$\pi^+\pi^-\pi^+\pi^-$ Photo-production in Ultraperipheral Heavy-ion Collisions at $\sqrt{s_{NN}} = 200$ GeV at the STAR Detector

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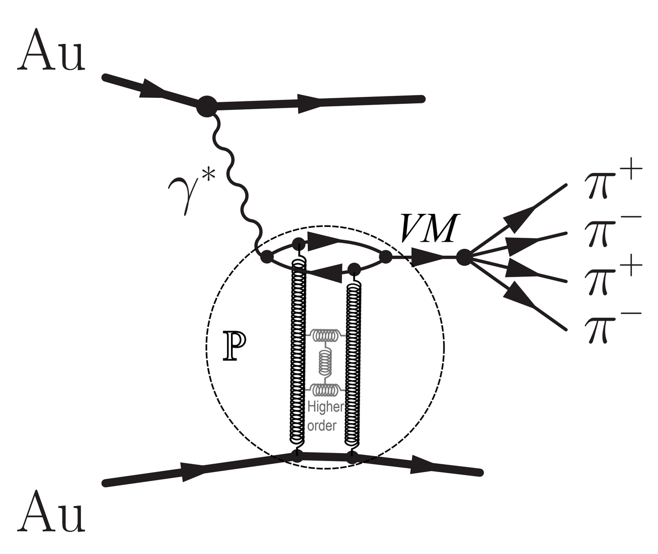
Abstract

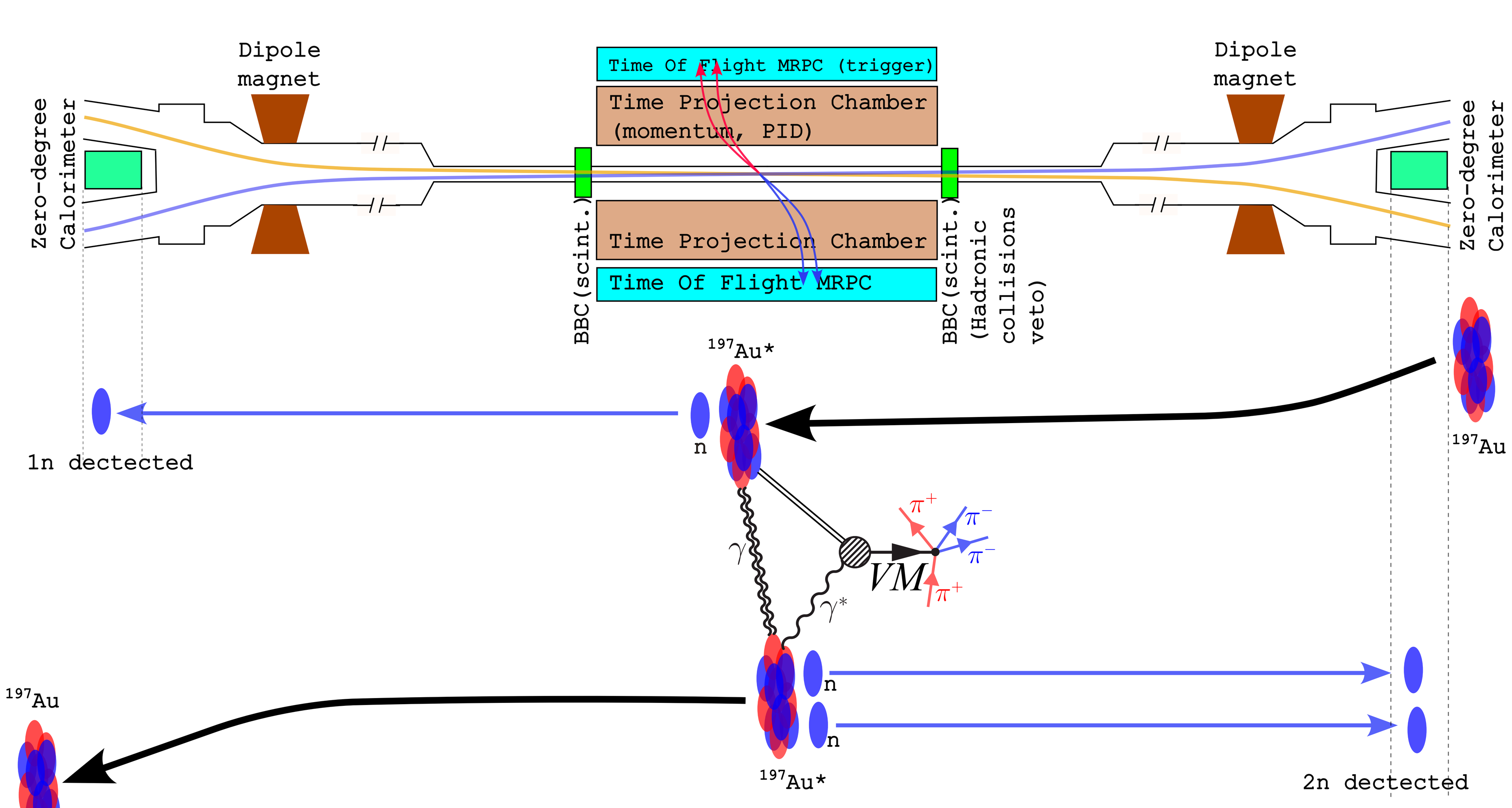
One of the most pressing questions in both hot and cold QCD communities is what the physics mechanism responsible for modified parton densities in heavy nuclei is. One promising channel to address this question is the photoproduction of vector mesons, which is considered a clean probe to the nuclear parton structures. We present a measurement of the coherent $\pi^+\pi^-\pi^+\pi^-$photonuclear production in ultraperipheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data were collected in 2010, 2011, and 2014 by the STAR experiment. The $\pi^+\pi^-\pi^+\pi^-$ invariant mass spectrum in coherent events exhibits a two resonance structure around ~ 1410 and ~ 1700 MeV/c 2 with widths of 400 and 330 MeV/c 2 , likely corresponding to ρ(1450) and ρ(1700). Furthermore, a peak corresponding to ρ(2150) is observed.

