FOUR-PION STATE IN UPC

Mariola Kłusek-Gawenda
The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

- $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$ data
- $\rho(1450)\&\rho(1700)/\rho(1570) \to \pi^+\pi^-\pi^+\pi^-$
- $AA \to AA\pi^+\pi^-\pi^+\pi^-$

*M.KG and J.Daniel Tapia Takaki,
Exclusive Four-pion Photoproduction in Ultra-peripheral Heavy-ion Collisions at RHIC and LHC Energies,
Acta Phys.Polon. **B51** (2020) 6, 1393-1404

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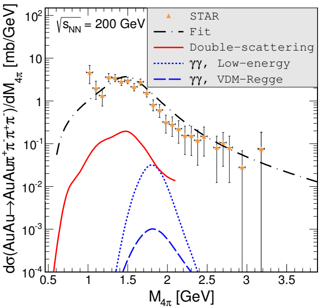
$\pi^+\pi^-\pi^+\pi^-$ CHANNEL

- $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$
- $\gamma p \to \rho^0(770)\pi^+\pi^- p$
- $\gamma p \to a_1(1260)\pi p$
- $\gamma p \to a_2(1320)\pi p$
- $\gamma p \to \rho' p$
- $\gamma p \to \Delta^{++}(1236)\pi^+\pi^-\pi^+$
- $\gamma p \to \Delta^{++}(1236)\rho^0(770)\pi^+$
- $\gamma p \to \Delta^0(1236)\pi^+\pi^+\pi^-$



NEW DATA

H1prelim-18-011
April 10, 2018

Submitted to **DIS-2018**, Kobe, 16–20 April, 2018

Exclusive Photoproduction of $2\pi^+2\pi^-$ Final State at HERA

Abstract

Exclusive production of four charged pions at the ep collider HERA is studied at small photon virtualities $Q^2 < 2$ GeV^2. The data were taken with the H1 detector in the years 2006 and 2007 at a centre-of-mass energies of $\sqrt{s} = 319$ GeV and $\sqrt{s} = 225$ GeV and correspond to an integrated luminosity of 7.6 pb^{-1} and 1.7 pb^{-1} respectively. The cross section of the reaction $\gamma p \to (2\pi^+2\pi^-)Y$ is determined in the phase space of $35 < W_{\gamma p} <$ 100 GeV, $|t| < 1$ GeV^2 and $M_Y < 1.6$ GeV. The 4π mass spectra indicate that the reaction proceeds predominantly via production and decay of ρ' resonances. The fit however does not allow yet to distinguish unambiguously between the hypotheses of one or two broad and overlapping ρ' resonances.

STAR Collaboration, B.I. Abelev et al.
Observation of $\pi^+\pi^-\pi^+\pi^-$ Photoproduction in Ultra-Peripheral Heavy Ion Collisions at STAR,
Phys.Rev. **C81** (2010) 044901
←Fig. from Phys.Rev. **C89** (2014) 024912,
M. KG and A. Szczurek,
Double-scattering mechanism in the exclusive $AA \to AA\rho^0\rho^0$ reaction in ultrarelativistic collisions

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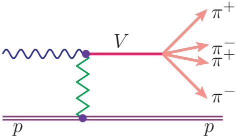
VDM-REGGE MODEL

$$\sigma_{tot}(Vp) = \alpha_1 W_{\gamma p}^{-\delta_1} + \alpha_2 W_{\gamma p}^{\delta_2}$$

