Recent results from the STAR experiment on Vector Meson production in ultra peripheral AuAu collisions at RHIC.

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On behalf of STAR Collaboration

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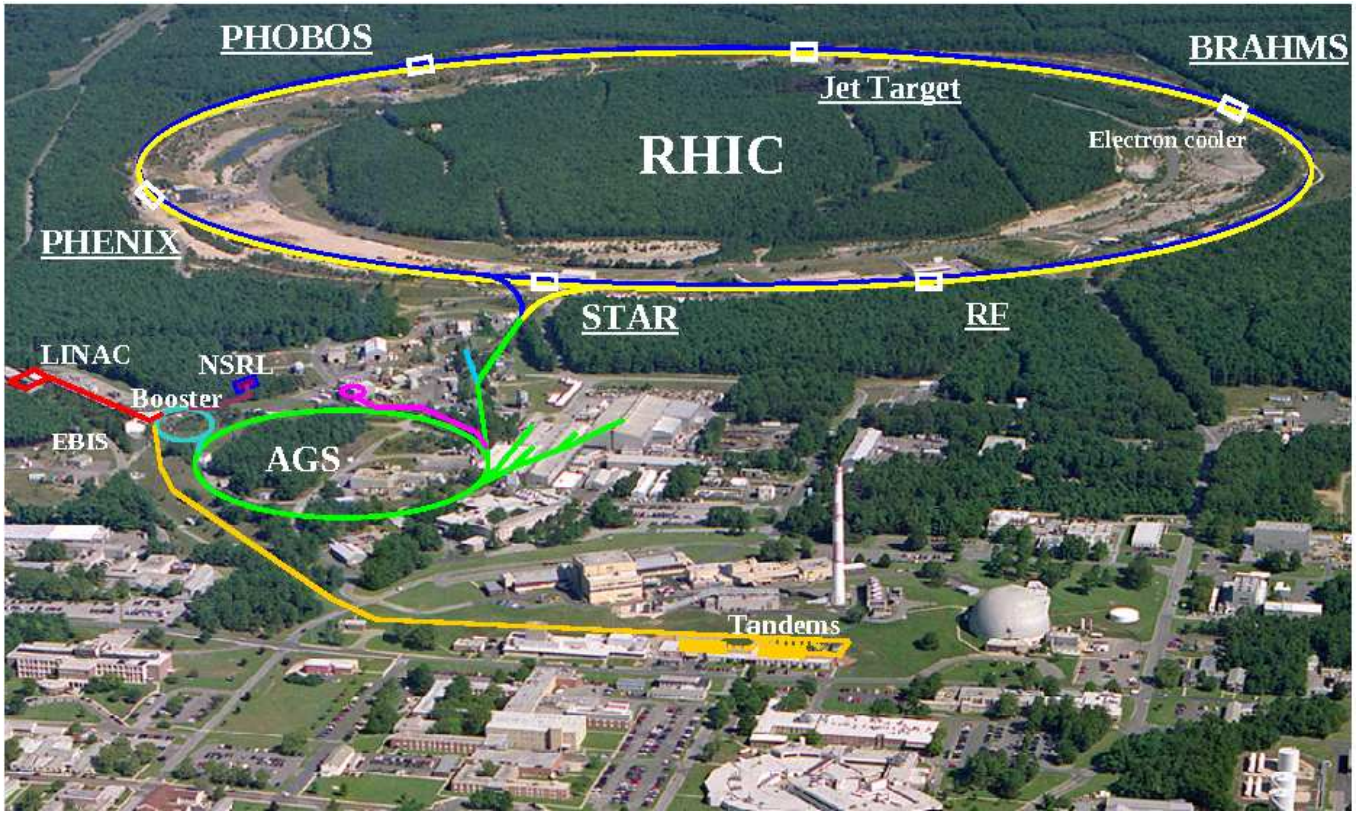
RHIC

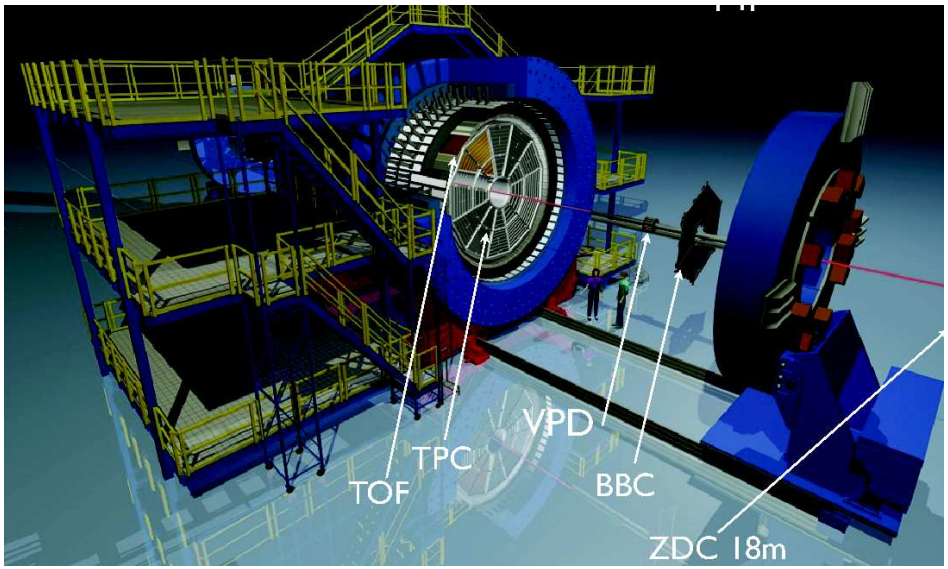
AA: Au+Au, Cu+Cu, Cu+Au, d+Au, U+U up to $\sqrt{s_{NN}} = 200$ GeV
new results: $\mathrm{Au} + \mathrm{Au} \to (\mathrm{Au})^{\star} + (\mathrm{Au})^{\star} + X$; X : direct $\pi\pi, \rho^0, \omega, \rho_3(?), J/\Psi$
polarized proton-proton: up to $\sqrt{s} = 510$ GeV
plans: $p + p \to p + p + J/\Psi$; $p + \mathrm{Au} \to p + (\mathrm{Au})^{\star} + J/\Psi$



Rafał Sikora talk at this conference:
$p + p \to p + p + X$; $X : \pi\pi, KK$

The STAR detector

new results: AuAu $\rightarrow$ (Au)*(Au)$^{\star}X$, $X =$ direct $\pi\pi, \rho^0, \omega, J/\Psi$.



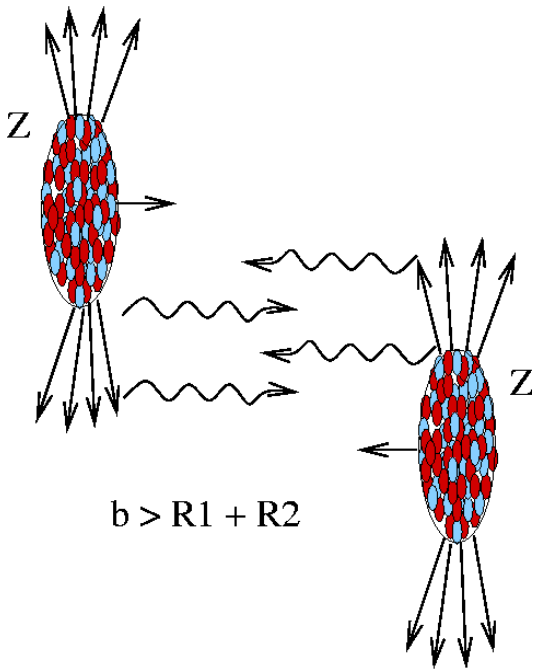
- high resolution tracking with TPC: $-1 < \eta < 1$
- particle identification TPC: dE/dx
- time-of-flight (TOF) system: triggering on low multiplicity events and selection in-time tracks
- possible rapidity gap: BBC veto, $2.1 < \eta < 5.2$
- tagging nucleon excitation: neutrons in ZDC

plans: $p + p \rightarrow p + p + J/\Psi$; $p + \mathrm{Au} \rightarrow p + (\mathrm{Au})^{\star} + J/\Psi$

- Barrel EM Calorimeter: triggering $J/\Psi \rightarrow ee$
- Roman Pot system: trigger/measure scattered proton (see Rafał Sikora/Łukasz Fulek talks at this conference)

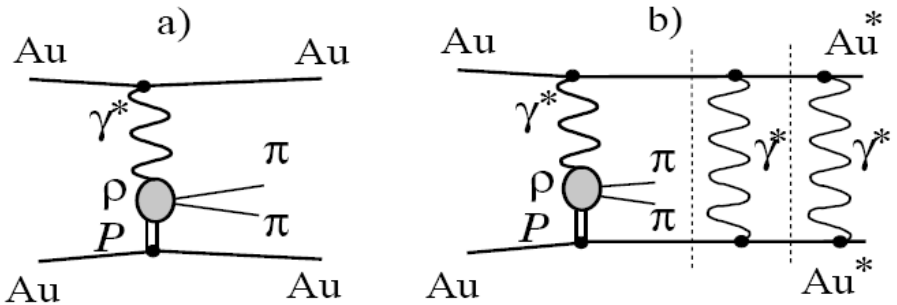
Photoproduction in Ultra-peripheral collisions

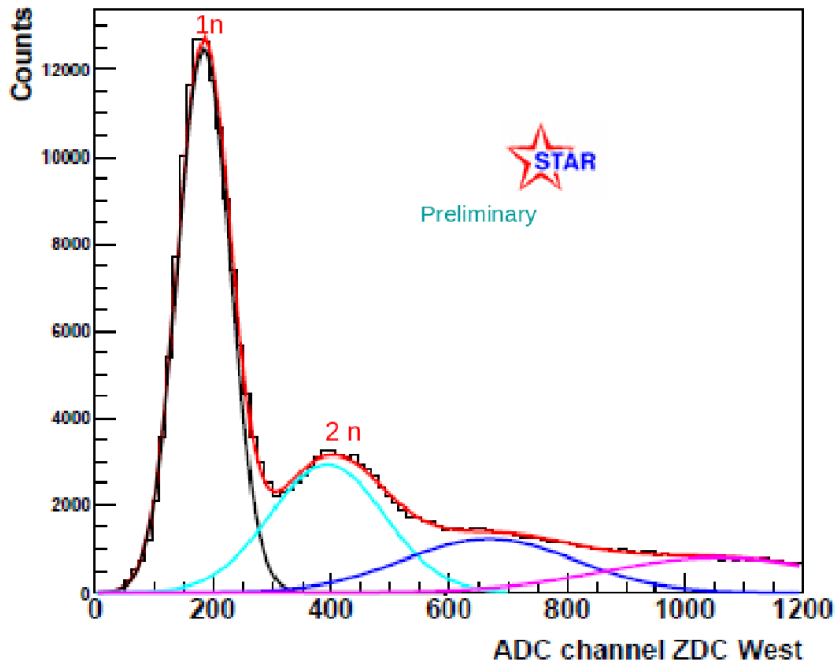
- relativistic heavy ions are an intense source of photon fluxes
- virtuality $Q^2 < (\hbar/R_A)^2 < 10^{-3}$ GeV^2
- 7.6 $GeV < \sqrt{s_{\gamma N}} <$ 20.6 GeV for Au Au with $\sqrt{s_{NN}} = 200$ GeV
- typically Vector Meson (VM) production
- production can occur:
  - coherently off whole nucleus (large size, low p_T)
  - incoherently off individual nucleons (small size, high p_T)



Photoproduction of low-multiplicity states in UPC

- photon emitted by one ion fluctuates into a $q\bar{q}$ state which then interacts with other ion by the Pomeron exchange
- coherent exclusive production (a) hard to trigger at STAR
- coherent with nuclear excitation (b) triggered by tagging fast forward neutrons coming from de-excitation of $(Au)^{\star}$ ($\approx$ 10% of the total cross section)
- use theoretically well known 1n1n events for overall cross-section normalization

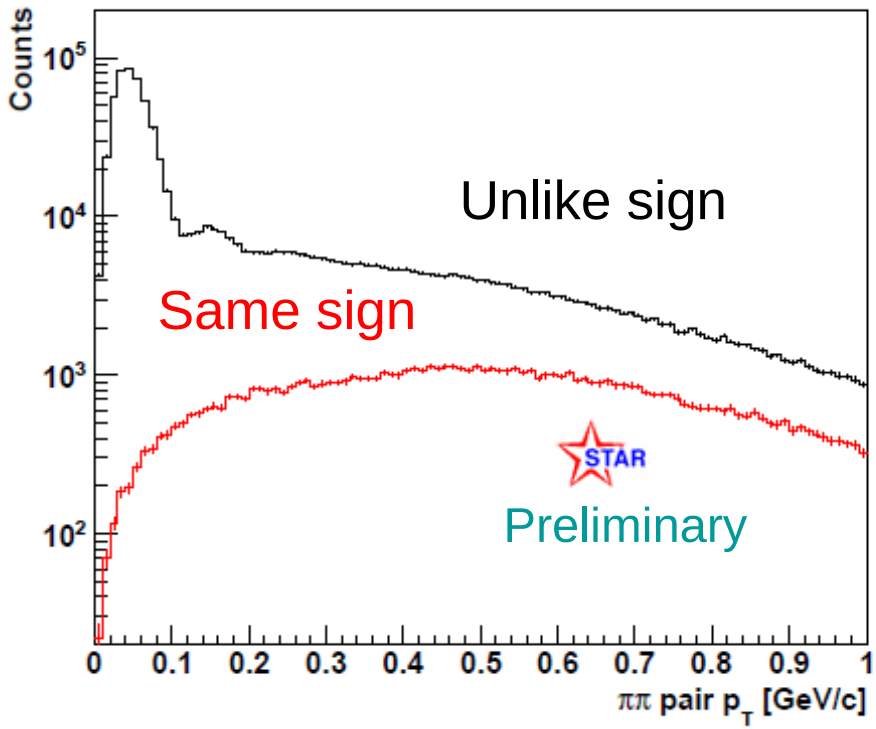




RHIC Run2010

Pion pair selection

- at least 14 hits in TPC (out of 45 normally possible)
- associated with a hit in the time-of-flight system (eliminates out-of-time tracks)
- |track pseudrapidity|< 1
- specific dE/dx within 3σ of pion expectation



RHIC Run2010

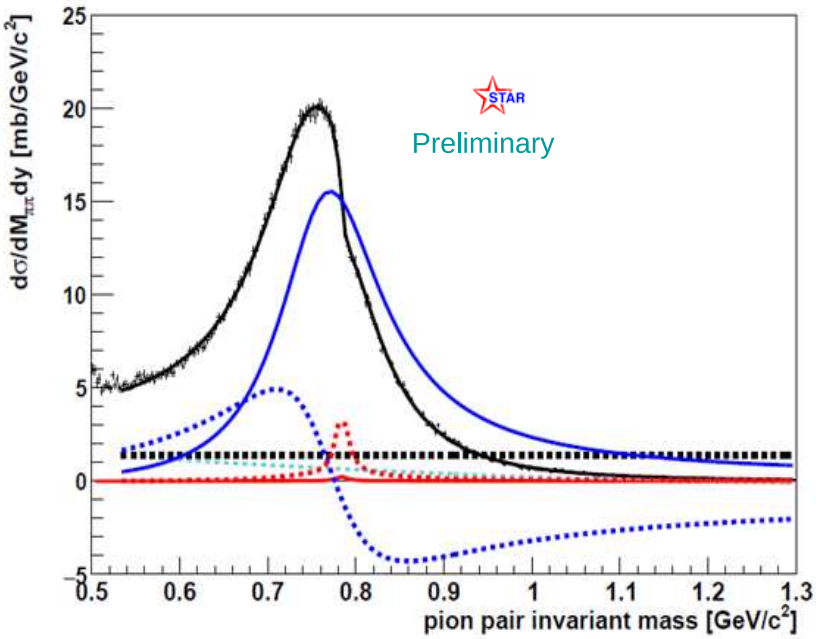
- like sign pairs are a background measure, and are subtracted.
- efficiency corrections done with STARlight Monte Carlo events embedded in zero-bias data.

STARlight: PRC C60, 014903 (1999) & PRL 84, 2330 (2000)

Fit to pion pair invariant mass spectrum

- 384,000 reconstructed pairs with $p_T < 100$ MeV/c
- 3 indistinguishable sources: ρ^0, ω^0 (small B.R.), direct $\pi\pi \rightarrow$ add amplitudes in fit:
- Fit parameters:
  - ρ^0, ω mass and width
  - ρ^0, ω and direct $\pi\pi$ amplitudes, and ω phase
  - quadratic polynomial for remaining backgrounds
- solid black : data points & fit
  solid blue: ρ^0
  dotted blue: ρ^0-$\pi\pi$ interference
  solid red: ω
  dotted red: $\omega - \rho^0$ interference
  dotted black : direct $\pi\pi$

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} \propto \left| A_\rho \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + i M_\rho \Gamma_\rho} + B_{\pi\pi} + C_\omega e^{i\phi_\omega} \frac{\sqrt{M_{\pi\pi} M_\omega \Gamma_\omega}}{M_{\pi\pi}^2 - M_\omega^2 + i M_\omega \Gamma_\omega} \right|^2 + f_p$$



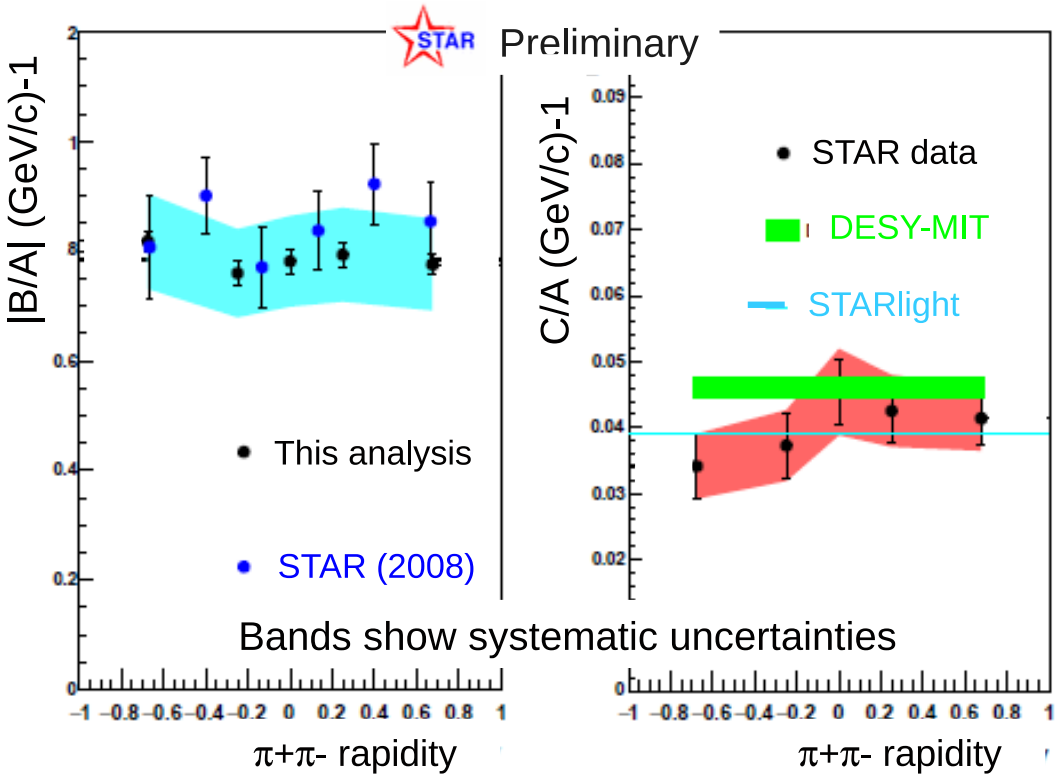
RHIC Run2010

χ^2/DOF = 314/297

- ρ^0 mass and width and ω mass consistent with PDG
- ω width higher (16 ± 2 vs. 8.5 MeV), likely because of detector resolution
- non zero ω phase ($\phi_\omega = 1.73 \pm 0.13$ rad)

ρ^0 : direct $\pi\pi$ and ρ^0 : ω amplitudes ratios

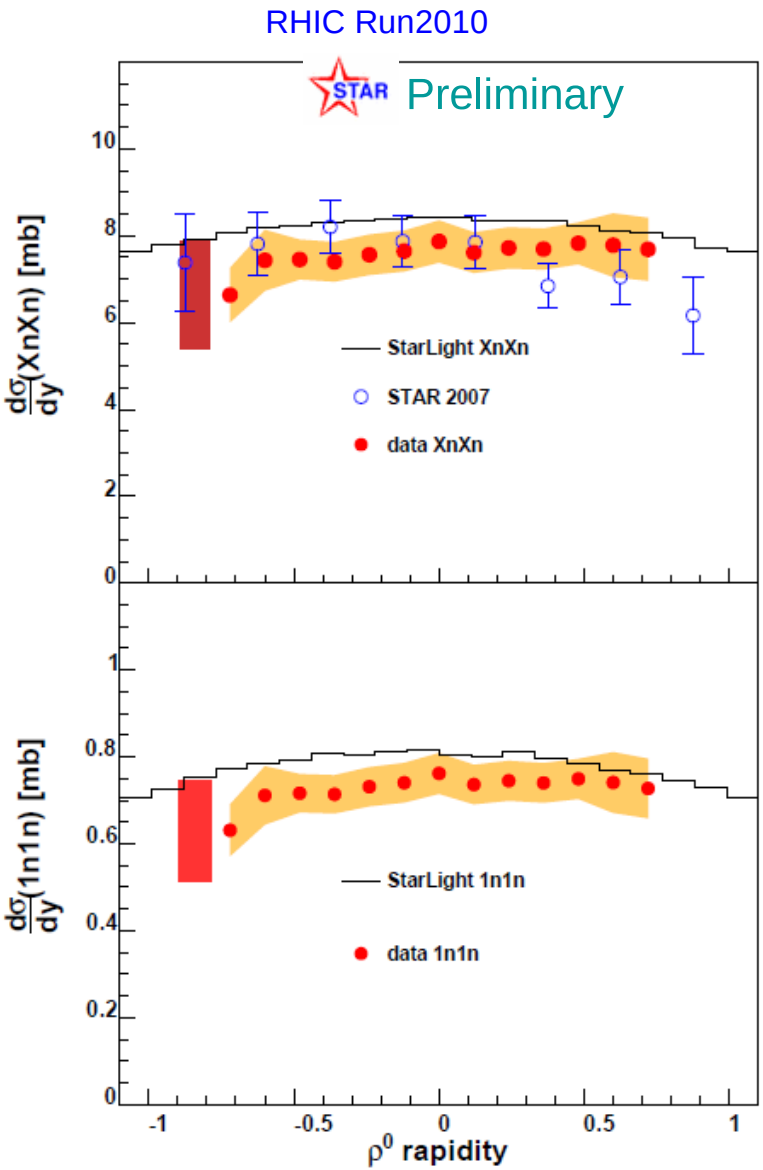
RHIC Run2010



- STAR 2008: PRC 77, 034910 (2008)
- ALICE: JHEP 1509, 095 (2015)
- DESY-MIT:
  PRL 27, 888 (1971)
  fixed-target experiment, with 5-7 GeV photons (low enough to be sensitive also to photon-meson fusion)

- ρ^0 : $\pi\pi$ ratio is consistent with previous STAR and ALICE results and also consistent with HERA results
- ρ^0 : ω ratio is consistent with measured $\gamma\pi \rightarrow \omega p$ cross-section, Glauber calculation (via STARlight) and measured (per PDG) Br($\omega \rightarrow \pi^+\pi^-$)= 0.015 $\pm$ 0.001 and with DESY fixed-target data
- ω phase $\neq$ 0; is consistent with previous DESY results

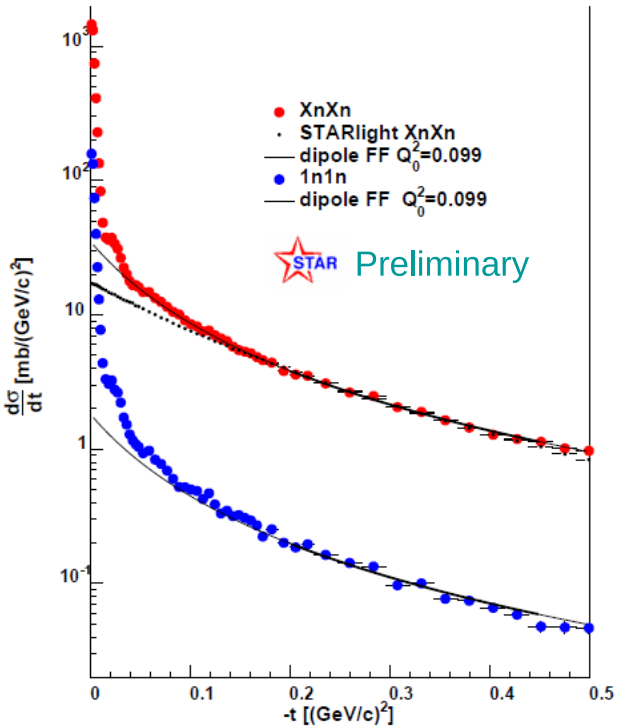
ρ^0 rapidity



- rapidity distribution is in good agreement with STARlight
- 1n,1n cross-section is consistent with STARlight 10% below prediction (< 1 $\sigma_{syst.}$)
- Xn,Xn cross-section is scaled from 1n,1n using STARlight
  - The distribution of the number of neutrons is not well known.

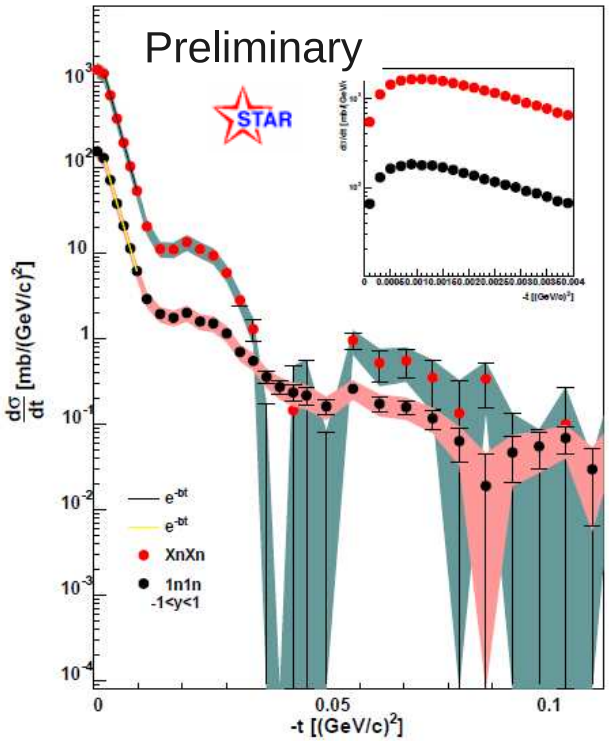
ρ^0 $d\sigma/dt$; RHIC Run2010

Coherent + incoherent



- fit incoherent part in $|t| > 0.2$ GeV^2 region to a dipole form factor $F(t) = A/(Q_0^2 + |t|^2)$ with $Q_0^2 = 0.099$ GeV^2
- find coherent spectrum by subtracting incoherent

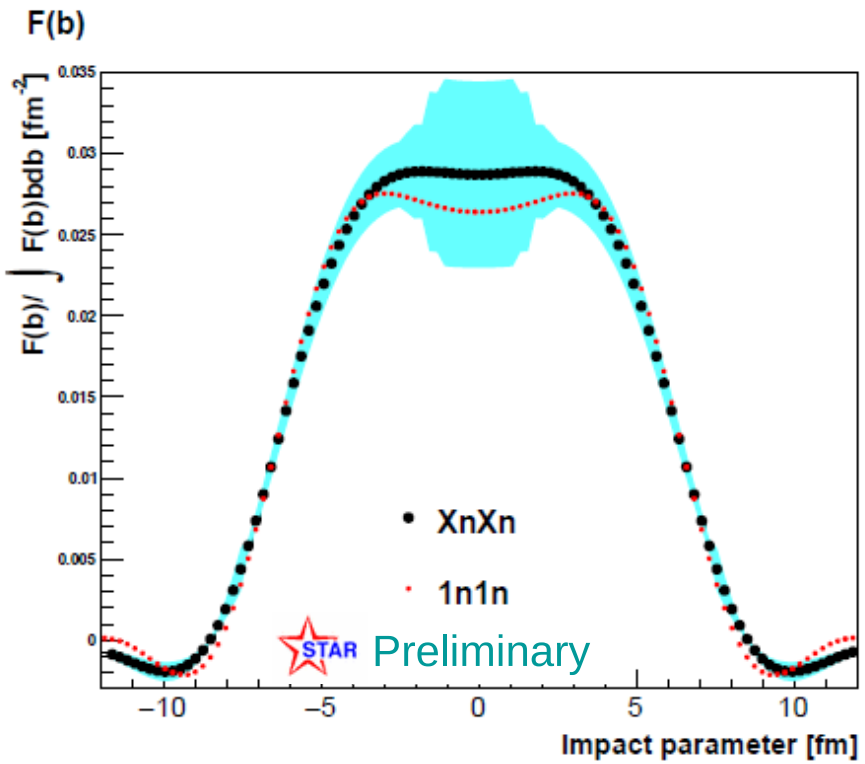
Coherent production



- multiple diffraction dips visible expected as nucleus approaches 'black disk'
- downturn for $|t| < 10^{-3}$ GeV^2 due to interference between the two production targets (nuclei)

ρ^0: targets spatial distribution inside Au nucleus

$$F(b) \propto \frac{1}{2\pi}\int_0^\infty dp_T\, p_T\, J_0(bp_T)\sqrt{\frac{d\sigma}{dt}}$$



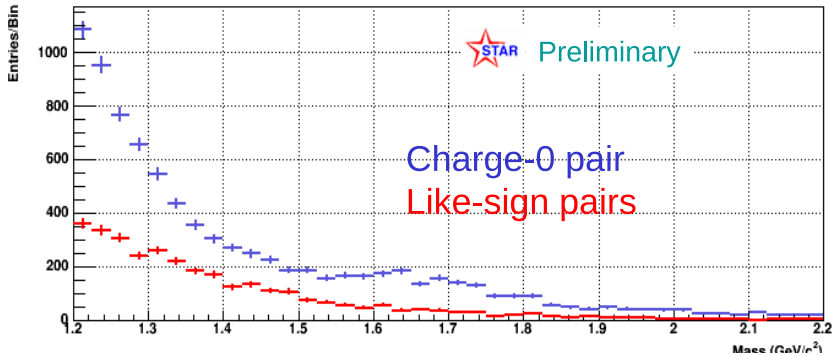
RHIC Run2010

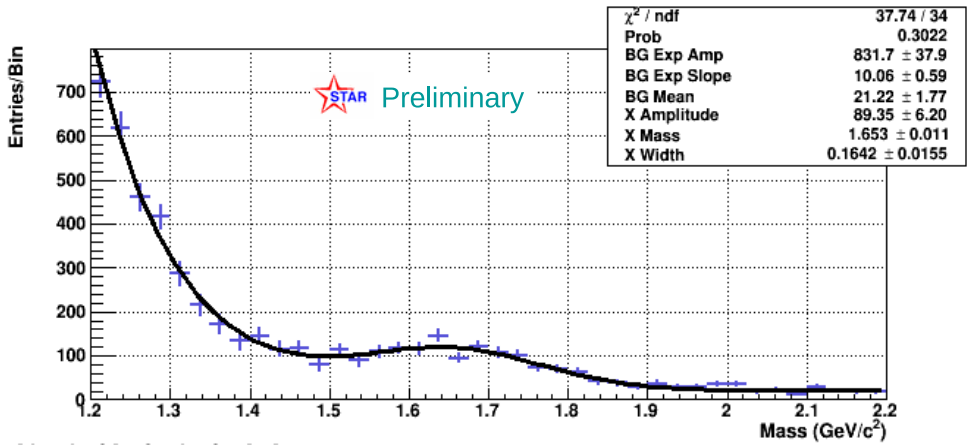
- Fourier 2-D transform of the $d^2\sigma/dydt$ relates to the targets spatial distribution in the Au nucleus integrated over z
- blue band shows effect of varying $|t|_{max}$ from 0.06 to 0.05 - 0.09 GeV^2
- variation at small |b| may be due to finite t range
- negative wings at large |b| are likely from interference between the two production nuclei
- FWHM=2*(6.17$\pm$ 0.12 fm)

pion pairs: high mass region

RHIC Run2010, Run2011

- like-sign background subtracted
- fit to exponential tail of ρ^0, flat remaining background and Gaussian peak for signal
- $M_X = 1653 \pm 10$ MeV, $\Gamma_X = 164 \pm 15$ MeV (stat. only)
- $N(X) = 1034 \pm 71$: 15 σ significance (stat. only)

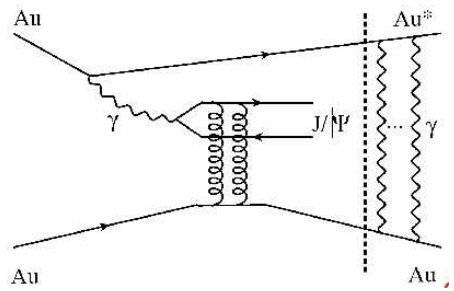




Consistent with $\rho_3(1690)$:

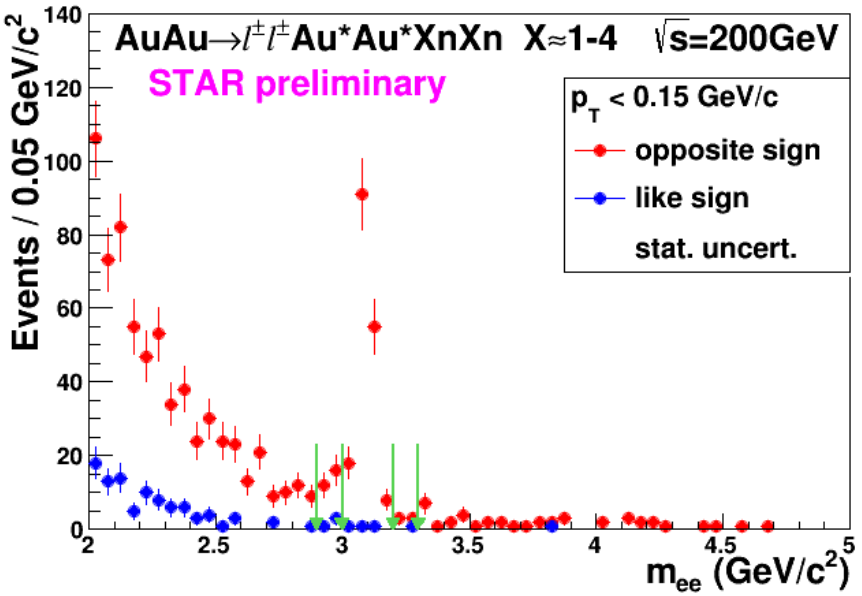
- $M = 1690$ and $\Gamma = 161$ MeV
- Br($\rho_3 \to \pi^+\pi^-$) $= 23.6 \pm 1.3$ %
- N(ρ_3)/N(ρ^0) 1/750 consistent with Br($\rho_3 \to \pi^+\pi^-$) and previous $\gamma p \to \rho_3 \to \eta\pi^+\pi^-$ data from OMEGA photon collaboration: Z Phys. C30, 531 (1986)

Photoproduction of J/Ψ in UPC



- heavy vector meson production probe short distance scales
- scattering may be described via 2-gluon exchange
- sensitive to gluon distribution at $x \approx 0.01$ and $Q^2 \approx M^2_{J/\Psi}$

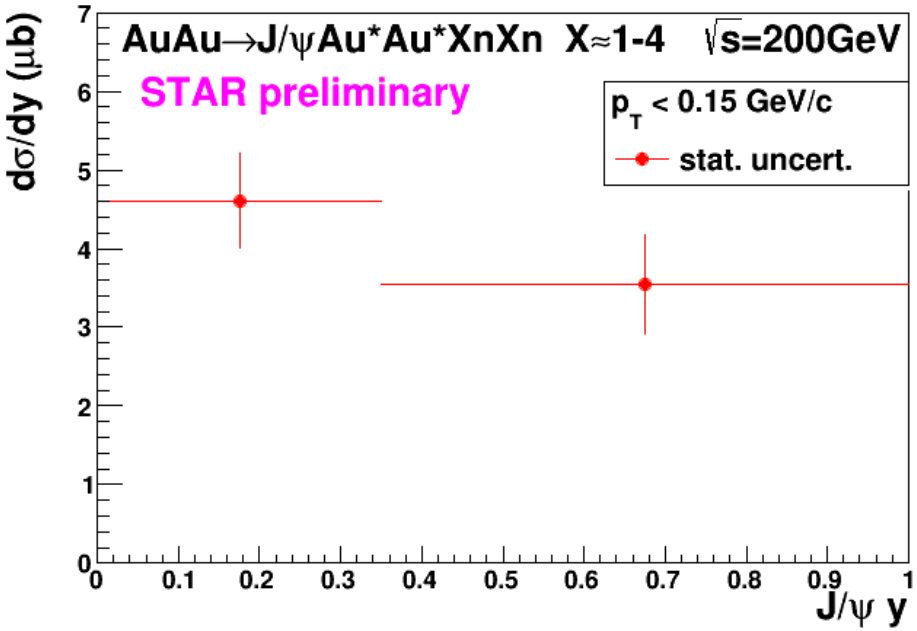
RHIC Run2010, Run2011



- two TPC tracks matched with a hit in TOF
- pair transverse momentum < 0.15 GeV
- pair rapidity $0.05 < |y| < 1$
- like-sign and side-bands background subtracted
- efficiency corrected

J/Ψ cross sections vs. rapidity

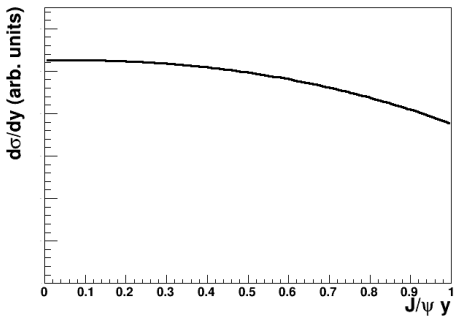
RHIC Run2010, Run2011



- physics distribution $d\sigma/dy$ symmetric under $y \rightarrow -y$ (symmetric beams)
- events y<0 binned |y|>0, total counts halved

- cross section falls slowly for 0<y<1, consistent with Starlight
- cross section factor 2.5 lower than STARlight + RELDIS expectation