Motivation [1]

Partons and nuclear effects: To expand measurements of parton distribution functions (PDF) in small-x and directly obtain more differential information about the nuclear structure, one needs to go beyond inclusive Deep inelastic scattering (DIS). Photo-production is one such approach. Until the Electron-ion Collider (EIC) is build, most high-energy photo-production studies use ultra-peripheral ion collisions (UPC). UPC are interactions that occur at impact parameters large enough that no hadronic interactions overshadow the electromagnetic processes. For coherent photo-production, the final state $p_T <$ few $\hbar/R_A \approx 150$ MeV/c => excellent background rejection. The photo-production probes the nuclear structure at a scale set by the mass of the final state. For vector mesons, $Q^2 = (M_{VM}c^2/2)^2$. $x = (M_{VM}c^2)^2/W^2$, where W is the γ-nucleon center of mass energy. STAR published detailed analysis of the ρ_0 photo-production [2], but much less is known about the ρ excitations. Questions have been raised as to the nature of the $\rho(1450)$ and its relation to the $\rho(1700)$ [3]. This poster presents extension of the STAR analysis [4] using almost 2 orders of magnitude more statistics.



Experiment

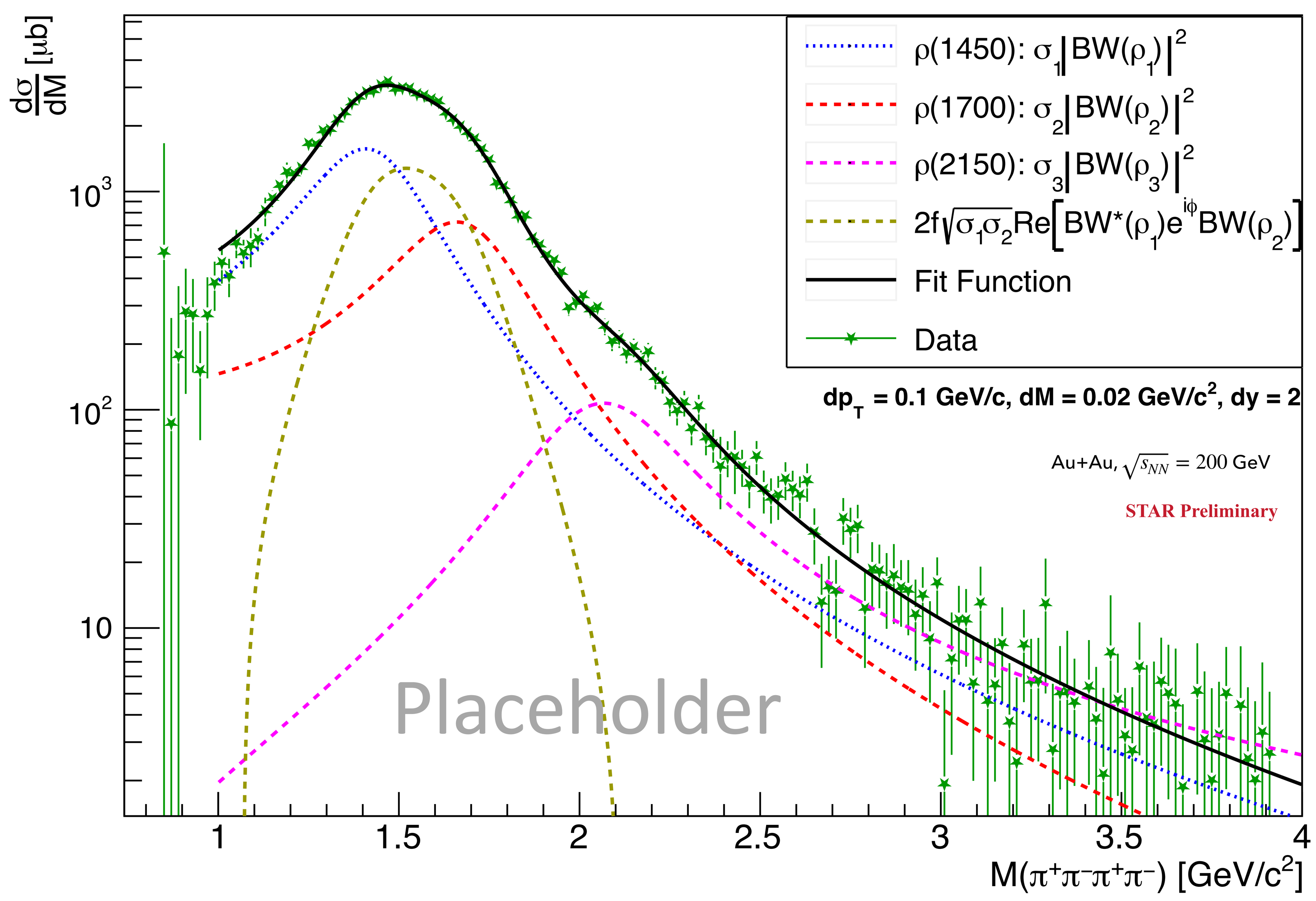


UPC Main Trigger:

- 1-10 (y2014), 1-3 (y2011), 1-5 (y2010) neutrons in both ZDC
- no signal in BBC
- 1 < number of Time-of-flight hits < 7

data taken in year	2010	2011	2014
Luminosity⁻¹ [μb⁻¹]	540±54	420±42	660±66
$\sigma_{trigger}/\sigma_{nn}$ [5]	0.62±0.05	0.45±0.04	0.55±0.05

Results