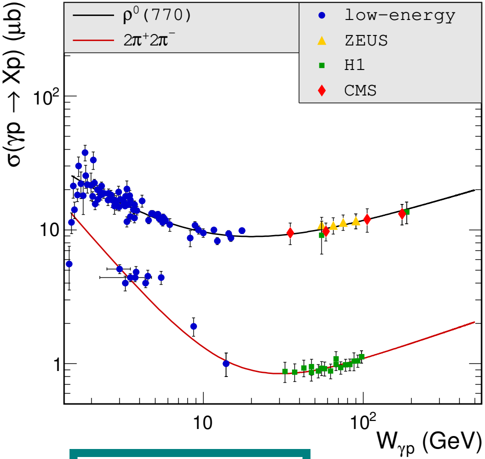


$$|\gamma> = \mathcal{N}|\gamma_{QED}> + |h>$$

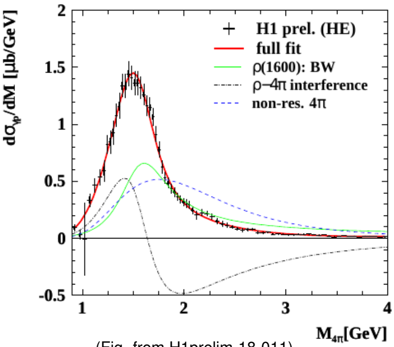
$$|h> = \sum_h \frac{e}{f_V}|V>$$

$$f_V{}^2 = \frac{4\pi\alpha_{em}^2 m_V}{3\Gamma(V \to e^+e^-)}$$

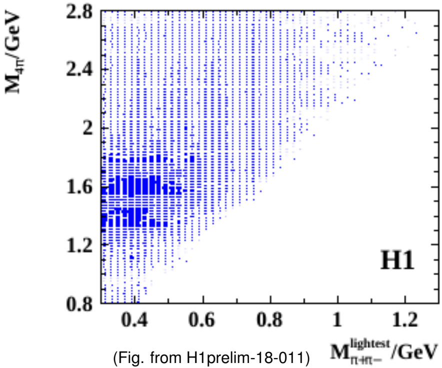
$$\sigma_{tot}(Vp) = \frac{f_V^2}{e^2}\sigma(\gamma p \to Vp)$$



vector meson ?



(Fig. from H1prelim-18-011)



(Fig. from H1prelim-18-011)

77. The $\rho(1450)$ and the $\rho(1700)$

Updated November 2015 by S. Eidelman (Novosibirsk), C. Hanhart (Juelich) and G. Venanzoni (Frascati).

In our 1988 edition, we replaced the $\rho(1600)$ entry with two new ones, the $\rho(1450)$ and the $\rho(1700)$, because there was emerging evidence that the 1600-MeV region actually contains two ρ-like resonances. Erkal [1] had pointed out this possibility with a theoretical analysis on the consistency of 2π and 4π electromagnetic form factors and the $\pi\pi$ scattering length. Donnachie [2], with a full analysis of data on the 2π and 4π final states in e^+e^- annihilation and photoproduction reactions, had also argued that in order to obtain a consistent picture, two resonances were necessary. The existence of $\rho(1450)$ was supported by the analysis of $\eta\rho^0$ mass spectra obtained in photoproduction and e^+e^- annihilation [3], as well as that of $e^+e^- \to \omega\pi$ [4].

The analysis of [2] was further extended by [5,6] to include new data on 4π-systems produced in e^+e^- annihilation, and in τ-decays (τ decays to 4π, and e^+e^- annihilation to 4π can be related by the Conserved Vector Current assumption). These systems were successfully analyzed using interfering contributions from two ρ-like states, and from the tail of the $\rho(770)$ decaying into two-body states. While specific conclusions on $\rho(1450) \to 4\pi$ were obtained, little could be said about the $\rho(1700)$.

DECAY MODE

$M_{4\pi}$ = 1.6 GeV

or

$M_{4\pi}$ = 1.45 GeV & $M_{4\pi}$ = 1.7 GeV

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RESONANCES SKETCH PDG

$\rho(1570)$ $I^G(J^{PC}) = 1^+(1^{--})$

$\rho(1570)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1570±36±62	54	[1] AUBERT	08S	BABR	10.6 $e^+e^- \to \phi\pi^0\gamma$

$\rho(1570)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
144±75±43	54	[3] AUBERT	08S	BABR	10.6 $e^+e^- \to \phi\pi^0\gamma$

$\rho(1570)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	
Γ_2	$\phi\pi$	not seen
Γ_3	$\omega\pi$	

$\rho(1450)$ [r] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1465 \pm 25$ MeV [l]
Full width $\Gamma = 400 \pm 60$ MeV [l]

$\rho(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	720
$\pi^+\pi^-$	seen	719
4π	seen	669

$\rho(1700)$ [r] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1720 \pm 20$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

$\rho(1700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$2(\pi^+\pi^-)$	seen	803

$\rho(770)$ [h] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 775.26 \pm 0.25$ MeV
Full width $\Gamma = 149.1 \pm 0.8$ MeV
$\Gamma_{ee} = 7.04 \pm 0.06$ keV

$\rho(770)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$	~ 100 %		363
$\pi^+\pi^-\pi^+\pi^-$	(1.8 ±0.9) × 10^{-5}		251

MY CALCULATION

m [GeV]	Γ [GeV]	$\Gamma(e^+e^-)$ [keV]
	$\rho(1570)$	
1.57 ± 0.07	0.144 ± 0.09	$0.35 - 0.5^*$
	$\rho(1450) \equiv \rho'$	
1.465 ± 0.025	0.40 ± 0.05	$4.3 - 10$
	$\rho(1700) \equiv \rho''$	
1.72 ± 0.02	0.25 ± 0.01	$6.30 - 8.9$

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e^+e^- CHANNEL

- $\rho(1450)$

$$\frac{\Gamma(\rho' \to \eta\rho) \times \Gamma(\rho' \to e^+e^-)}{\Gamma_{tot}^2} = 7.3 \times 10^{-7}$$
$$= 4.3 \times 10^{-7}$$
$$\frac{\Gamma(\rho' \to \eta\rho)}{\Gamma_{tot}} < 0.04$$
$$\Gamma(\rho' \to e^+e^-) > 7.28\,\text{keV}$$
$$> 4.3\,\text{keV}$$

$$\frac{\Gamma(\rho' \to \omega\pi) \times \Gamma(\rho' \to e^+e^-)}{\Gamma_{tot}^2} = 2.1 \times 10^{-6}$$
$$= 5.3 \times 10^{-6}$$
$$\frac{\Gamma(\rho' \to \omega\pi)}{\Gamma_{tot}} \approx 0.21$$
$$\Gamma(\rho' \to e^+e^-) \approx 4.3\,\text{keV}$$
$$\approx 10\,\text{keV}$$

$$\Gamma(\rho' \to e^+e^-) = (4.3 - 10)\,\text{keV}$$

- $\rho(1570)$

$$\frac{\Gamma(\rho'' \to \phi\pi) \times \Gamma(\rho'' \to e^+e^-)}{\Gamma_{tot}} = 3.5\,\text{eV}$$
$$< 70\,\text{eV}$$
$$\frac{\Gamma(\rho'' \to \phi\pi)}{\Gamma_{tot}} < 0.01$$
$$\Gamma(\rho'' \to e^+e^-) > 0.35\,\text{keV}$$
$$\Gamma(\rho'' \to e^+e^-) = (0.35 - 0.5)\,\text{keV}$$

- $\rho(1700)$

$$\Gamma(\rho(1700) \to e^+e^-) = 7.6 \pm 1.3\,\text{keV}$$

*2019 Review of Particle Physics
M. Tanabashi et al. (Particle Data Group),
Phys. Rev. **D98**, 030001 (2018) and 2019 update

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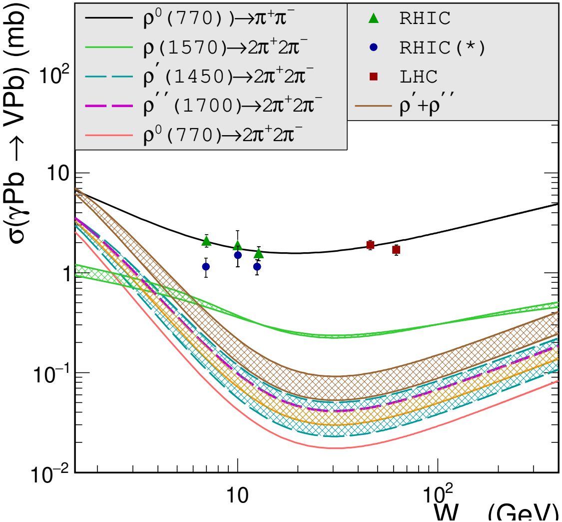
PHOTOPRODUCTION ON AU AND PB NUCLEI



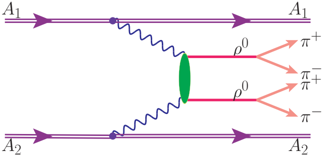
$$\sigma_{tot}(VA) = \int \left[1 - \exp\left(-\sigma_{tot}(Vp)\, T_A(\vec{b})\right)\right] \mathrm{d}^2 b$$

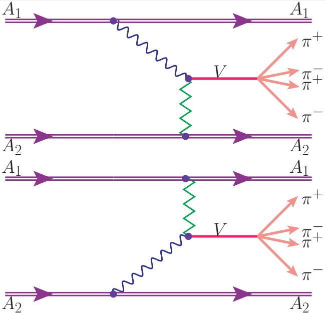
$$T_A(\vec{b}) = \int_{-\infty}^{+\infty} \rho(\vec{b}, z)\mathrm{d}z$$

$$\sigma(\gamma A \to VA) = \frac{1}{16\pi}\frac{e^2}{f_V^2}\sigma_{tot}^2(VA)\int |F(t)|^2\,\mathrm{d}t$$

$$F\left(\mathbf{q}^2\right) = \frac{4\pi}{|\mathbf{q}|}\int \rho(r)\sin(|\mathbf{q}|\,r)\, r\mathrm{d}r$$

TOTAL CROSS SECTION





$$\sigma(A_1 A_2 \to A_1 A_2\, 2\pi^+ 2\pi^-) =$$

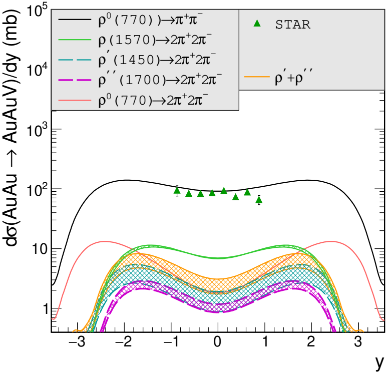
$\gamma\gamma$-FUSION

$$\begin{aligned} = \quad & \int N(\omega_1, \mathbf{b_1})\, N(\omega_2, \mathbf{b_2}) \\ \times \quad & \sigma_{\gamma\gamma\to\rho^0\rho^0}\left(W_{\gamma\gamma}\right) S^2_{abs}(\mathbf{b}) \\ \times \quad & \mathrm{d}^2 b\, \mathrm{d}\bar{b}_x\, \mathrm{d}\bar{b}_y \\ \times \quad & \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\, \mathrm{d}Y_{\rho^0\rho^0} \\ \times \quad & 2\, Br(\rho^0 \to \pi^+\pi^-) \end{aligned}$$

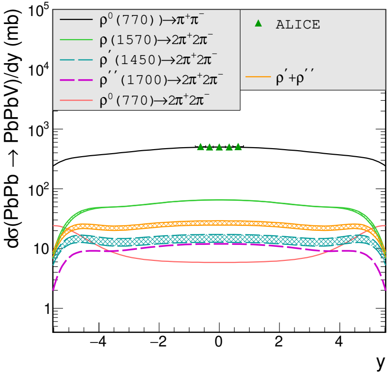
PHOTOPRODUCTION

$$\begin{aligned} = \quad & \mathrm{d}^2 b\, \mathrm{d}y_V \\ \times \quad & \left[\int \omega_1 \frac{\mathrm{d}N(\omega_1, b)}{\mathrm{d}^2 b \mathrm{d}\omega_1} \sigma_{\gamma A_2 \to V A_2}\left(W_{\gamma A_2}\right)\right. \\ + \quad & \left.\int \omega_2 \frac{\mathrm{d}N(\omega_2, b)}{\mathrm{d}^2 b \mathrm{d}\omega_2} \sigma_{\gamma A_1 \to V A_1}\left(W_{\gamma A_2}\right)\right] \end{aligned}$$

$\sqrt{s_{NN}}$ = 200 GeV



$\sqrt{s_{NN}}$ = 5.02 TeV



RATIO: $\sigma(4\pi)/\sigma(\rho)$

process	$\|y\| < 10$	$\|y\| < 1$
$\rho' \to 2(\pi^+\pi^-)$	(2.1 - 2.8) %	(1.9 - 2.5) %
$\rho'' \to 2(\pi^+\pi^-)$	1.2 %	1.3 %
$\rho(1570) \to 2(\pi^+\pi^-)$	(5.8 - 6.2) %	8.2 %
$\rho^0(770) \to 2(\pi^+\pi^-)$	6.8 %	2.54 %
RHIC (Phys. Rev. **C81** (2010) 044901)	(13.4 ± 4.5) %	(16.4 ± 5.3) %

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PbPb → PbPb $\pi^+\pi^-\pi^+\pi^-$ @ $\sqrt{s_{NN}}$ = 5.5 TeV

Total cross section in mb

process	$\lvert y\rvert < 10$	$\lvert y\rvert < 1$	$\lvert y\rvert < 2.4$	$2.5 < y < 4$	$2 < y < 5$
$\rho^0(770) \to \pi^+\pi^-$	5 015	930	2390	620	1203
$\rho' \to 2(\pi^+\pi^-)$	138-185	24-33	63-84	17-23	36-48
$\rho'' \to 2(\pi^+\pi^-)$	114	23	58	16	29
$\rho(1570) \to 2(\pi^+\pi^-)$	582-589	121-122	306-307	77-78	148-150
$\rho^0(770) \to 2(\pi^+\pi^-)$	144	11	30	12	30
CERN Yellow Rep.Monogr. (2019) 1159-1410		16	190	14	92

