J/ψ photoproduction at RHIC using $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions

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For the STAR collaboration

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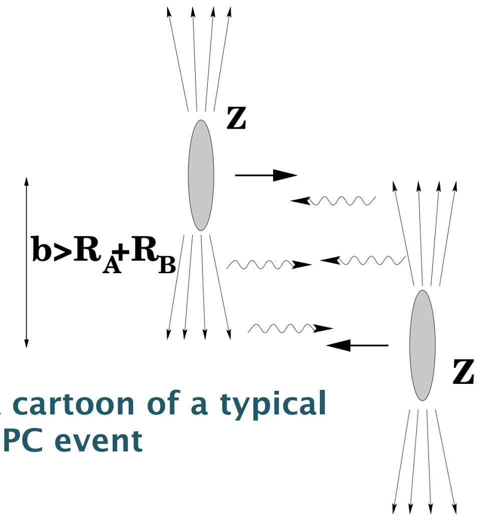
High Energy Photonuclear Reactions



A cartoon of a typical UPC event

- Impact parameter (**b**) is larger than the sum of radii of participating nuclei
- The strong electromagnetic field of relativistic particles can be represented by a spectrum of equivalent photons

Weizsäcker-Williams (EPA) formula

$$\frac{dN_\gamma}{d\zeta}(b > b_{\min}) = \frac{\alpha_{em} Z^2}{\pi}\frac{1}{\zeta}\left[2xK_0(x)K_1(x) - x^2\left(K_1^2(x) - K_0^2(x)\right)\right];\ \zeta = \frac{E_\gamma}{E_A}\ \&\ x = \zeta m_A b_{\min}$$

Nucleus Form factor dependence is included in modified Bessel functions K_1 and K_0

- High energy photons can have a point-like interaction like (e.g.: Compton scattering) or quantum fluctuate into vector meson ($J^{pc} = 1^{--}$) or fermion-antifermion pair
- The validity of EPA for heavy ions requires coherent emission of photons

Photon Kinematics

$$Q^2 = \left(\omega^2/\gamma^2 + q_\perp^2\right) \lesssim 1/R_A^2 \qquad \omega < \omega_{max} \approx \frac{\gamma}{R} \qquad q_\perp \lesssim \frac{1}{R} \approx 30\ \text{MeV}$$

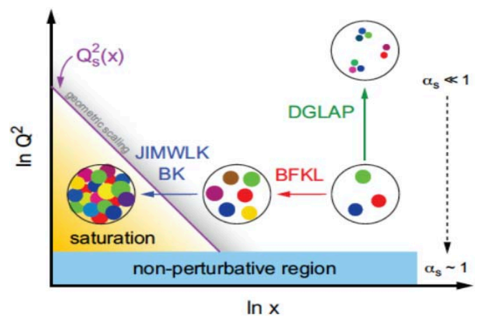
At RHIC energies γ=108 *ω_{max} ~ 3 GeV* *In the CM system $\omega_{\gamma N}$ (max) ~ 34 GeV*

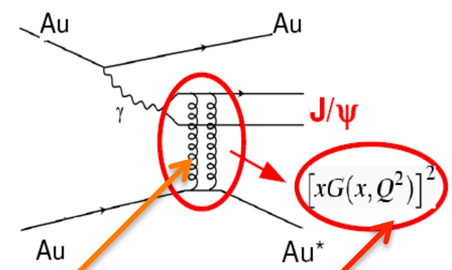
Photoproduction of J/ψ

STAR

- Test perturbative Quantum Chromodynamics (pQCD)
  - ✓ The quarkonium mass, m_V, gives a perturbative scale even in the photo-production limit, allowing us to study low-x gluons in the nuclear target

$$x = \frac{M_V}{\sqrt{S_{NN}}} e^{\pm y} \sim 10^{-3} - 10^{-2} \; and \; Q^2 \sim M_V^2$$





  - ✓ At the RHIC energy regime we can study Pomeron exchange (or two gluon exchange without color transfer)

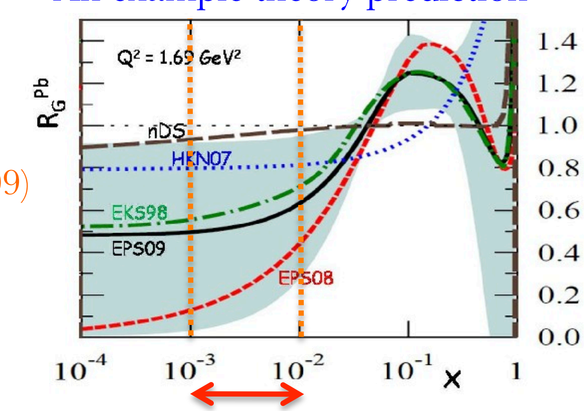
Study Gluon distributions

- To study nuclear ratio for the gluon density, R_G, (nuclear shadowing)

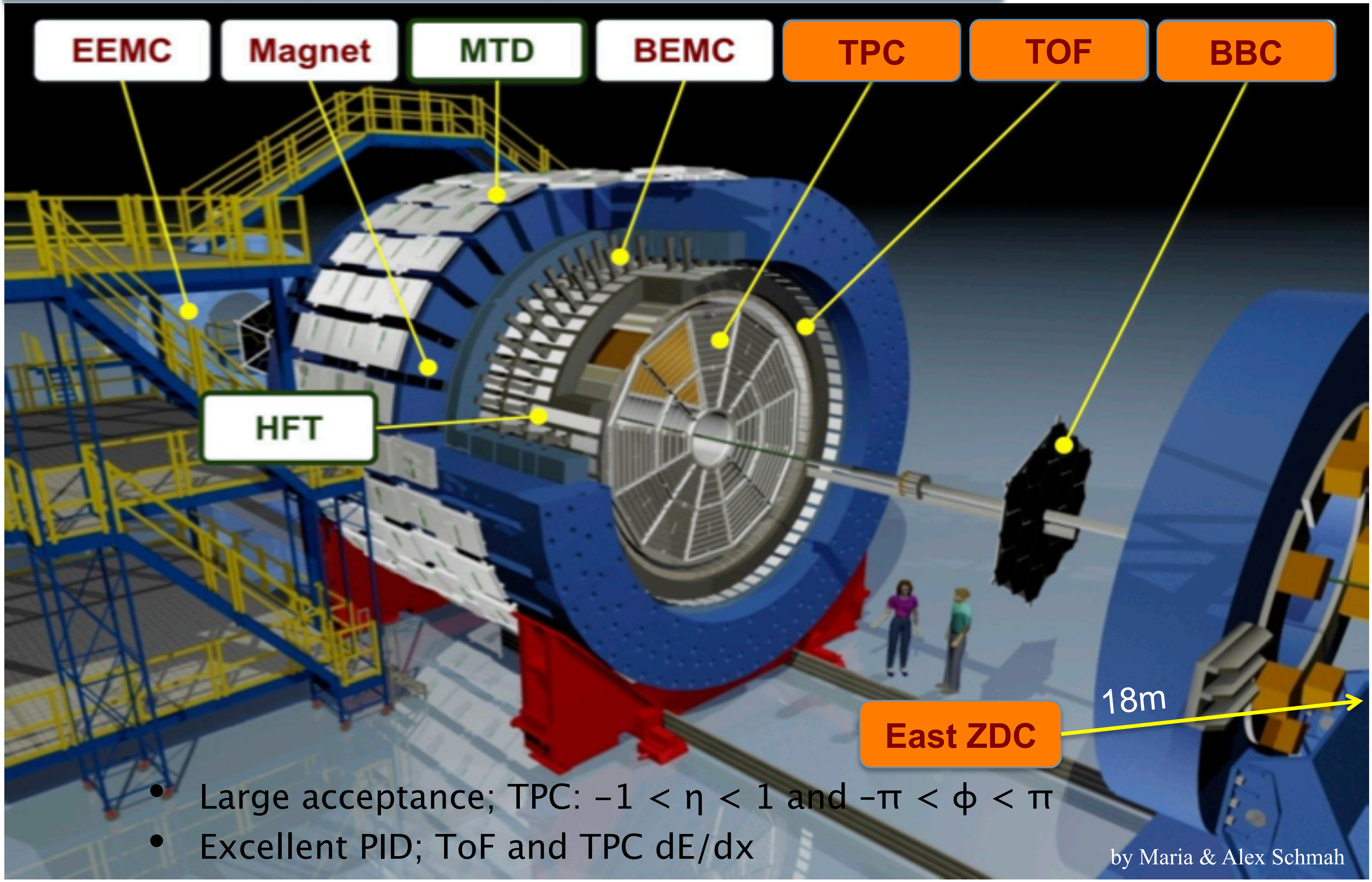
Paukkunen et al, talk at DIS 2009; JHEP 0904:065 (2009)

- Measurements of differential cross section as a function of rapidity(y) and momentum transfer(t) enable us to test theory predictions

An example theory prediction

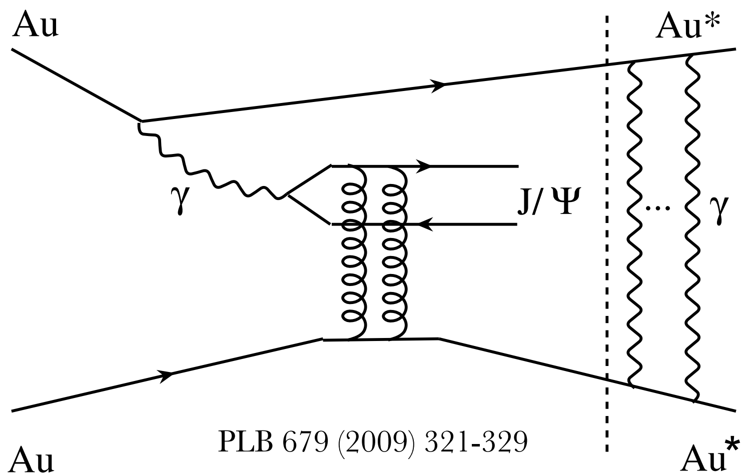


STAR – Solenoidal Tracker At RHIC

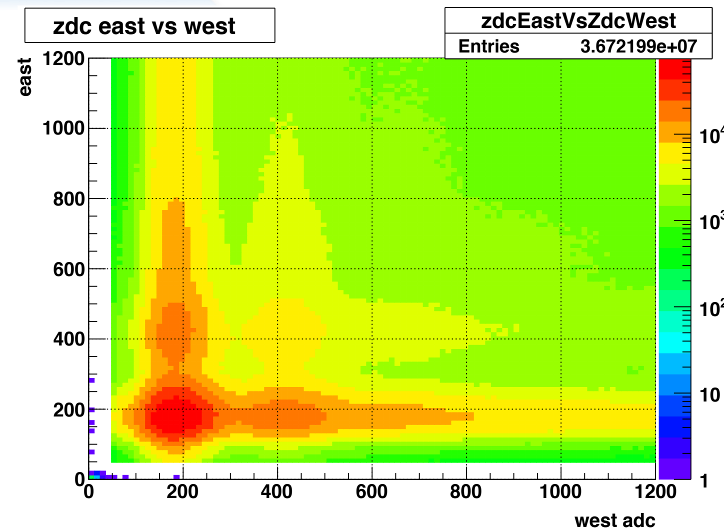


- Large acceptance; TPC: $-1 < \eta < 1$ and $-\pi < \phi < \pi$
- Excellent PID; ToF and TPC dE/dx

STAR UPC trigger



Lowest order Feynman diagram for exclusive J/ψ production in UPCs. The photons to the right of the dashed line are soft photons



Forward/backward going neutrons as detected by STAR ZDC East and West

STAR UPC trigger consists of:

- $2 \leq$ TOF hits ≤ 6
- Veto on small BBC tiles $2 < |\eta| < 5$
- The strong fields associated with heavy ions at high energies lead to large probabilities for exchanging additional soft photons in the same event
- The soft photons excite nuclei to a Giant Dipole Resonance (GDR), which then decay by emitting neutrons in the forward/backward directions
  - ✓ $1 \leq$ beam neutrons ≤ 5 in both ZDCs

Data and Analysis cuts for J/ψ

- 38 Million Run10 200 GeV Au+Au UPC trigger events with $\int L = 1075\ \mu b^{-1}$

Select events:

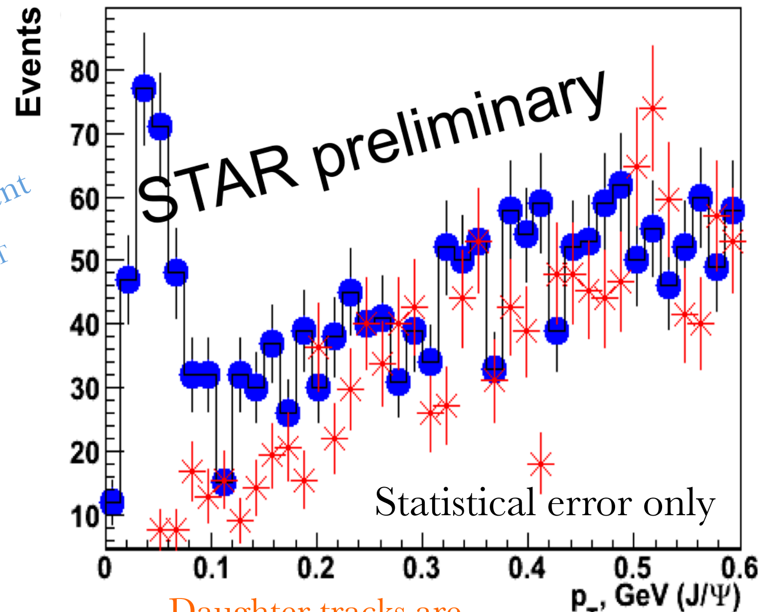
- [2-4] primary tracks in the TPC
- Z-vertex position; [-50, 50]cm
- An event vertex has two tracks associated to it (exclusive production)
- Require both tracks to be matched to Time of Flight (trigger)
- Background modeled with like-sign pairs
- Mass cuts
  - J/ψ: $3.0 < M_{inv} < 3.2$ GeV/c^2
- J/ψ rapidity distribution
  - coherent cut; $p_T < 0.15$ GeV/c

Pair p_T Distribution

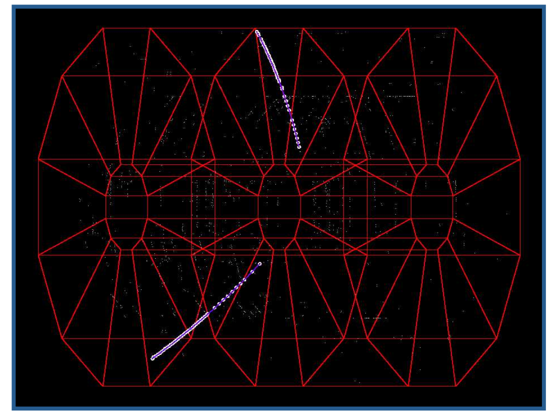
2010 AuAu 200 GeV data

Only acceptance corrected

Clear signal for coherent production seen in p_T distribution



Daughter tracks are not constrained to TOF



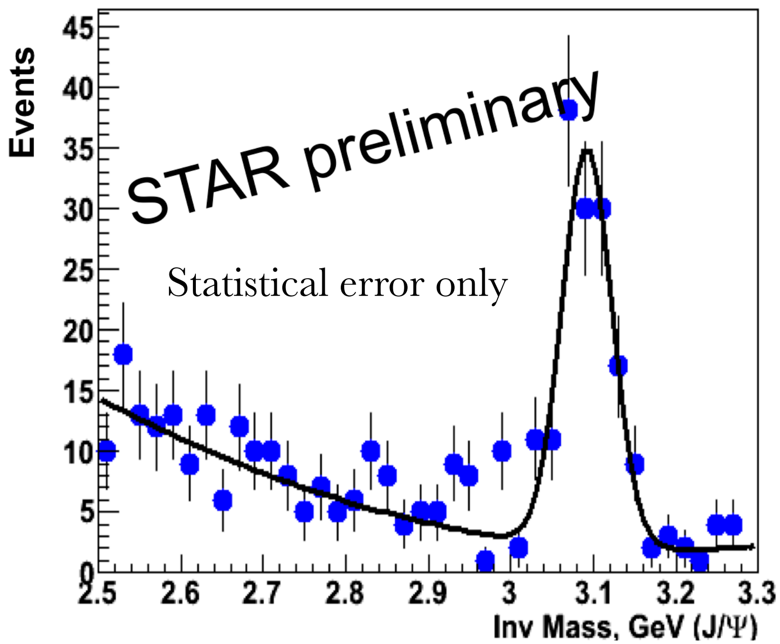
J/ψ is generated at rest, daughters decay back to back

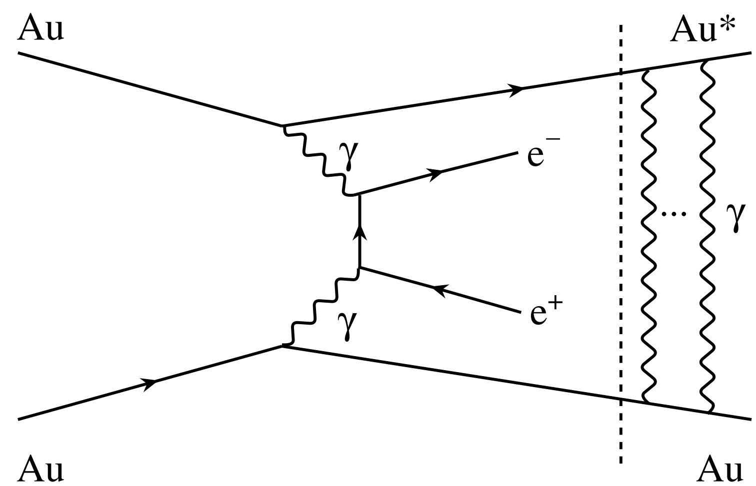
- Blue: unlike-sign pairs
- Red: background estimated with like-sign pairs
- The peak at low transverse momenta is consistent with coherent production
- For J/ψ rapidity distribution analysis, only events with $p_T < 0.15$ GeV/c are used (coherent momentum cut ~ $\hbar/R_A$)
- Only statistical error bars are presented

Inv. Mass Distribution

2010 AuAu 200 GeV data

$J/\psi \rightarrow e^+e^- / \mu^+\mu^+$





Lowest order Feynman diagram for exclusive photo production of dielectrons in UPCs. This contribution needs to be subtracted from J/ψ candidates

- J/ψ particles are identified using an invariant mass reconstruction
- After like sign background subtraction, we fit the data with an exponential for e^+e^- continuum, a Gaussian for J/ψ signal and a polynomial background
- We reconstruct 78 J/ψ mesons after correcting for e^+e^- continuum background
- Only statistical error bars are shown

Vector Meson Rapidity Distribution

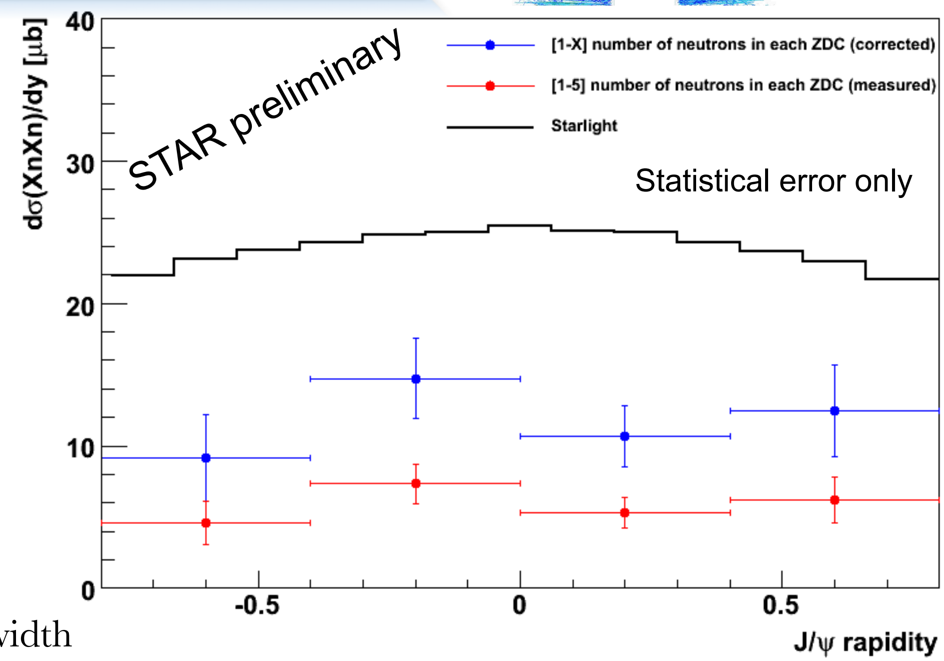
Background subtraction is carried out using like-sign pairs

Cross section normalization uses the following formula

Normalization:

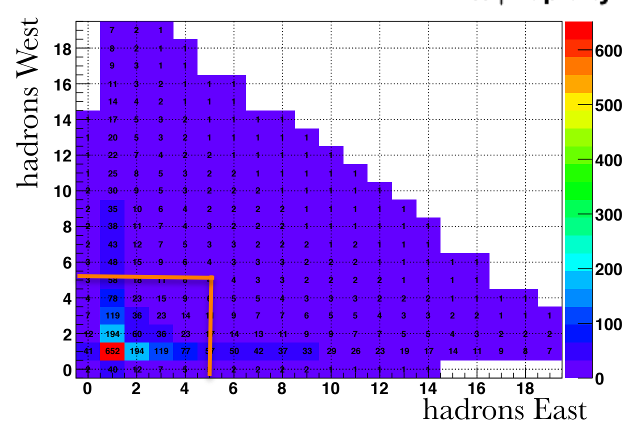
$$\frac{d\sigma}{dy} = \frac{N_{J/\psi}}{\varepsilon_{trigg} \cdot Acc \cdot \varepsilon} \cdot \frac{1}{\Delta y} \cdot \frac{1}{BR} \cdot \frac{1}{L_{int}} \cdot Trigger\,correction$$

$N_{J/\psi}$ = Background corrected Vector meson count
BR = Branching ratio
L_{int} = Integrated luminosity Δy = Histogram bin width
E_{trigg} = Trigger efficiency   Acc = Acceptance ε = Tracking efficiency



Trigger correction : Correct cross section for detecting up to X {1,2,3, …} neutrons in both ZDCs

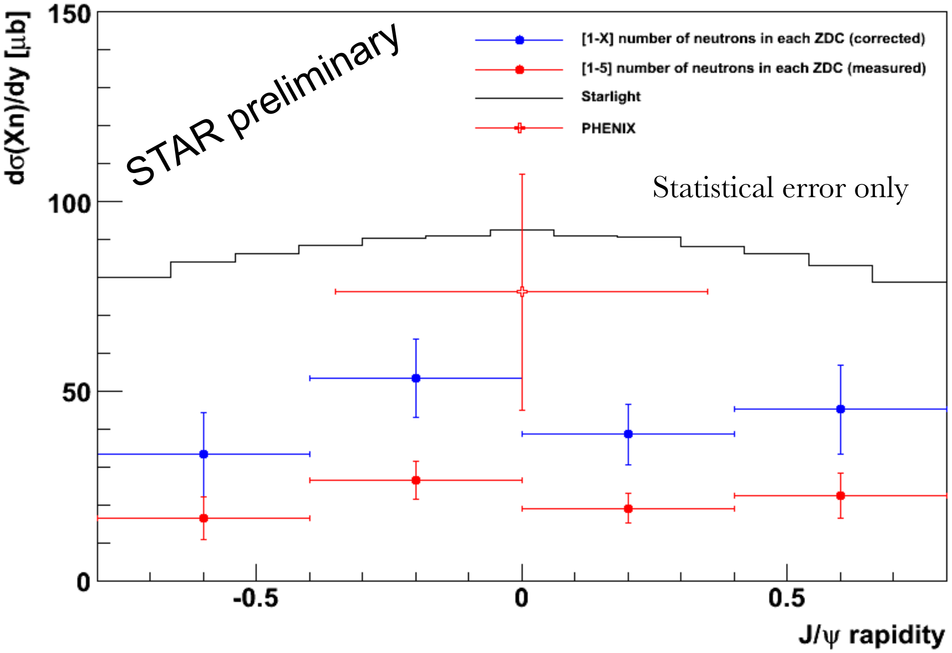
- STAR 2010 UPC_Main trigger detected up to 5 neutrons in both ZDCs
- The cross section was corrected for losing events which emitted more than 5 neutrons
- The correction was done using a mutual heavy ion dissociation model *A. Pshenichnov et al., Physical Review C, 64, 024903*



Model cross section values for all possible combinations of number of neutrons and other hadrons emitted towards East and West ZDCs

Comparisons

Xn : X [1,2,3, … number of neutrons on either ZDC]



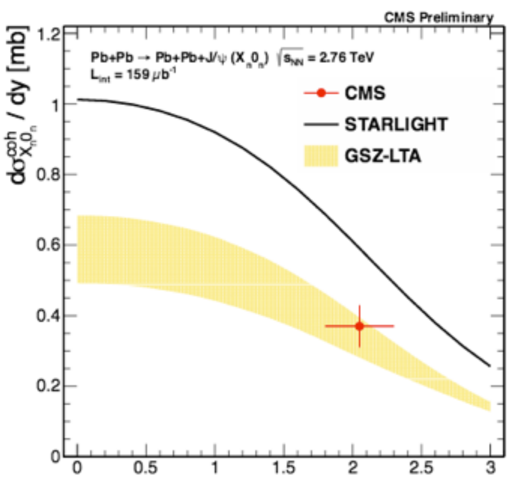
- Using Starlight we scale STAR XnXn cross section to Xn (a 3.64 factor)

- Scaled STAR Xn cross section has been compared with PHENIX data with statistical errors only

PLB 679 (2009) 321–329

- STAR & PHENIX data have been compared with Starlight predictions

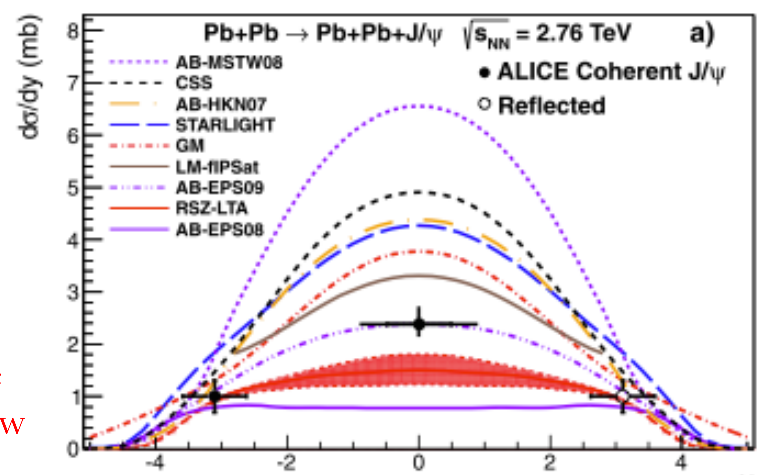
- Systematic error is not included



CMS PAS HIN-12-009 (2014)

- J/ϕ differential cross section measurements for ALICE and CMS at 2.76 TeV
- LHC data are compared to Starlight and other theory predictions

- Both LHC and RHIC data are approximately a factor of 2 below the Starlight prediction



Eur. Phys. J. C (2013) 73:2617

Summary and outlook

- We have analyzed 38 million UPC trigger events from 2010 Au+Au 200 GeV data set ($\int L = 1075\ \mu b^{-1}$)
- After applying offline analysis cuts, and subtracting e^+e^- continuum, STAR measures a <XnXn> cross section of ~12 μb^{-1} (78 coherently produced J/ψ particles)
- We report the efficiency corrected differential cross section for UPC J/ψ production
- STAR data were compared with theory prediction and other experimental measurements for J/ψ photo-production
- Both RHIC and LHC measurements are approximately a factor of two below Starlight predictions
- Systematic uncertainties need to be estmated