Branching ratios unknown, thus $\sigma = \Gamma(\rho \to \pi^+\pi^-\pi^+\pi^-)\sigma$. Fit function:

$$\frac{d\sigma}{dM} = \sigma_1|BW(\rho_1)|^2 + \sigma_2|BW(\rho_2)|^2 + 2f\sqrt{\sigma_1\sigma_2}\Re\left[BW^*(\rho_1)e^{i\delta}BW(\rho_2)\right] + \sigma_3|BW(\rho_3)|^2$$

where $BW(\rho) \equiv \left(\frac{M_\rho}{M}\right)^n \frac{\sqrt{\Gamma_\rho M_\rho}}{M^2 - M_\rho^2 + iM_\rho\Gamma_\rho}$, δ is phase shift of $\rho(1700)$, f degree of coherence, M_ρ, Γ_ρ masses and widths.

$\delta = 1.71 \pm 0.12$ rad

$f = 0.995 \pm 0.022$

Resonance	M [MeV/c²]	PDG M [3]	Γ [MeV/c²]	PDG Γ [3]	σ [μb]
$\rho(1450)$	1465 ± 10	1465 ± 25	388 ± 17	400 ± 60	814 ± 147
$\rho(1700)$	1721 ± 16	1720 ± 20	410 ± 22	250 ± 100	466 ± 81
$\rho(2150)$	2095 ± 40	-	479 ± 104	-	106 ± 42

Summary

1. Clear presence of double resonance structure with $\rho(1450)$ and $\rho(1700)$ masses consistent with PDG best estimation.
2. $\rho(1700)$ width larger than PDG best estimation, but consistent with $\gamma p \to p4\pi$ experiments
3. Another possible resonance in the $\rho(2150)$ location, need to investigate further if it indeed is $\rho(2150)$ - possibly in 6π decay channel
4. Need to investigate high mass tail of ρ_0 in $\pi^+\pi^-$ channel (similar to [6])

References

[1] Klein, S.R., Mäntysaari, H. Imaging the nucleus with high-energy photons. Nat Rev Phys 1, 662–674 (2019).
[2] Phys. Rev. C96, 054904
[3] R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022) and 2023 update.
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[5] reference to nOOn
[6] Eur. Phys. J. C (2012) 72 1869

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations