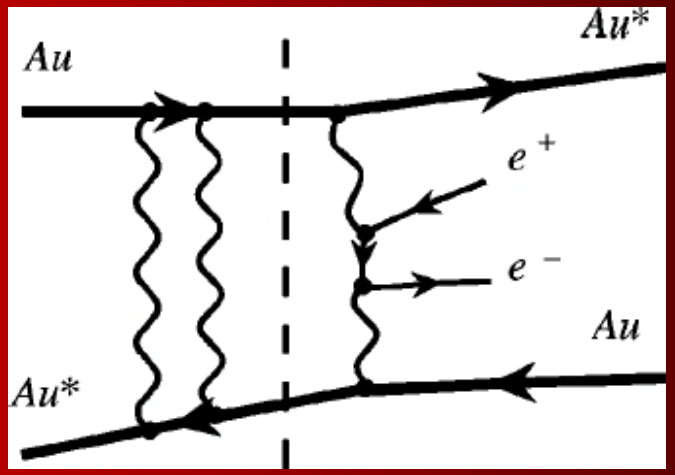
Where all this is done: BNL@RHIC

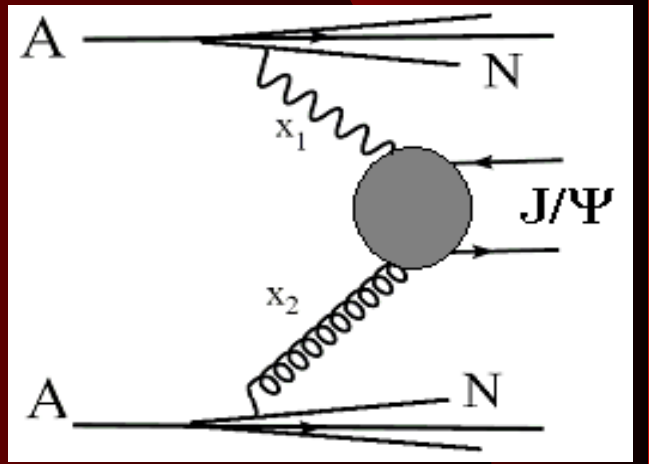
- **RHIC: Au+Au @ E_{cms} = 200 GeV/nucleon**
  - Au+Au, Cu+Cu, pp+pp, d+Au collisions
  - 4 experimental collaborations: BRAHMS, PHENIX, PHOBOS, STAR
- **PHENIX: several hunded scientist, a lot of topics**
- **See earlier talks of Rachid Nouicer, David Kawall and Atsushi Taketani**

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"): $E_{photon,max} \sim \gamma/R \sim$ 3GeV (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 ρ 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/Ψ 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

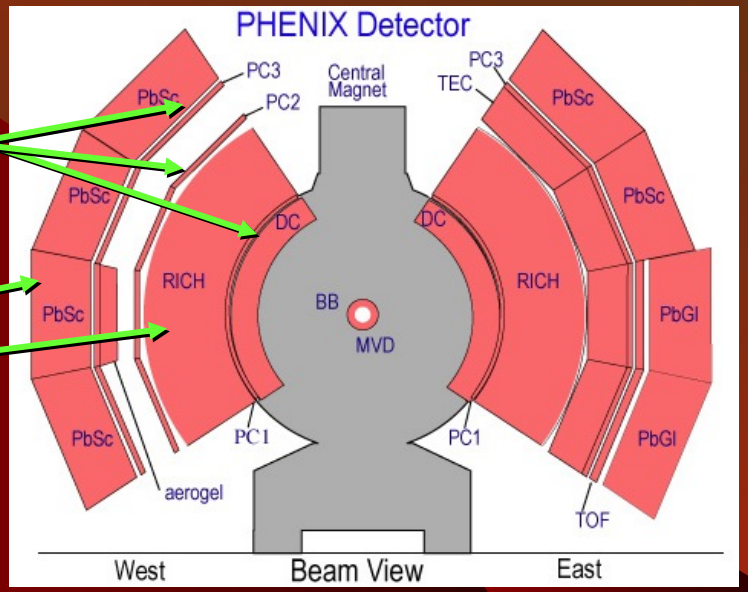
- **"Non-physical":**
  - Cosmic rays: no ZDC, no good vtx.
  - Beam-gas collision: no good vertex, large multiplicity, asymmetric dN/dy
- **Physical processes:**
  - Peripheral nuclear A+A: "large" multiplicity, large p_t
  - Hadronic diffractive (Pomeron-Pomeron): forward proton emission, larger p_t: $p_t(\gamma\gamma)<p_t(PP)$, like-sign pairs. Hard-diffractive J/Ψ production.
  - Incoherent UPC $\gamma+n\rightarrow n+J/\Psi$: $p_t(\gamma\gamma) < p_t(\gamma P)$, wider & asymm. dN/dy, ≥2 neutrons (induced nuclear break-up) with same direction as J/Ψ.
  - Other coherent UPC processes: $\gamma\gamma\rightarrow e^+e^-$ (important , $\gamma A\rightarrow jet+A$ (lower cross-sections)

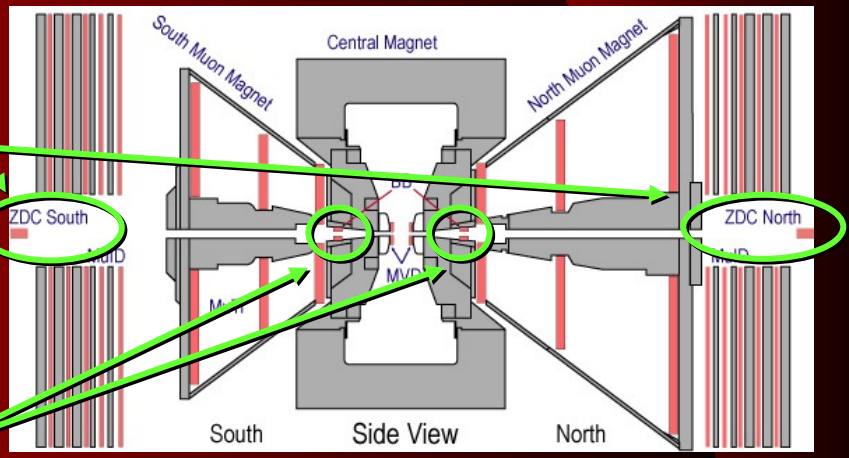
trigger level

final signal

PHENIX detectors for UPC

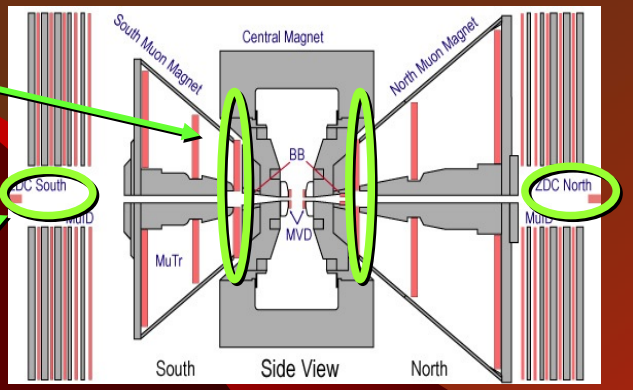
- DC + PC's: Full central-arm charged tracking ($e^{\pm}$ momentum).
- EMCal + RHIC: $e^{\pm}$ identification in central rapidity.
- ZDC: Forward neutron detection (Au* dissociation):
- BBC: charged tracks





Triggering on UPC's

- **PHENIX Run-4 AuAu UPC level-1 trigger:**
  - Sensitive to $\gamma + Au \rightarrow Au^* + J/\Psi(\rightarrow e^+e^-)$
- **Veto on coincident BBC (|y|~3-4):**
  - avoid periph. nuclear, beam-gas colls.
- **Neutron in ZDC (E>30 GeV)**
  - sensitive to Au* Coulomb dissociation



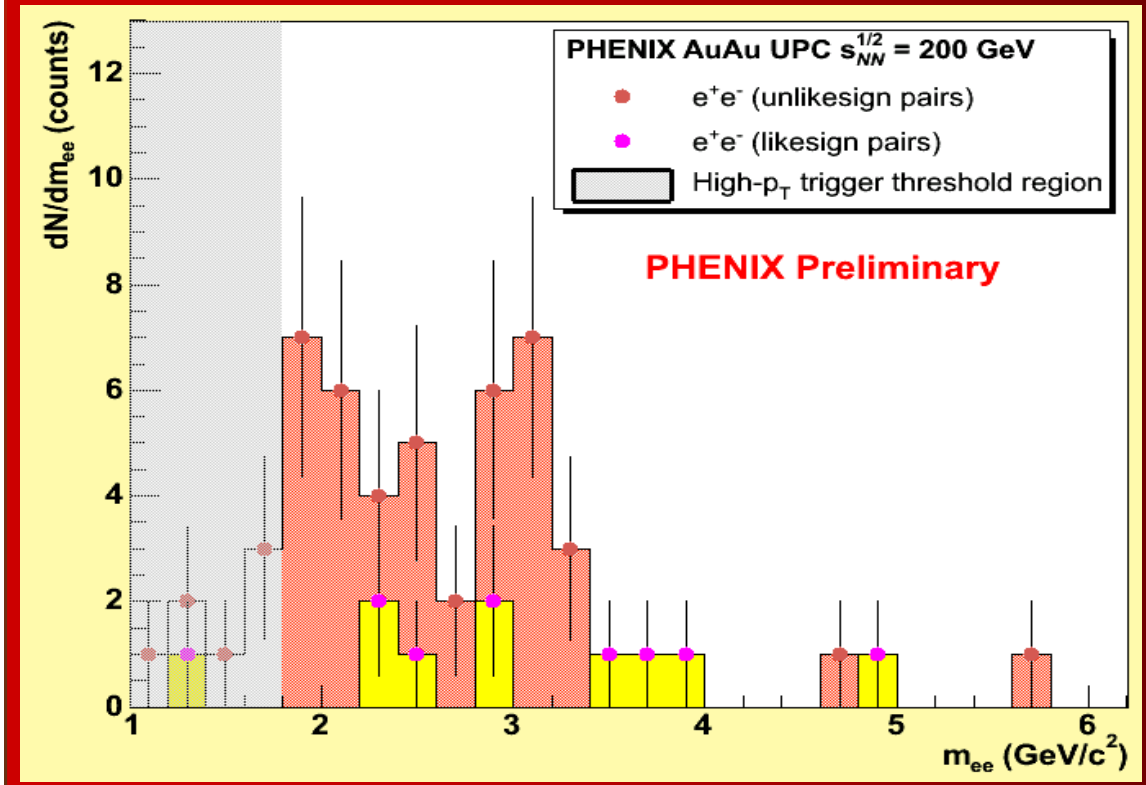
- **Large energy (E > 0.8 GeV) cluster in EMCal:**
  - e^+e^- decay from J/Ψ
- **Trigger definition based on the above**
- **Events collected (~0.4% of MB trigger):**
  - UPC AuAu: 8.5 M
  - MinBias AuAu (BBCLL1): 1122 M ($\int L = 120\ \mu b^{-1}$)

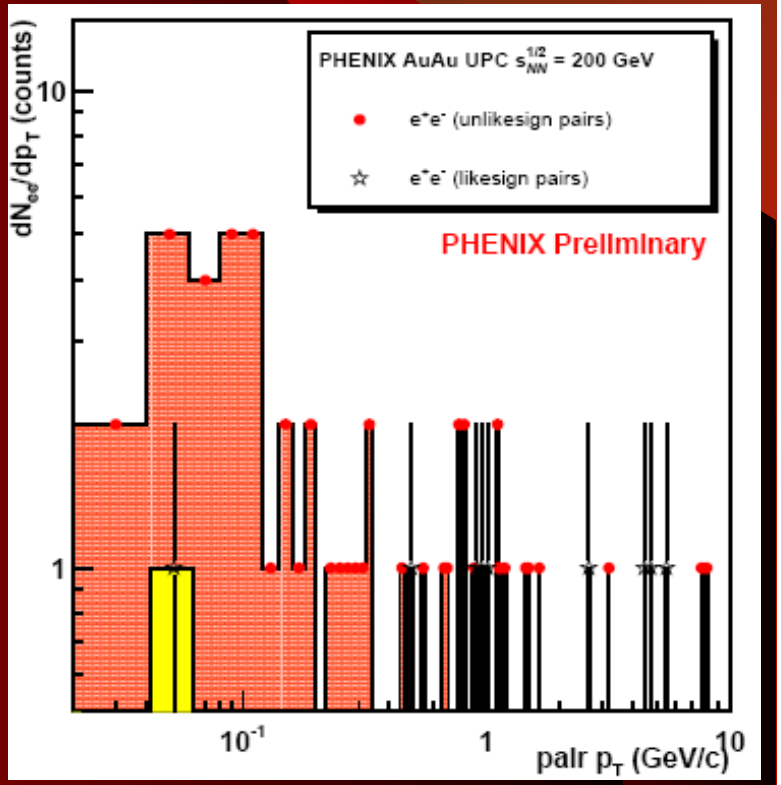
PHENIX UPC analysis cuts

- **Cuts made on the 8.5M UPC triggered events**
- **Global cuts:**
  - Standard vertex cut: $|z_{vtx}| < 30$ cm
  - Multiplicity (number of tracks) < 15, removes non-UPC
- **Eletron 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

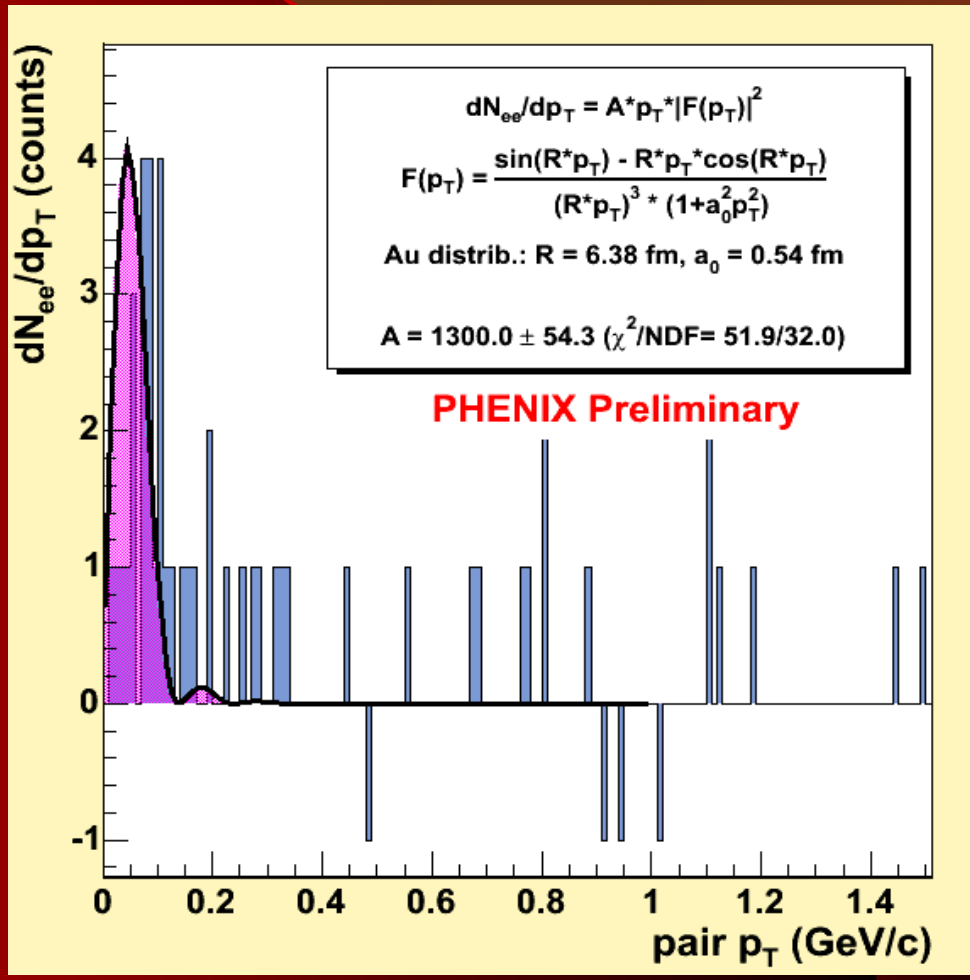
- Invariant mass distribution with continuum background
- Pair transverse momentum distribution
- Unlike-sign (red) and like-sign (yellow) pairs





Transverse momentum distribution

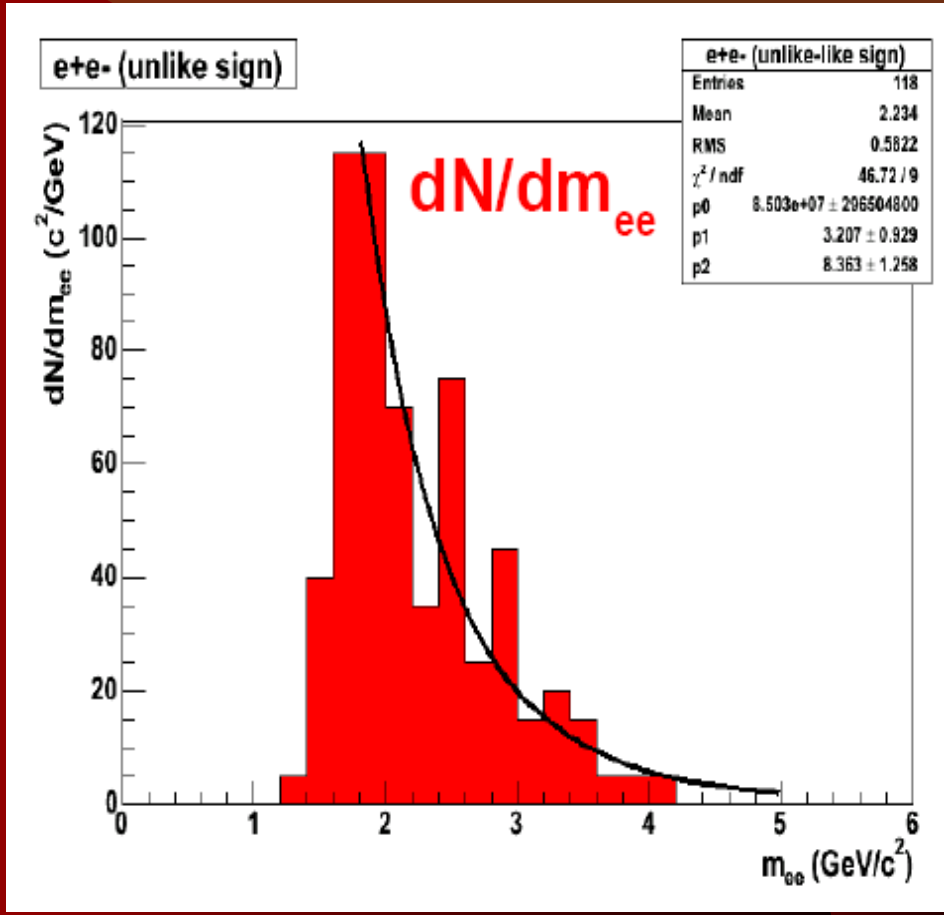
- Nuclear form factor fit (J.Nystrand, nucl-th/0112055)
- Unlike minus like sign pairs
- dN/dp_t peak at p_t~90 MeV/c
- Shape in accordance with simulation



Background substraction

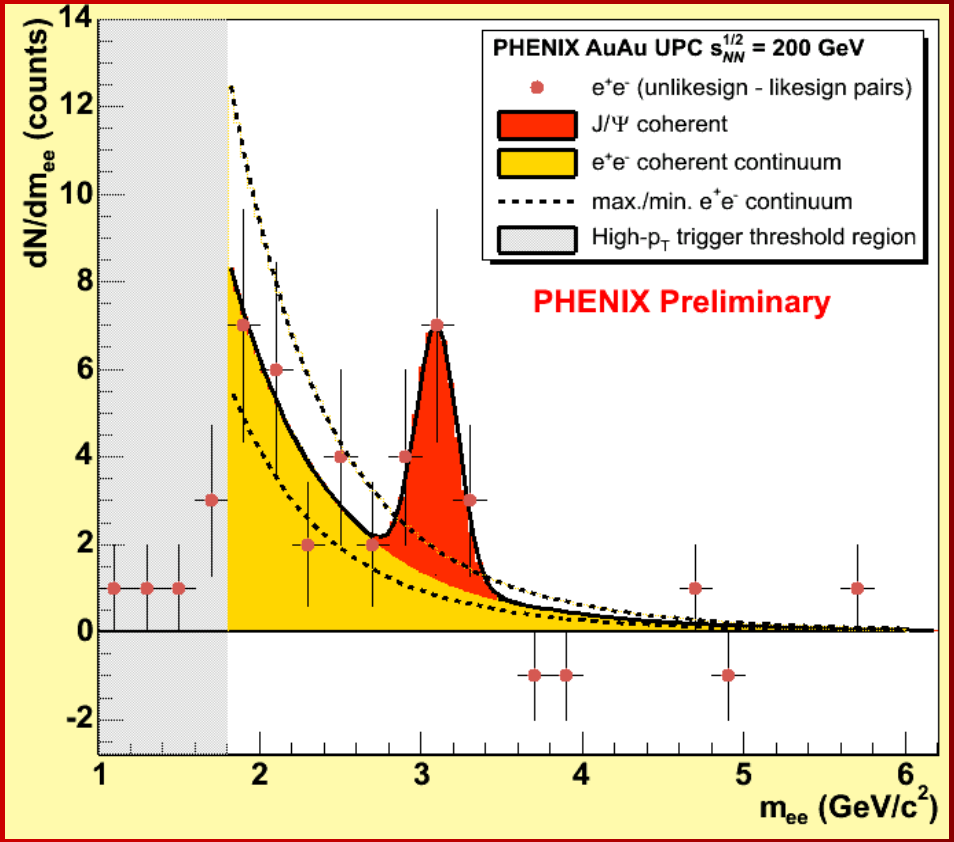
- Starlight Monte Carlo simulation
- Determine continuum shape
- 700k e^+e^- pairs with m_{inv}>1.5 GeV, 500 μb^{-1}
- Fit: $A/(m_0+m)^b$
- m_0=3.2, b=8.36

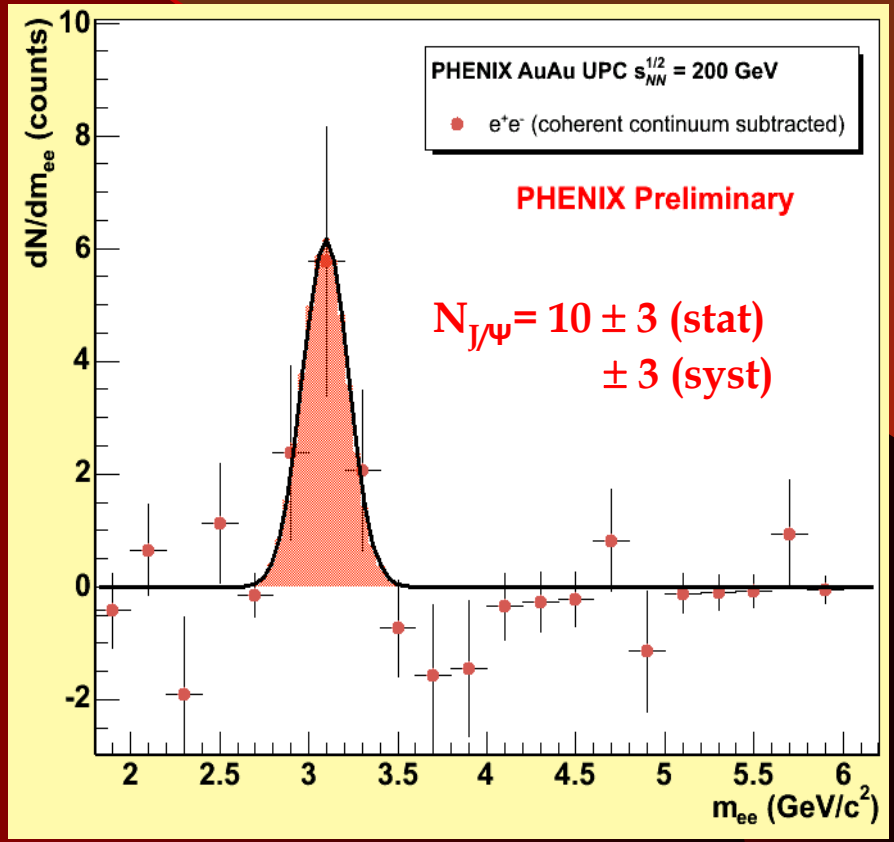
J. Nystrand, hep-ph/0412096, NPA752(2005)470



Background substraction

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





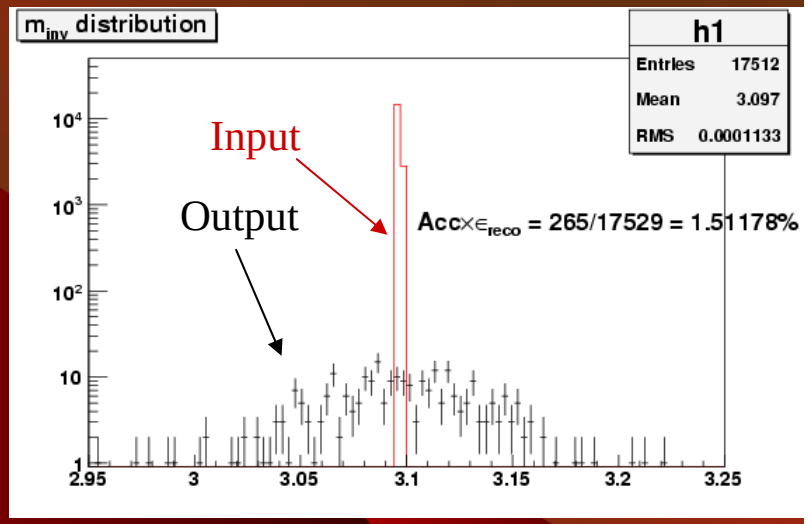
- Continuum in good agreement with theoretical input
- J/Ψ peak & width also (theoretical input + full MC resp.+reco)

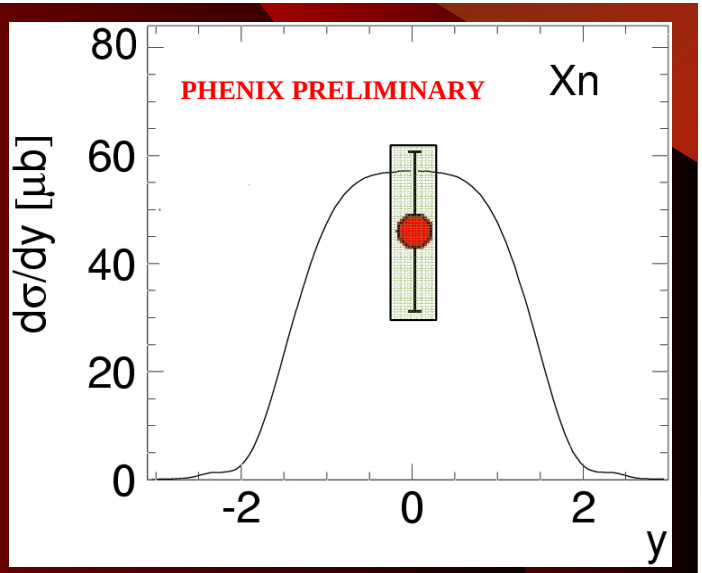
Cross-section extraction

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

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

  - Branching ratio: 5.9%
  - Acceptance: 5.7%
  - Reco. efficiency: 56.4%
  - Trigger efficiency: 90%
  - L = 120 μb^{-1}

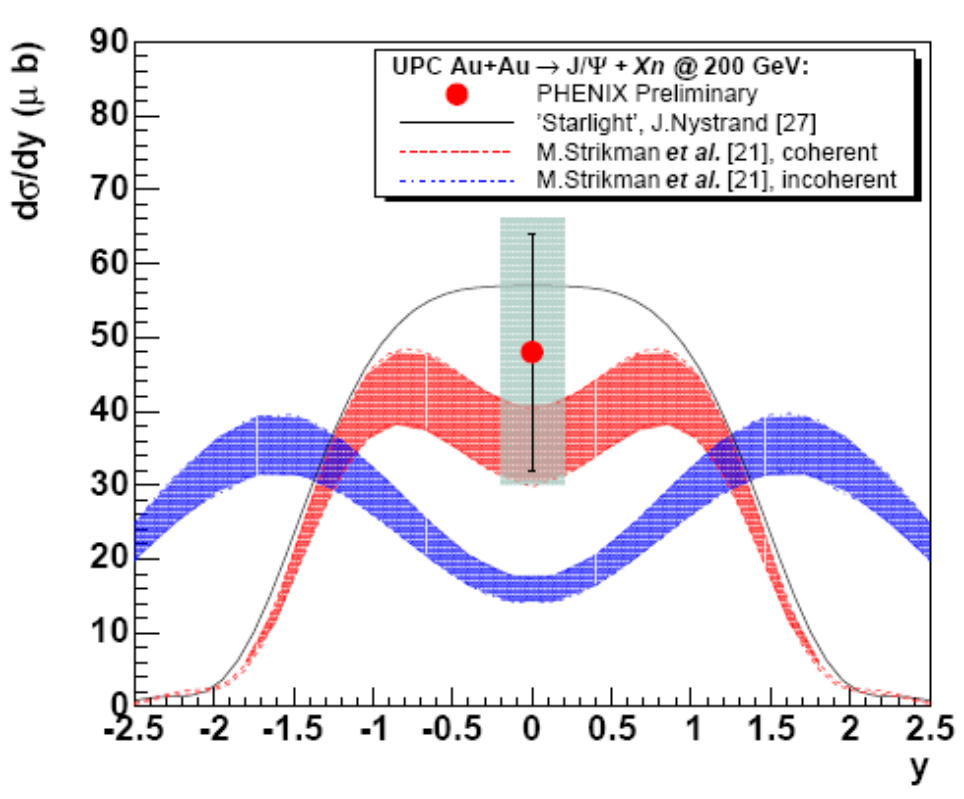




- **$\sigma_{J/\Psi} = 48 \pm 16 \pm 18$ μb**
- **Agreement with theoretical results ☺**

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



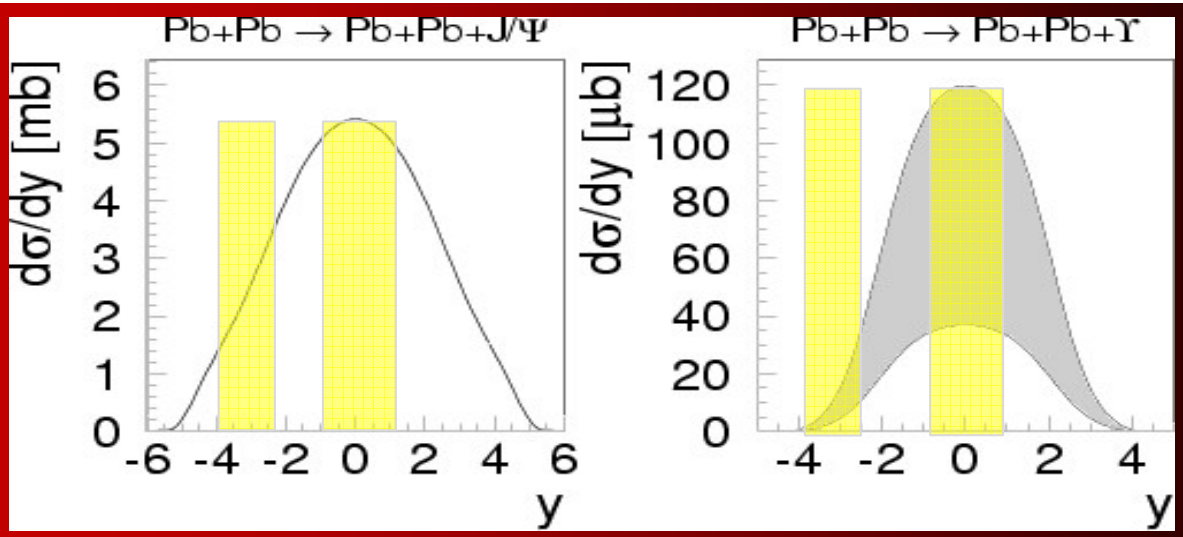
- Present status: detailed study of $G_A(x,Q^2)$, J/Ψ absorption in cold nuclear matter not possible
- Final data on the way

LHC prospects

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

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

Accelerator	Hadroproduction $A+A \to V+X$	Photoproduction $A+A \to A+A+V$
RHIC $\sqrt{s_{nn}} = 0.2$ TeV, $V = J/\Psi$	160 mb	290 μb
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 μb



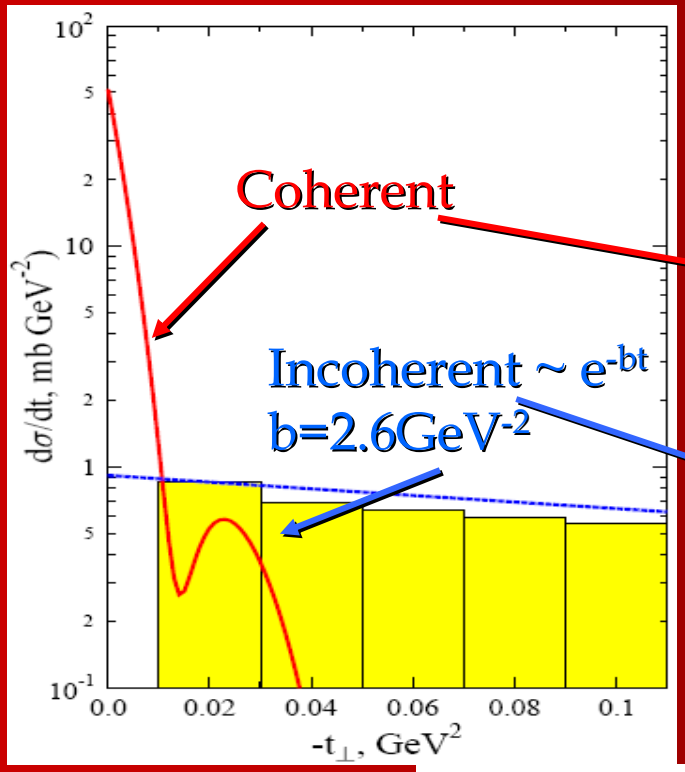
Summary

- **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 uncertainity: dielectrons
  - No strong constraint on model ingredients yet
- **To be continued at LHC**
  - Incoherent procecesses, continuum cross-section
  - Higher rates and energies

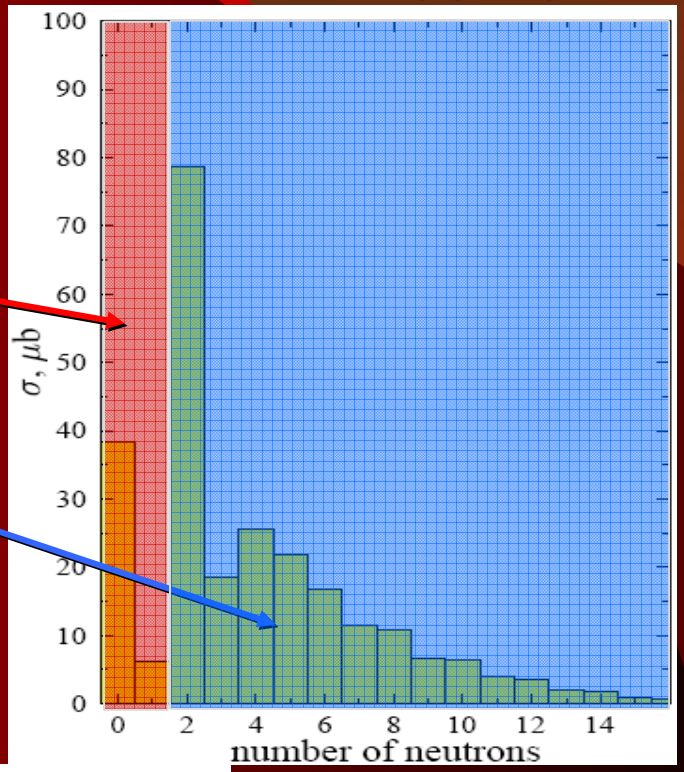
Incoherent J/Ψ production

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

Via t distribution



Via neutron tagging



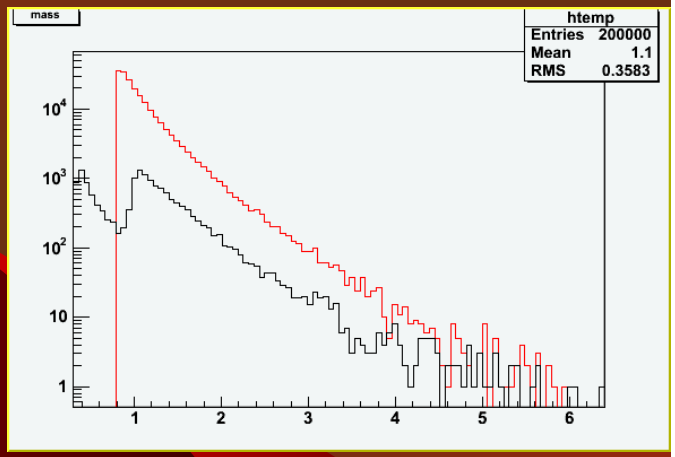
Strikman et al., hep-ph/0505023

- Approved results yet to come

Continuum cross-sections

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

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



- **Results: approved data yet to come**
  - E.g. two m_{inv} bins, $d\sigma/dy\,|_{|y|<0.5}$ to calculate
  - Results soon

- **Systematic errors:**
  - Acceptance correction: 10%
  - dep cut: 5% vs 10%