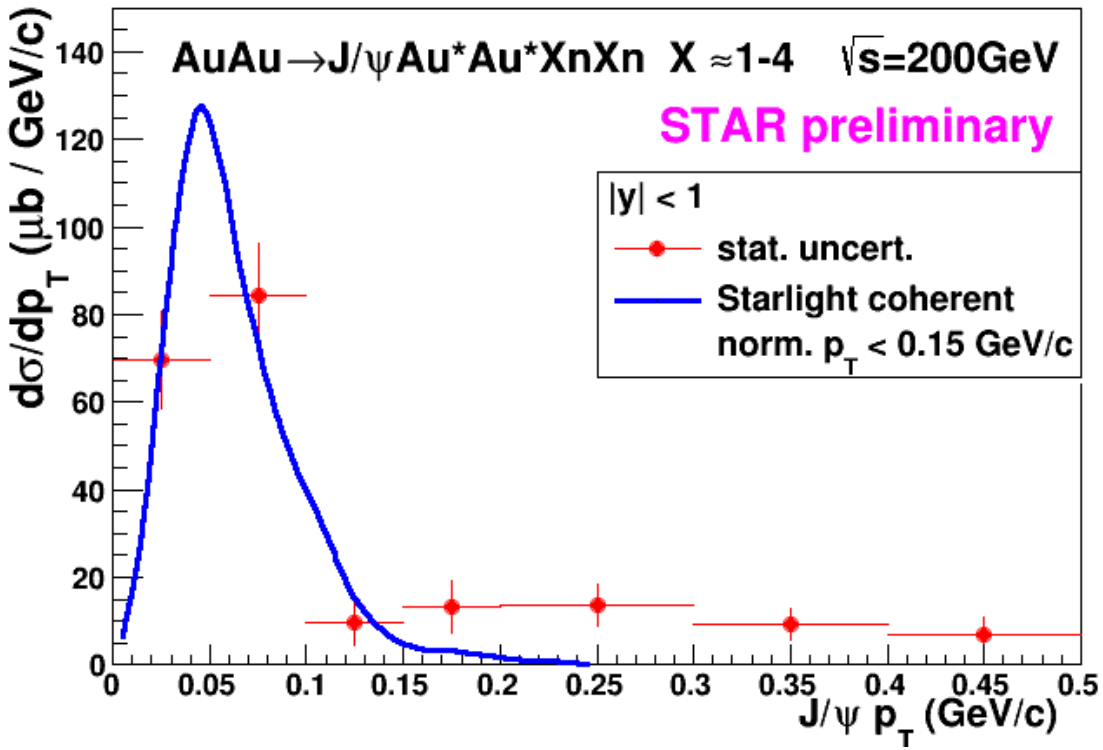
STARLight



RELDIS: PRC C64, 024903 (2001) & PPN 42, 215 (2011)

J/Ψ cross sections vs. p_T

RHIC Run2010, Run2011



- cross section for $p_T > 0.5$ GeV/c consistent with zero
- STARlight coherent normalized to data at $p_T < 0.15$ GeV/c dominant coherent component
- significant incoherent component at $p_T > 0.15$ GeV/c 30% of total signal.

Outlook: J/Ψ in UPC of AuAu

- RHIC Run2014 data processed soon:
  - new EM calor. trigger for $J/\Psi \rightarrow e^+e^-$, 3.5 larger sample
- Current RHIC Run2016:
  - EM trigger quiet, drop neutron requirement
  - factor of 10 larger cross section
  - factor of 10 increase in total luminosity, but lost $J/\Psi \rightarrow \mu^+\mu^-$
    factor 30-50 larger data sample coming
- Above data enable:
  - precise cross section measurement/comparison with models
  - measurement with/without Coulomb dissociation
  - finer study of p_T distribution: coherent/incoherent, diffractive peaks?

Outlook: J/Ψ in UPC of polarized protons pp and pAu

- J/Ψ photoproduction on polarized protons:
  - Measurement of J/Ψ azimuthal angle w.r.t. proton - ϕ
  - Measure J/Ψ transverse asymmetry A

$$\frac{d\sigma}{d\phi} \approx (1 + A\cos(\phi))$$

  - Transverse asymmetry A calculable with Generalized Parton Distribution and sensitive to gluon orbital angular momentum
  - STAR has Roman Pot system: tag/measure scattered proton

Plans:

- RHIC Run2017:
  - pp collisions with $\sqrt{(s)} = 500$ GeV, Luminosity = 400 pb^{-1}
  - expect 11 k $J/\Psi \rightarrow e^+e^-$ with hit in Roman Pot system
- RHIC Run202?:
  - consider pAu collisions with $\sqrt{(s)} = 200$ GeV, Luminosity = 1.75 pb^{-1}
  - expect 13 k $J/\Psi \rightarrow e^+e^-$ with hit in Roman Pot system (p-target)
  - expect 5 k $J/\Psi \rightarrow e^+e^-$ (Au-target)

Summary and outlook

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}X, \quad X = \text{direct } \pi^{+}\pi^{-}, \rho, \omega$

- high-statistics study of photoproduced $\pi^{+}\pi^{-}$ in ultra-peripheral collisions.
  - we observe the ρ^{0}, direct $\pi\pi$ and ω photoproduction.
  - The ω is observed through its interference with the ρ^{0}.
  - The ω amplitude is consistent with the measured ω photoproduction cross-section and branching ratio to $\pi^{+}\pi^{-}$.
  - The ω phase angle is non-zero, and consistent with previous studies.
- We see 2 diffraction minima in $d\sigma/dt$ for ρ^{0} photoproduction
- We observe an excited state with a mass of 1653 MeV and width of 164 MeV. The closest match in the particle data book is the $\rho_3(1690)$. The cross-section is consistent with a previous photoproduction measurement

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}J/\Psi$

- Clear UPC J/Ψ signal
- Cross section 2.5 lower than Starlight/RELDIS expectation
- Rapidity distribution flat as expected
- Dominant coherent (low p_T) component, plus 30% incoherent
- Factor 30-50 larger data sample coming

J/Ψ with polarized protons

- Large sample of $p + p \rightarrow p + p + J/\Psi$ expected in 2017
- Considered for 202?: large sample $p + Au \rightarrow p + (\text{Au})^{\star} + J/\Psi$
- Through transverse asymmetry access to GPD sensitive to gluon orbital angular momentum.