J/Ψ photo-production in ultra-peripheral collisions

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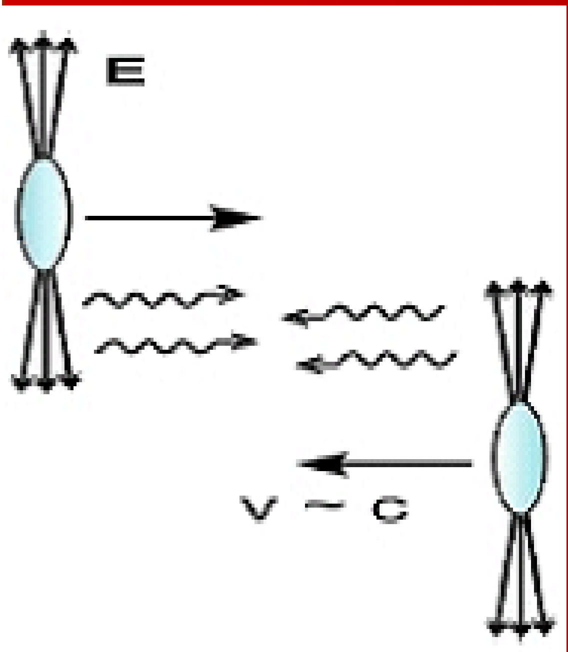
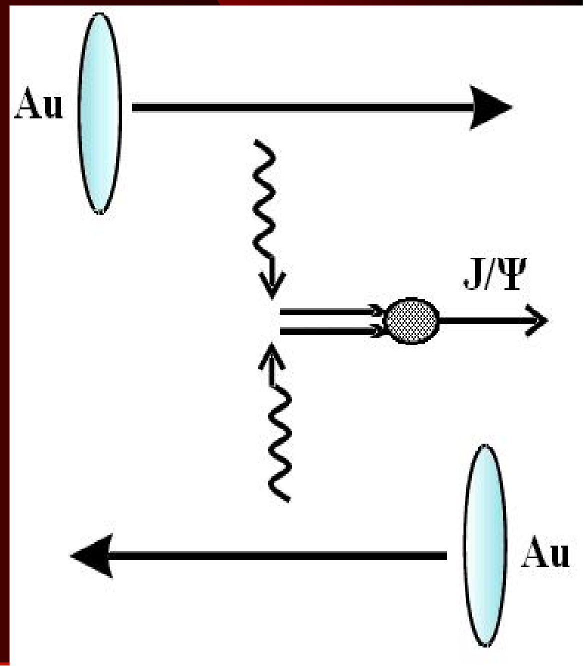
Deep Inelastic Scattering and Related Subjects
Madrid, April 25-30, 2009



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



Based on …

- David d'Enterria for the PHENIX Coll.
  Quark Matter 2005, nucl-ex/0601001
- Zaida Conesa del Valle for the PHENIX Coll.
  Quark Matter 2009
- PHENIX publication (submitted to PLB)
  arXiv: 0903.2041
- 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 $Q^2=M_V^2/4$, $x=M_V^2/W_{\gamma N}^2$):**

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

- **Photon-photon processes: tested in e^+e^- or ep (HERA)**
  - Fermi 1924: The effect of the electromagnetic field of a relativistic particle is equivalent to a flux of photons with a continous energy spectrum.
- **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

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

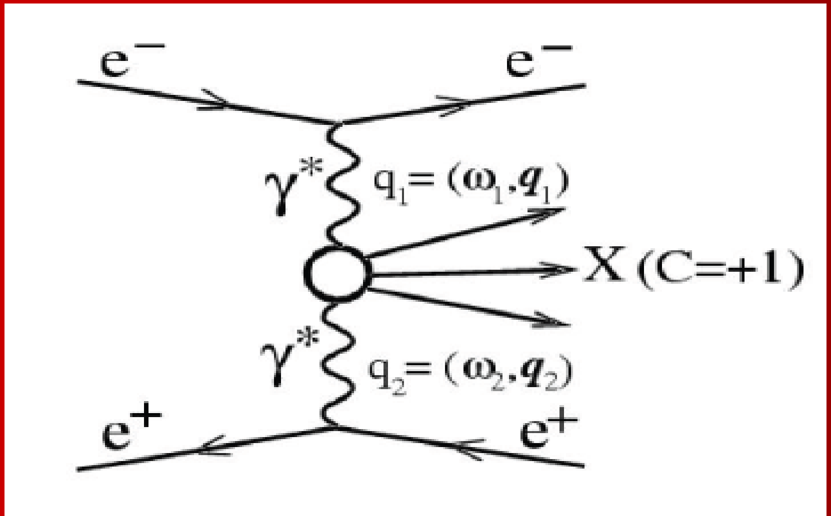
- γ_0 dominates, but $\gamma \to V, qq$ fluctuations interact strongly and give largest contribution to $\gamma\gamma$ cross-sections

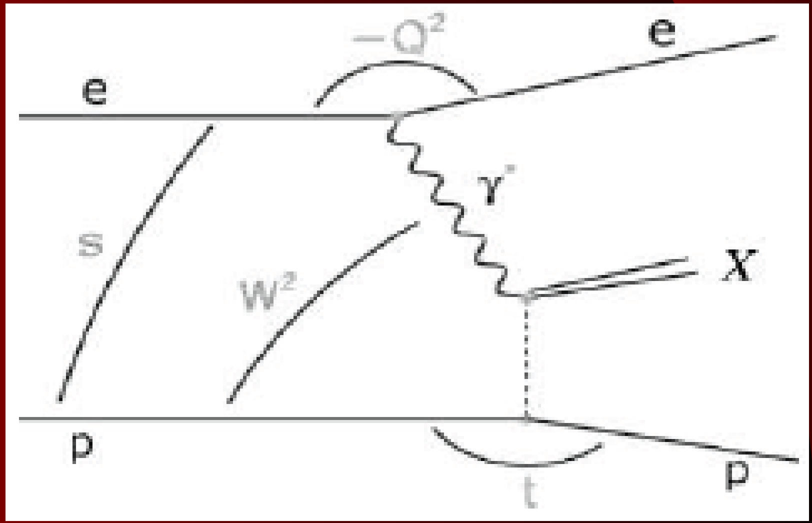
How to make γγ collisions?

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

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

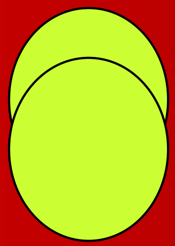
- Scattered beam close to parent beam (kinematics) ⇒ low p_t products & quasi-real photons ($Q^2 \sim 0$)



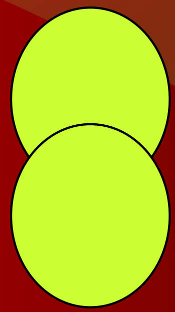


$\gamma\gamma$ in nucleon-nucleon collisions

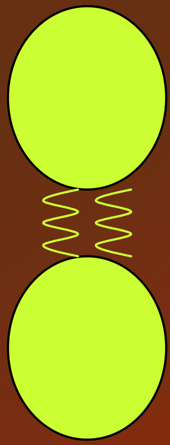
Central collision:



Peripheral collision:



Ultra-peripheral collision:



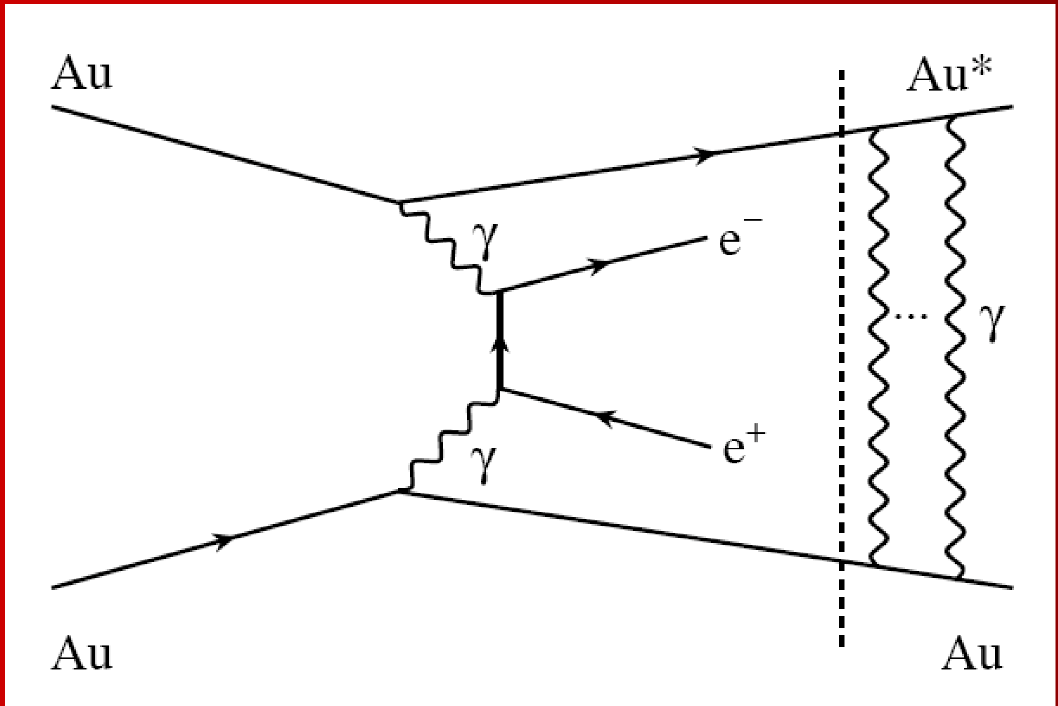
- **Two heavy nuclei not overlapping**
  - $b>b_{min}\approx 2R$
  - Ultra-Peripheral Collision (UPC)
- **Emitting a quasi-real photon**
  - $z=E_\gamma / E_A$, $x=zm_A b_{min}$, K … Bessel functions
  - flux: $$\frac{dN_\gamma}{dz}\approx\frac{\alpha_{em}Z^2}{2\pi}\frac{1}{z}\left(2xK_0(x)-x^2\left(K_1^2(x)-K_0^2(x)\right)\right)$$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

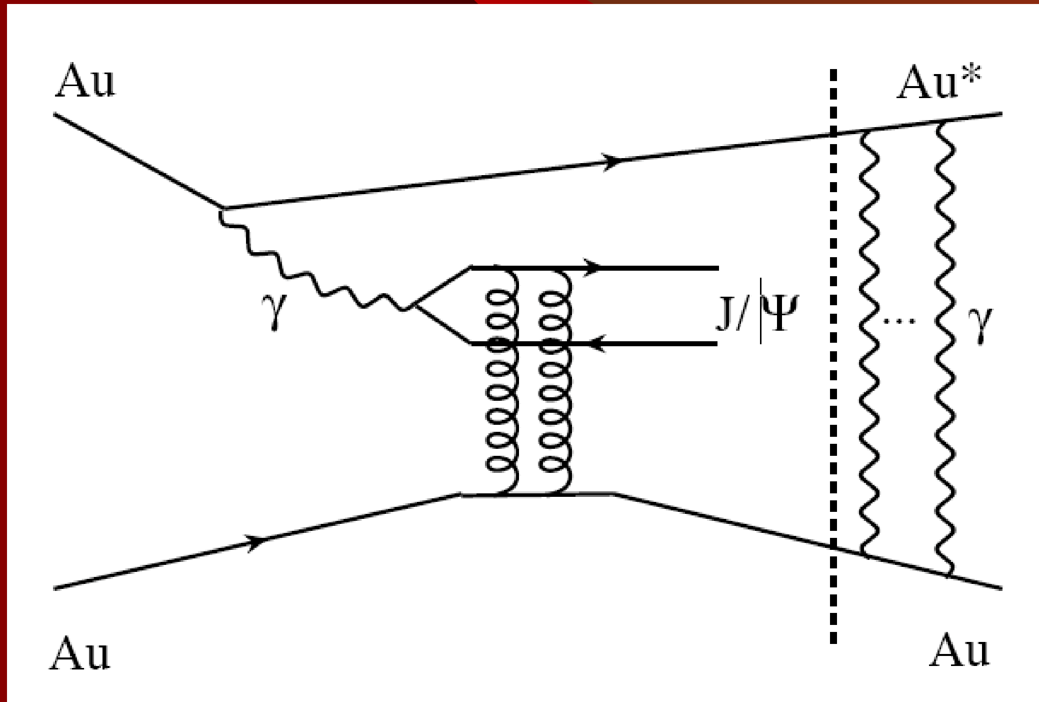
Where all this is done: BNL@RHIC

- **RHIC: Au+Au @ E_{cms} = 200 GeV/nucleon + …**
  - Au+Au, Cu+Cu, pp+pp, d+Au collisions, up to 500 GeV/nucl.
  - 4 experimental collaborations: BRAHMS, PHENIX, PHOBOS, STAR
- **PHENIX: several hundred scientist, a lot of topics**
- **See talks of David d'Enterria, John Koster, Raphael Granier de Cassagnac, Todd Kempel, Swadhin Taneja, Rachid Noucier, Yoshinori Fukao**

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): $\gamma+A\rightarrow A'+xN+J/\Psi(\rightarrow e^{+}e^{-})$, much larger p_t of the pair

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 (prelim.), 0903.2041 (final)
  - J/Ψ production: $\gamma + A \rightarrow A^{*} + J/\Psi(\rightarrow e^{+}e^{-})$
  - Dielectron continuum at high m_{inv} : $\gamma + \gamma \rightarrow e^{+}e^{-}$

Eliminating background sources

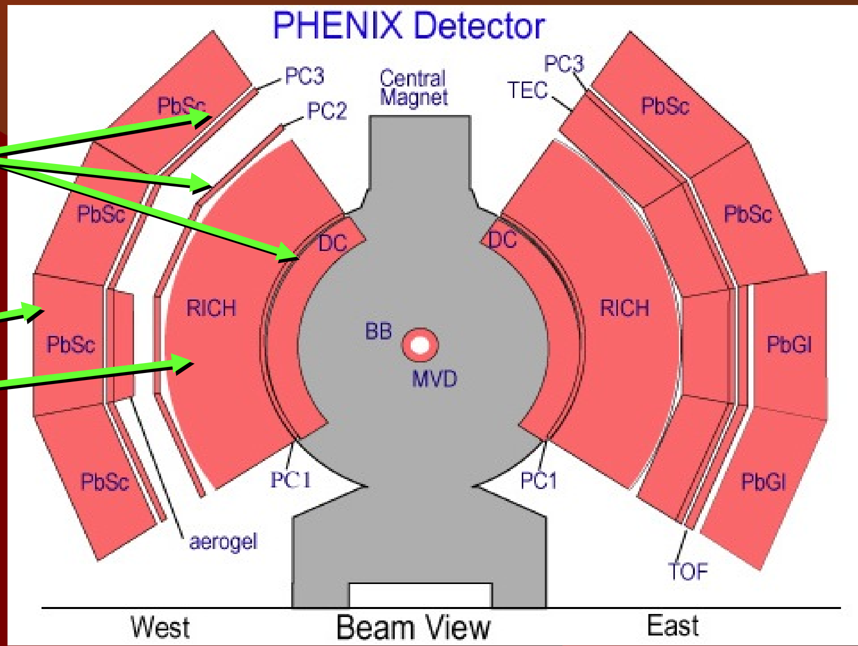
- **"Non-physical":**
  - Cosmic rays: no ZDC, no good vtx.
  - Beam-gas collision: no good vertex, large multiplicity, asymmetric dN/dy
- **Physical processes:**
  - Peripheral nuclear A+A: "large" multiplicity, large p_t
  - Hadronic diffractive (Pomeron-Pomeron): forward proton emission, larger p_t: $p_t(\gamma\gamma) < p_t(PP)$, 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)

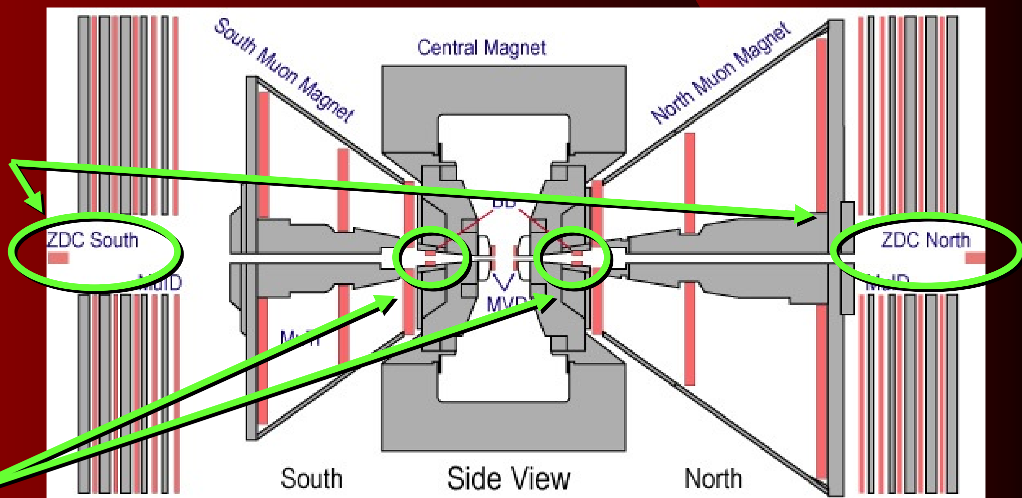
trigger level

final signal

PHENIX detectors for UPC

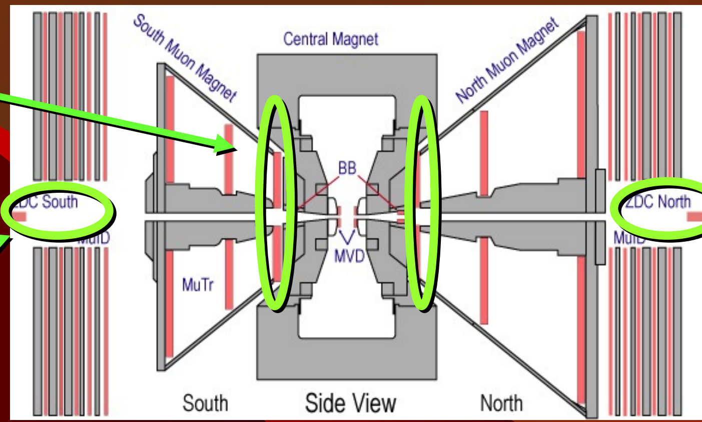
- DC + PC's: Full central-arm charged tracking (e$^{\pm}$ momentum).
- EMCal + RHIC: e$^{\pm}$ identification in central rapidity.
- ZDC: Forward neutron detection (Au* dissociation):
- BBC: charged tracks





Triggering on UPC's

- **PHENIX Run-4 AuAu UPC level-1 trigger:**
  - Sensitive to γ+Au$\rightarrow$Au*+J/Ψ($\rightarrow e^+e^-$)
- **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 μb^{-1})

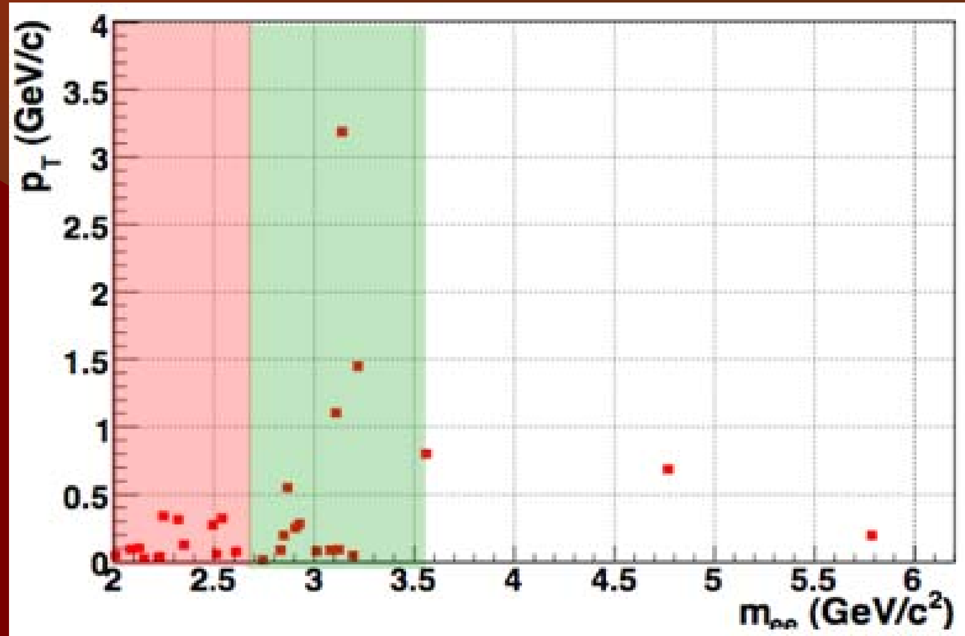


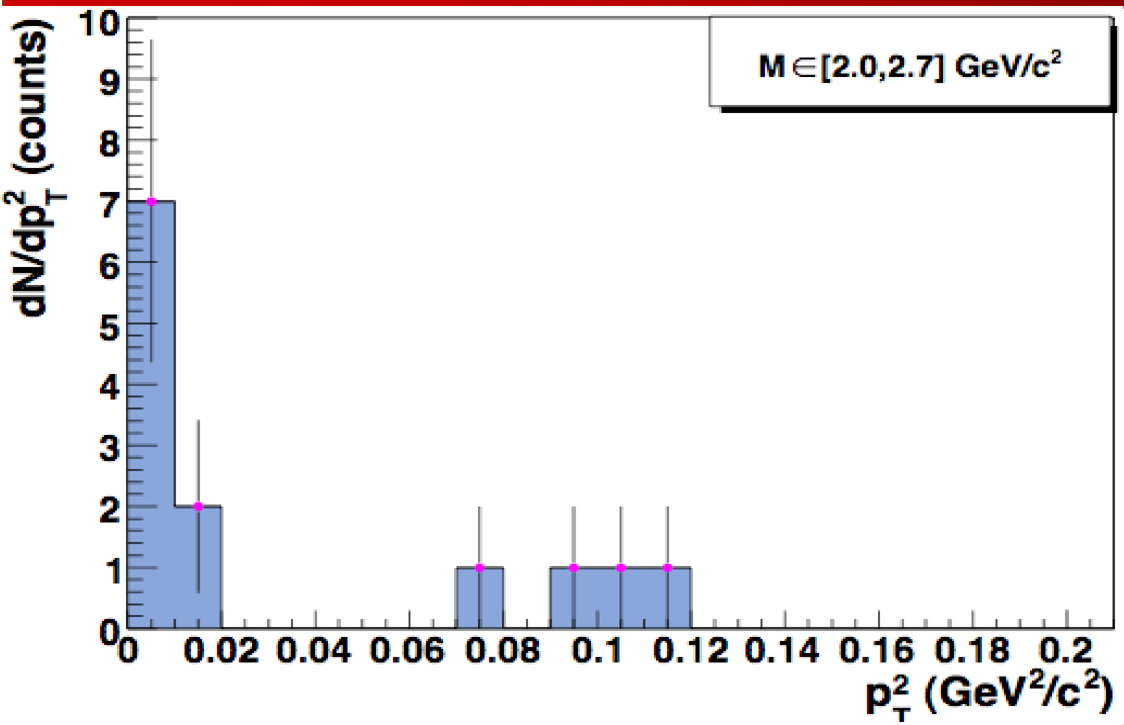
PHENIX UPC analysis cuts

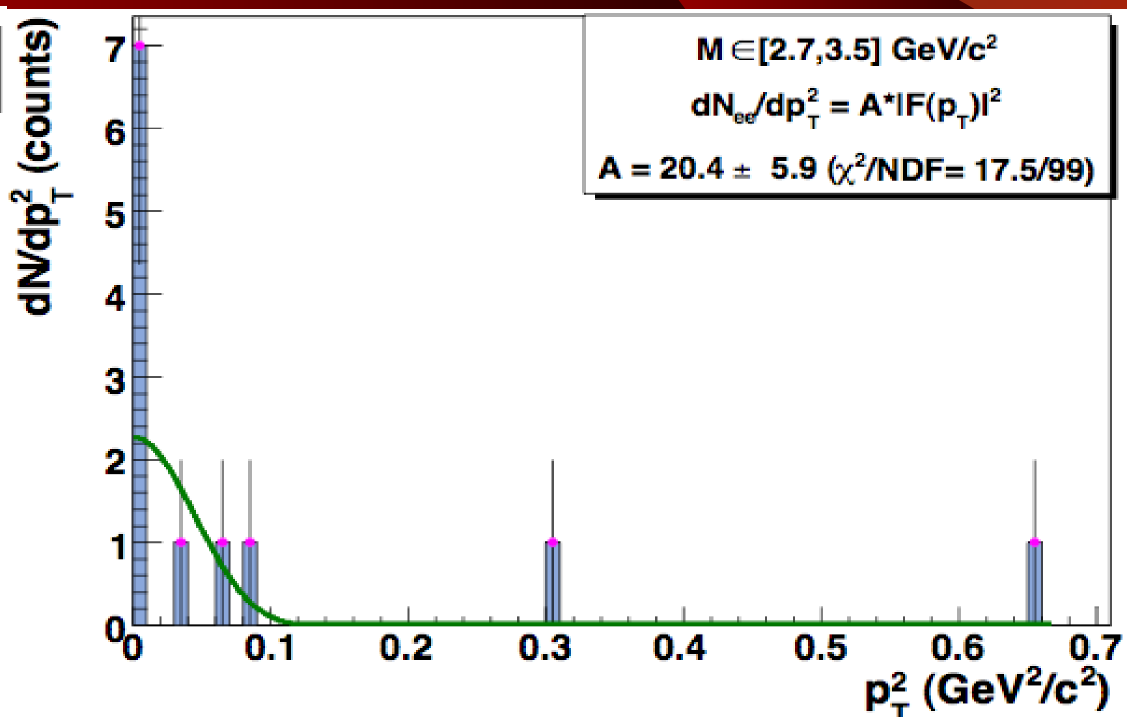
- **Cuts made on the 8.5M UPC triggered events**
- **Global cuts:**
  - Standard vertex cut: |zvtx| < 30 cm
  - Multiplicity (number of tracks) = 2, removes non-UPC
- **Eletron ID cuts:**
  - RICH: # of photo-tubes within nominal ring radius >2
  - Electrons: E_1>1 GeV or E_2>1 GeV, high-p_t trigger threshold
- **Pair cuts:**
  - Dielectrons back-to-back (low sum p_t)
- **Residual background subtraction:**
  - unlike-sign pairs – like-sign pairs
- **Result: 28 unlike-sign pairs and no like-sign pairs of m_{ee} > 2 GeV/c^2: clean sample with 0 net charge**

Transverse momentum distribution

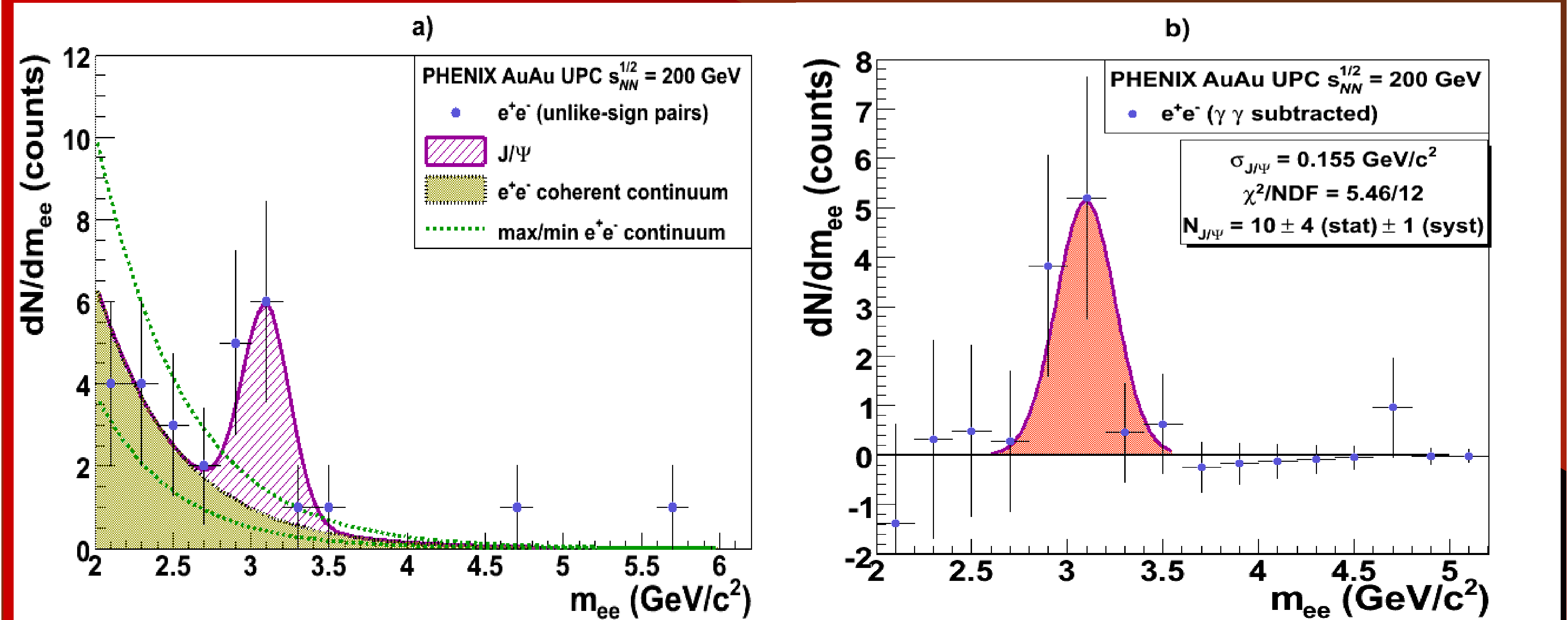
- J/Ψ: low p_t region consistent with Au form factor fit
- High p_t region: also an incoherent component
- Continuum: coherent nature







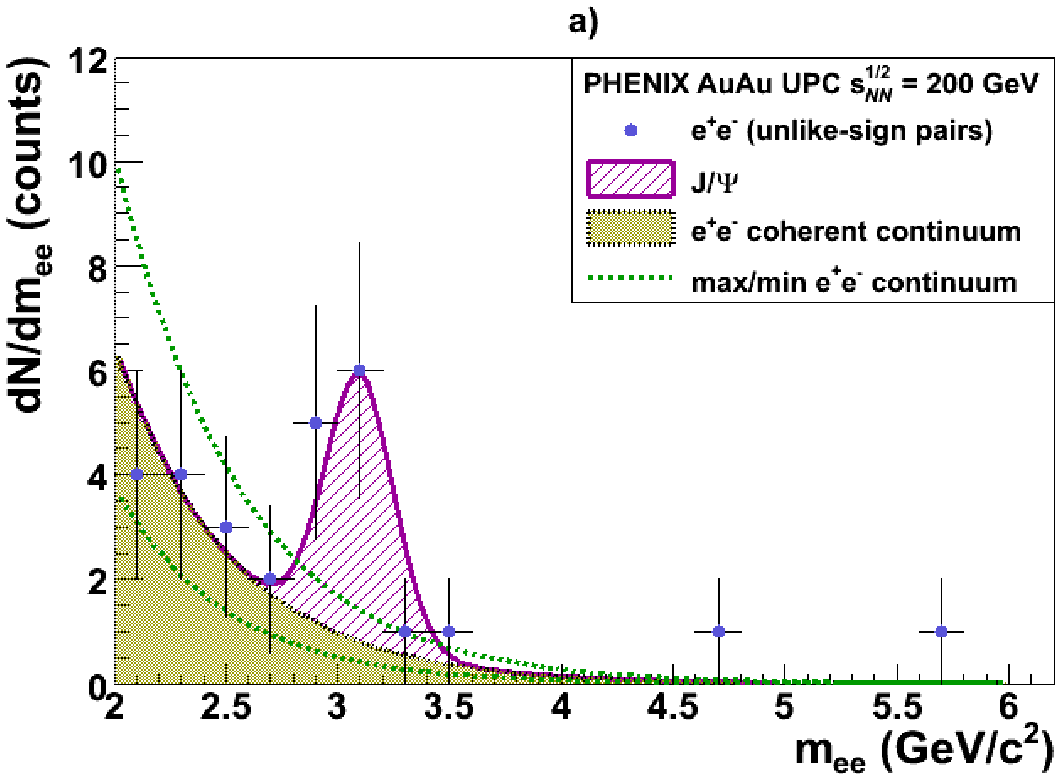
Invariant mass distributions

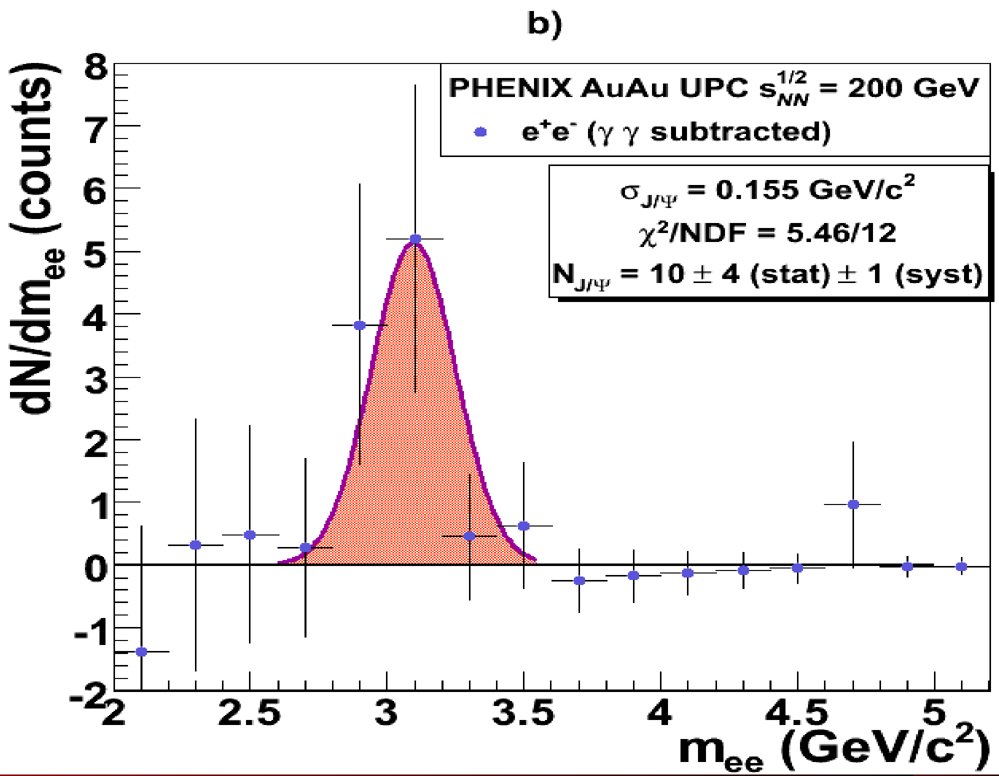


- Continuum in good agreement with theoretical input
- J/Ψ peak & width also (theoretical input + full MC resp.+reco)

Yields

Sample, m_{e+e-} [GeV/c^2]	Yield
J/Ψ [2.7,3.5]	9.9 ± 4.1 (stat) ± 1.0 (syst)
e^+e^- continuum [2.0,2.8]	13.7 ± 3.7 (stat) ± 1.0 (syst)
e^+e^- continuum [2.0,2.3]	7.4 ± 2.7 (stat) ± 1.0 (syst)
e^+e^- continuum [2.3,2.8]	6.2 ± 2.5 (stat) ± 1.0 (syst)





Continuum cross-sections

$$\left.\frac{d^2\sigma_{e^+e^-+Xn}}{dydm_{ee}}\right|_{|y|<0.35,\Delta m_{ee}} = \frac{N_{e^+e^-}}{Acc\cdot\varepsilon\cdot\varepsilon_{trigg}\cdot L}\frac{1}{\Delta y}\frac{1}{\Delta m_{ee}}$$

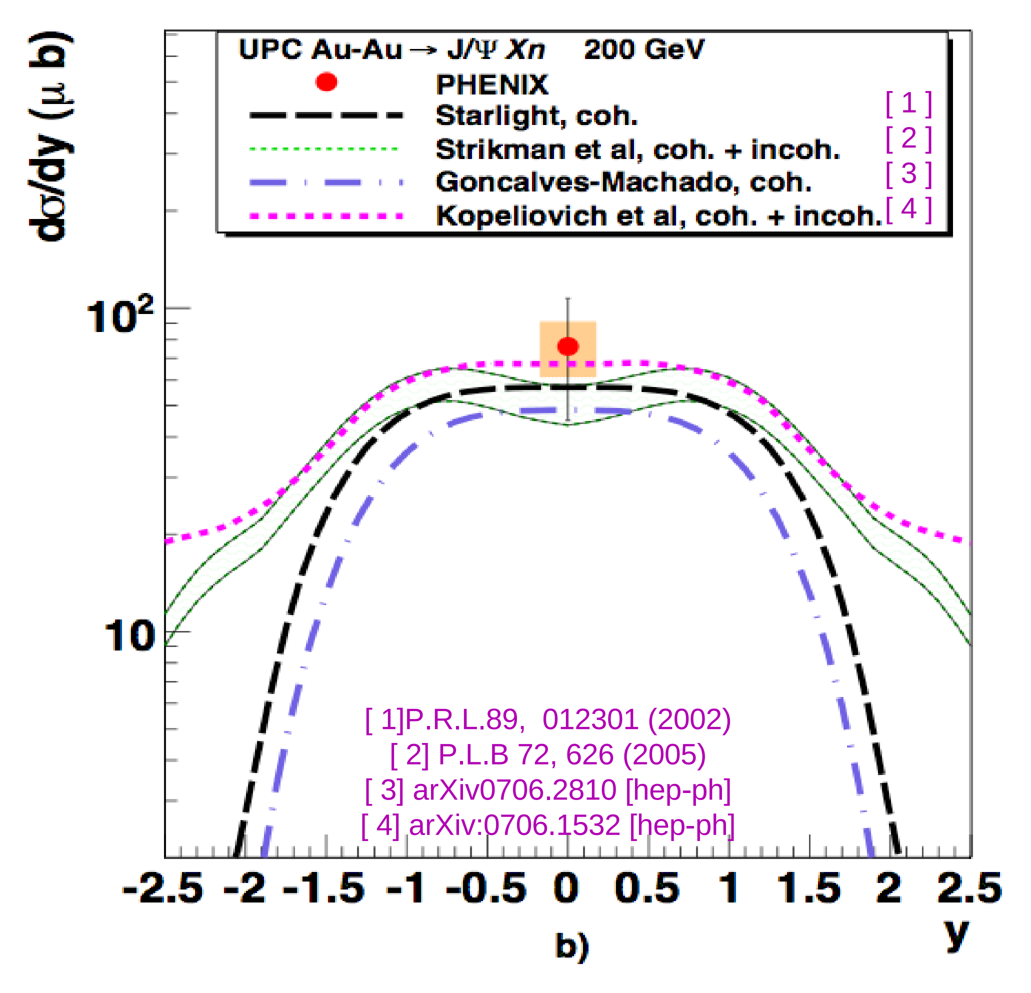
- **Cross-sections after efficiency corrections:**

m_{e+e-} interval [GeV/c²]	$d^2\sigma/dm_{ee}dy\,|_{y=0}$ [μb c²/ GeV]	STARLIGHT
e^+e^- continuum [2.0,2.8]	86 ± 23 (stat) ± 16 (syst)	90
e^+e^- continuum [2.0,2.3]	129 ± 47 (stat) ± 28 (syst)	138
e^+e^- continuum [2.3,2.8]	60 ± 24 (stat) ± 14 (syst)	61

- **Results agree with QED theoretical (STARLIGHT) calculations even though we are in a strongly interacting regime !**
- **Lacking of other model comparisons on this kinematical region… input from theorists is most welcome !**

J/Ψ cross-sections

$$\left.\frac{d\sigma_{J/\Psi}}{dy}\right|_{|y|<0.35} = \frac{1}{BR}\,\frac{N_{J/\Psi}}{Acc\cdot\varepsilon\cdot\varepsilon_{trigg}\cdot L}\,\frac{1}{\Delta y}$$



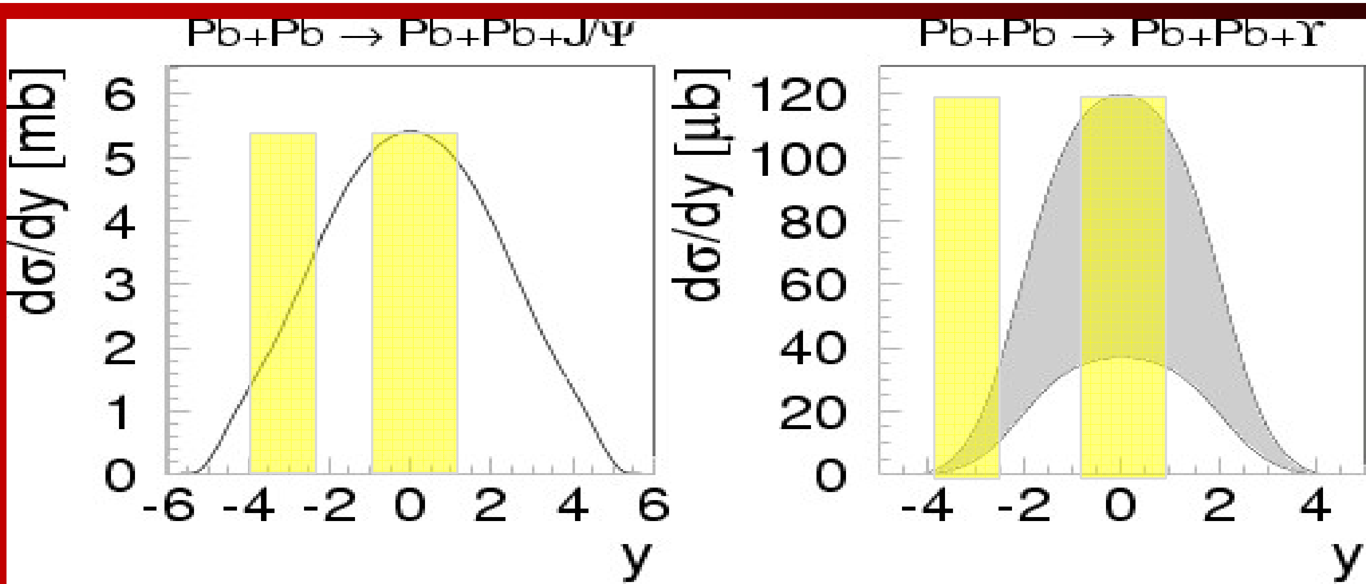
- **Agreement with theoretical results**
- **But: coherent + incoherent production**
- **Main systematic error: coherent continuum**
- **Statistical errors: larger luminosity**
- **Present status: detailed study of $G_A(x,Q^2)$, J/Ψ absorption in cold nuclear matter not possible**

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

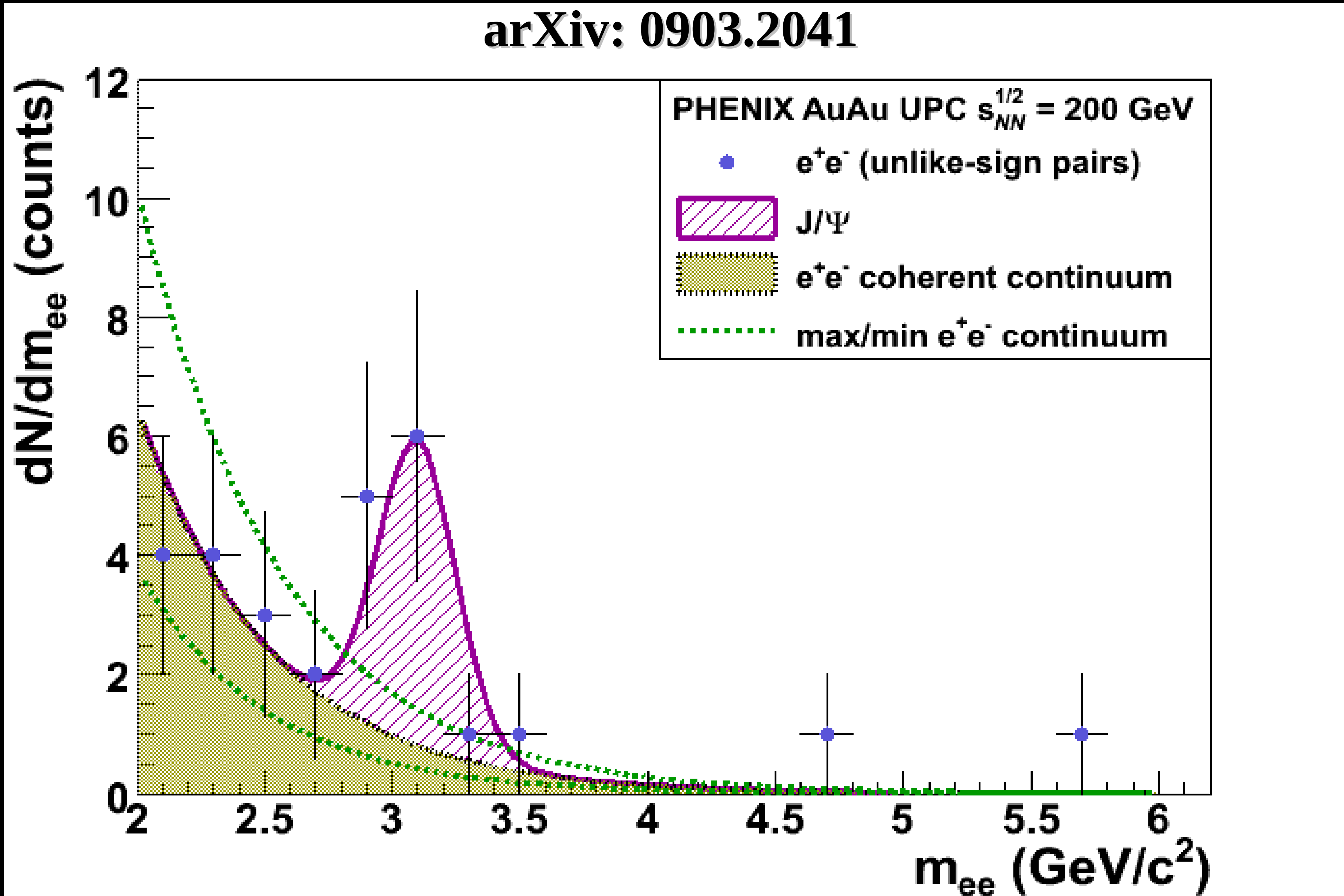
Accelerator	Hadroproduction $A+A \to V+X$	Photoproduction $A+A \to A+A+V$
RHIC $\sqrt{s_{nn}}=0.2$ TeV, $V=J/\Psi$	160 mb	290 μb
LHC $\sqrt{s_{nn}}=5.5$ TeV, $V=J/\Psi$	820-2100 mb	32 mb
LHC $\sqrt{s_{nn}}=5.5$ TeV, $V=\Upsilon(1S)$	8-12 mb	170 μb



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

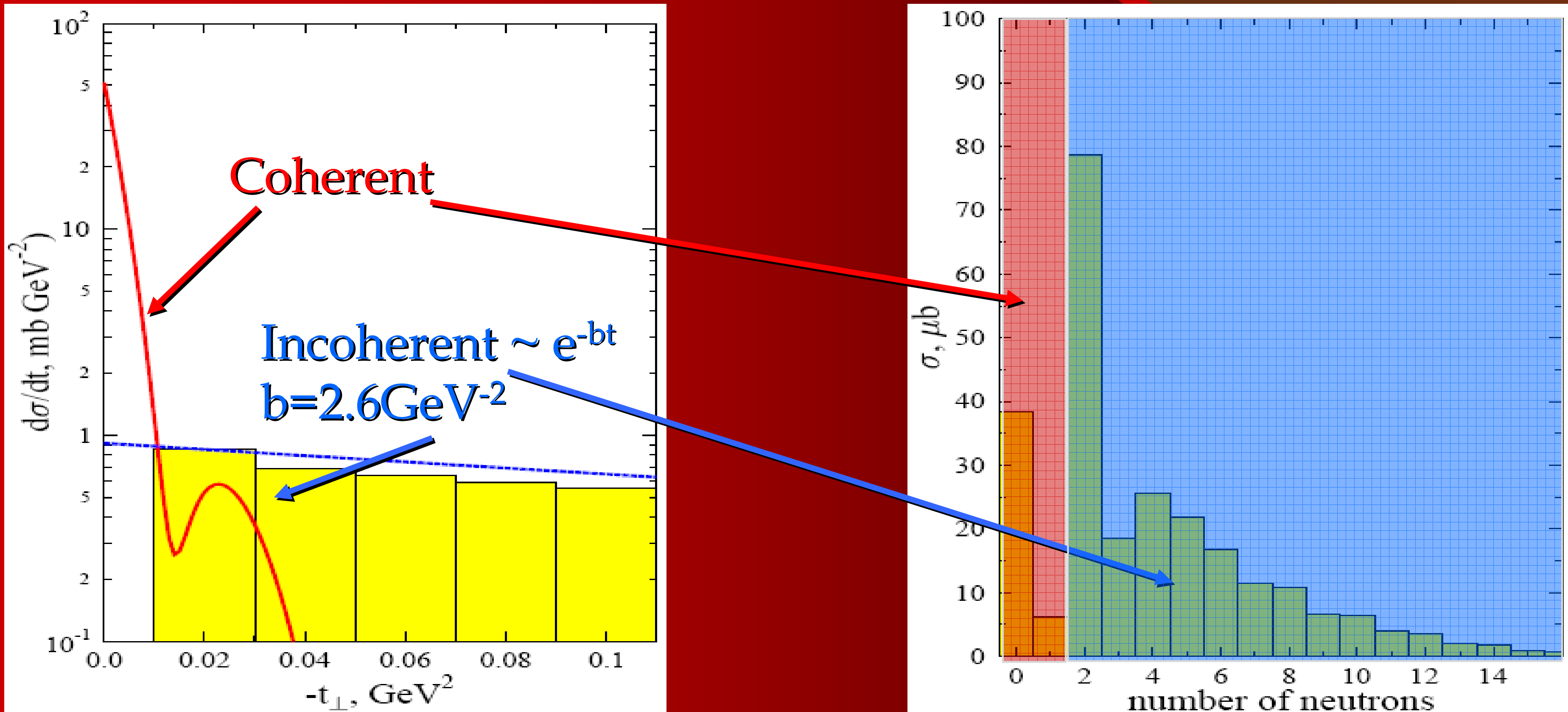
Thank you for the attention!



Incoherent J/Ψ production

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

Via t distribution — Via neutron tagging

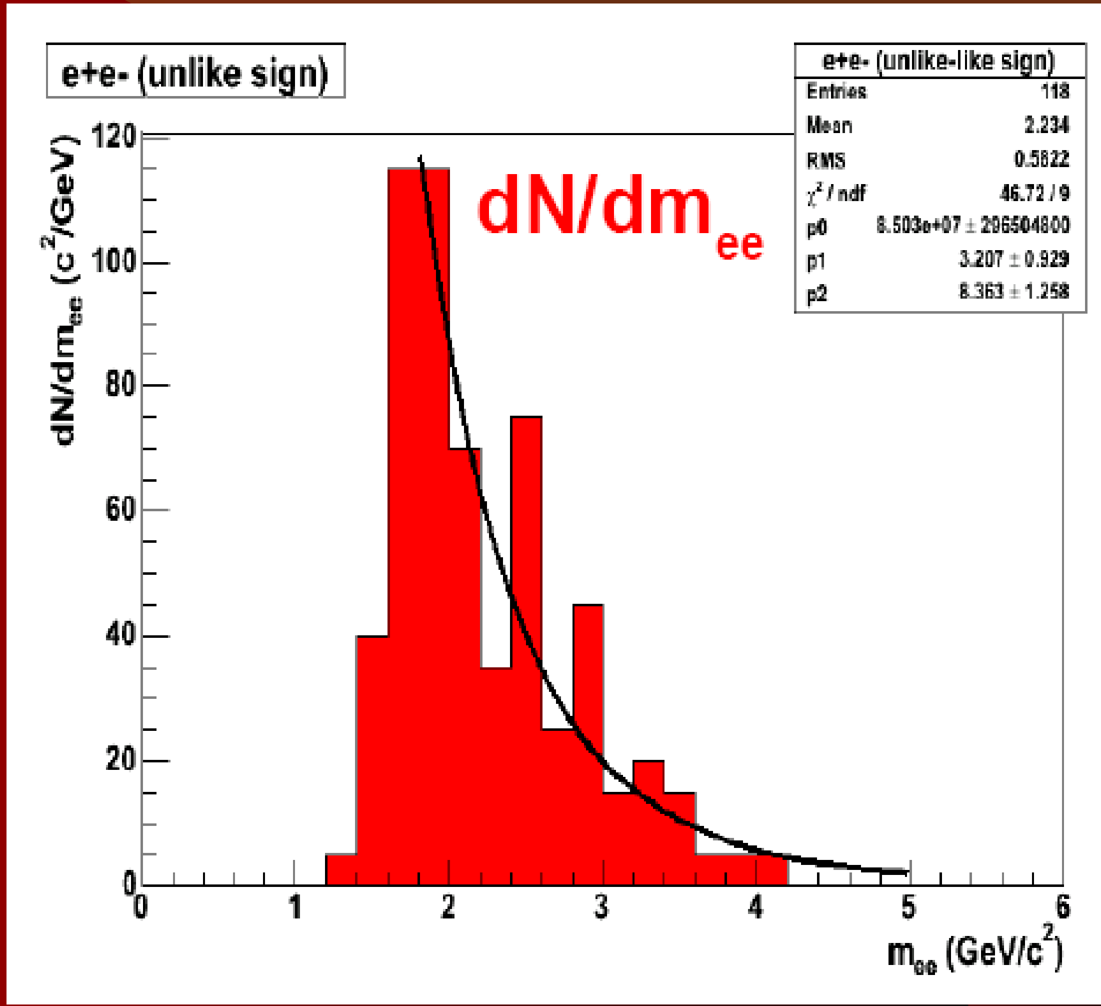


Strikman et al., hep-ph/0505023

- **Limited statistics …**

Background substraction

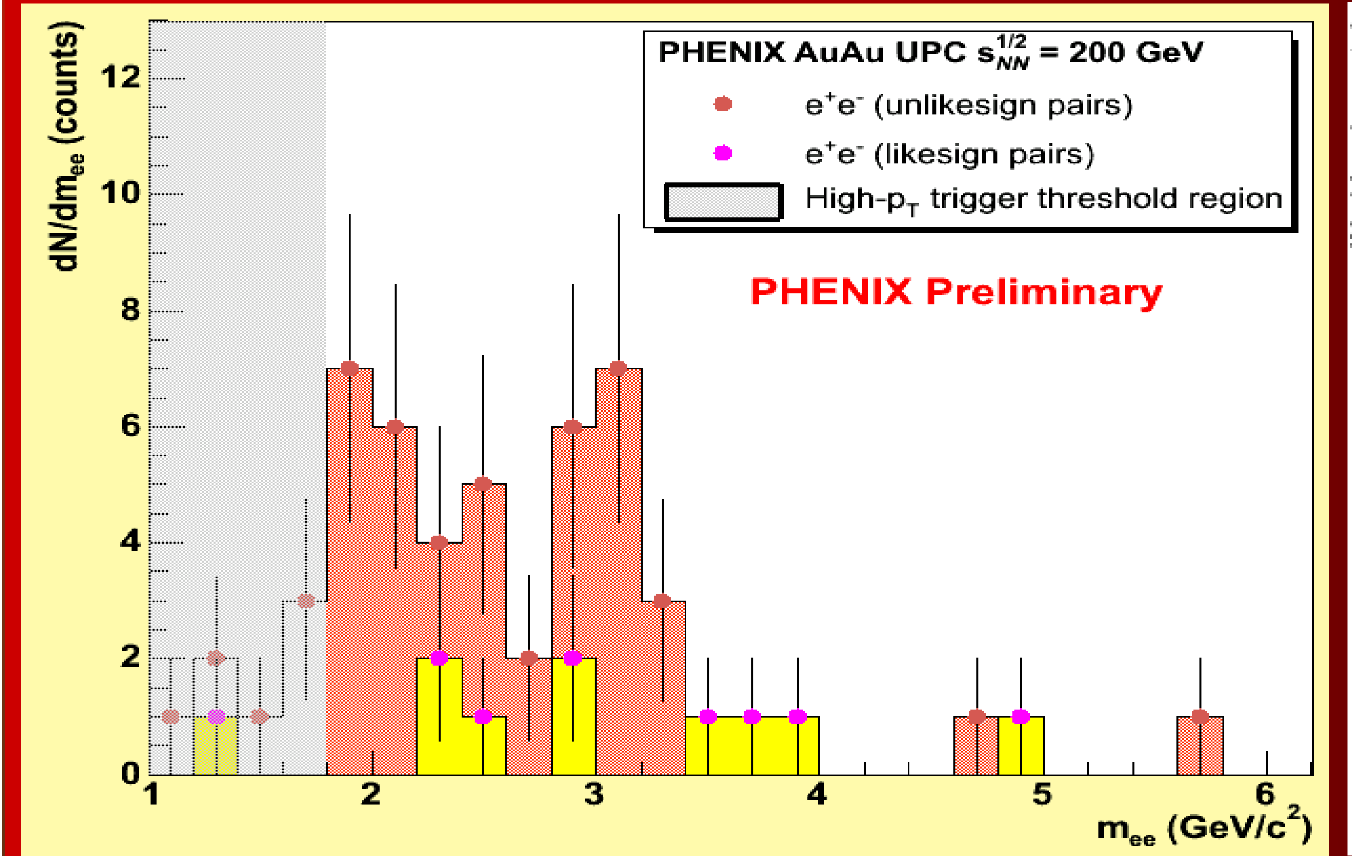
J. Nystrand, hep-ph/0412096, NPA752(2005)470

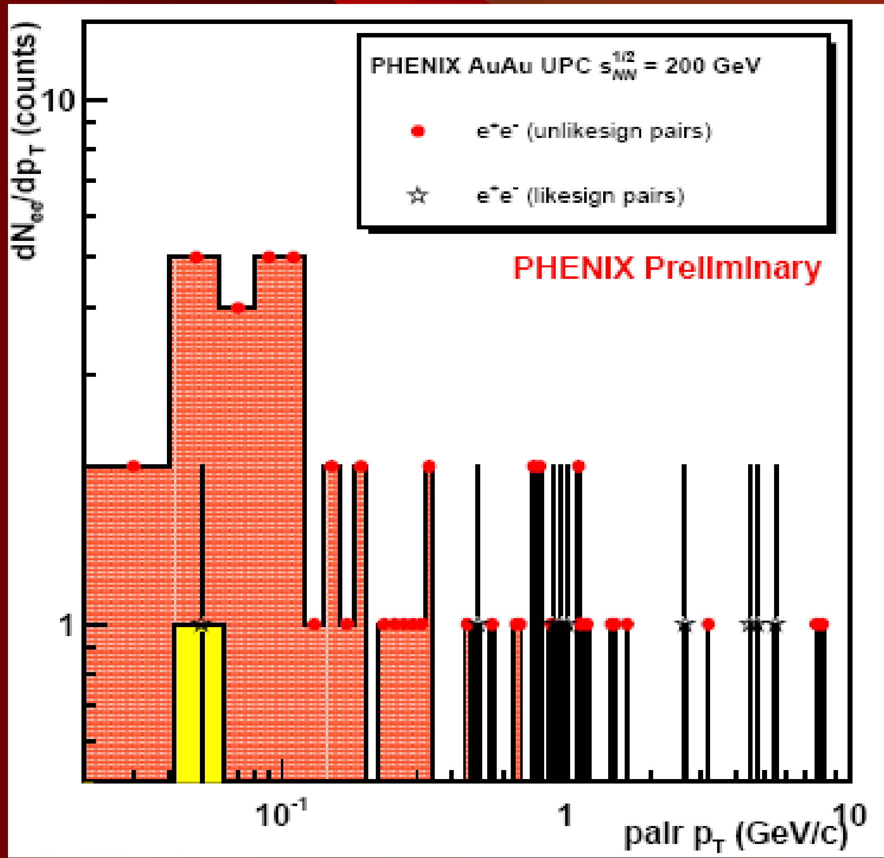


- Starlight Monte Carlo simulation
- Determine continuum shape
- 700k e^+e^- pairs with m_{inv}>1.5 GeV, 500 μb^{-1}

Resulting distributions

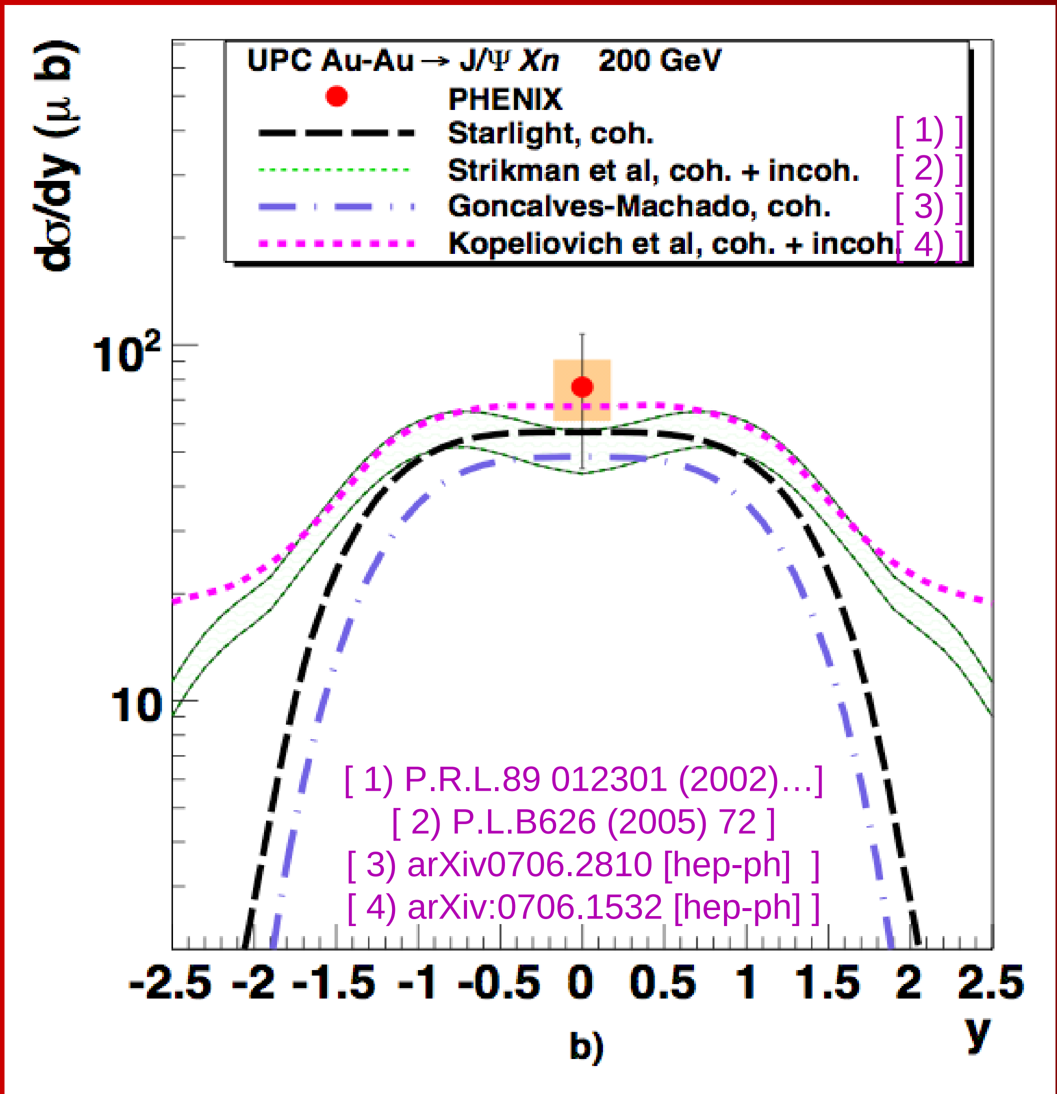
- Invariant mass distribution with continuum background
- Pair transverse momentum distribution
- Unlike-sign (red) and like-sign (yellow) pairs





Theoretical calculations

- **Cross-section is consistent with different model predictions**
- **… though current precision precludes yet any detailed conclusion on the basic ingredients: shadowing and nuclear absorption**



Rough comparison with HERA

e-p data, $\sigma_{\gamma p} = A^{\alpha}\, \sigma_{\gamma A}$

If coh. incoh. ratio is 50% - 50%

- $\alpha_{coh} = 1.01 \pm 0.07$
- $\alpha_{incoh} = 0.92 \pm 0.08$

⇒ α ~ 1, good agreement with HERA data hard probes scaling!

- **Similar comparison with STAR ρ measurement gives $\alpha_{coh} = 0.75 \pm 0.02$, closer to $A^{2/3}$ soft scaling**

[ZEUS, Eur.Phys.J. C24 (2002) 345]
[H1, Eur.Phys.J. C46 (2006) 585]
[STAR, Phys.Rev.C77 (2008) 034910]