Ratio: $\sigma(4\pi)/\sigma(\rho)$

process	$\lvert y\rvert < 10$	$\lvert y\rvert < 1$	$\lvert y\rvert < 2.4$	$2.5 < y < 4$	$2 < y < 5$
$\rho' \to 2(\pi^+\pi^-)$	≈ 3.7 %	≈ 3 %	≈ 3 %	≈ 3.2 %	≈ 3.5 %
$\rho'' \to 2(\pi^+\pi^-)$	2.3 %	2.4 %	2.4 %	2.6 %	2.4 %
$\rho(1570) \to 2(\pi^+\pi^-)$	≈ 11.6 %	13 %	12.8 %	12.5 %	12.4 %
$\rho^0(770) \to 2(\pi^+\pi^-)$	2.9 %	1.2 %	1.2 %	1.9 %	2.5 %

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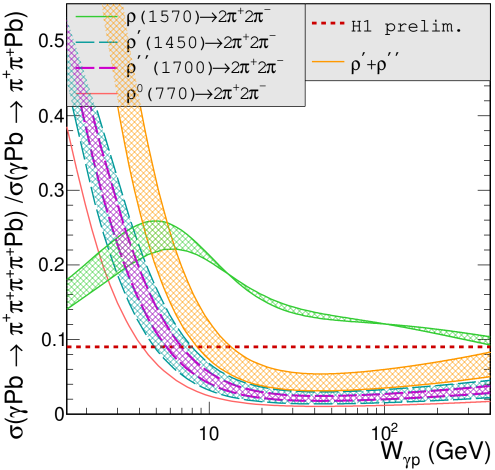
H1 predictions $\rightarrow R = \frac{\sigma(\gamma p \rightarrow 2\pi^+ 2\pi^- p)}{\sigma(\gamma p \rightarrow \pi^+ \pi^- p)} \approx 9\%$



Heavy-ion collisions:

- $\omega = \frac{m_V}{2} e^{\pm y}$
- $W = \sqrt{2\omega\sqrt{s_{NN}}}$

- $\sqrt{s_{NN}} = 200$ GeV

$\rho(1570)$ &

$y = \pm 4 \rightarrow W = (^2/_{120})$ GeV

& $y = 0 \rightarrow W = 18$ GeV

- $\sqrt{s_{NN}} = 5.02$ TeV

$\rho(1570)$ &

$y = \pm 4 \rightarrow W = (^{12}/_{650})$ GeV

& $y = 0 \rightarrow W = 90$ GeV

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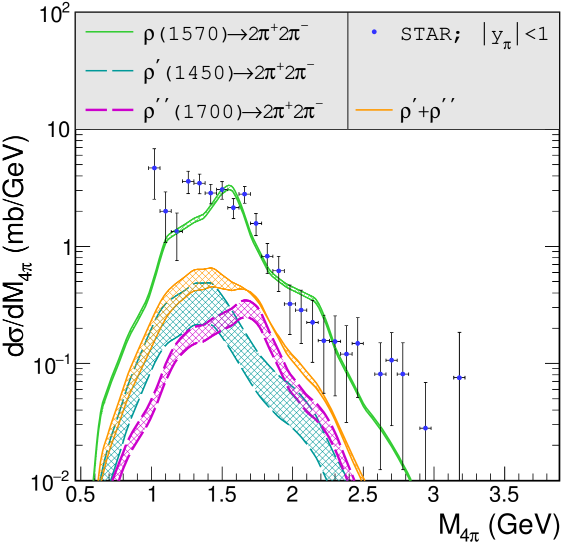
INVARIANT MASS DISTRIBUTION



$$\sigma(AA \to AAV \to AA\pi^+\pi^-\pi^+\pi^-, y_V) = \mathcal{C} \times$$
$$\times \left[\sigma(AA \to AAV \to AA\pi^+\pi^-\pi^+\pi^-; y_{\pi_1} y_{\pi_2}) \right.$$
$$\left. \times\ \sigma(AA \to AAV \to AA\pi^+\pi^-\pi^+\pi^-; y_{\pi_3} y_{\pi_4}) \right]$$

$\mathcal{C}$ - includes Breit-Wigner formula

$$\mathcal{A} = \mathcal{A}_{BW} \frac{\sqrt{m m_V \Gamma(m)}}{m^2 - m_V^2 + i m_V \Gamma(m)} + \mathcal{A}_{bkg}$$

$$\Gamma(m) = \Gamma_V \frac{m_V}{m} \left(\frac{m^2 - 4m_V^2}{m_V^2 - 4m_\pi^2} \right)^{\frac{3}{2}}$$

$\rho(1570)$ describes the data

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- The $\gamma p \to 2\pi^+ 2\pi^- p$ reaction is interesting from the point of view of resonance production
- A new preliminary H1 data[1] gives an opportunity to analysis the $\rho \to 2\pi^+ 2\pi^-$ decay
- Description of $\sigma(\gamma p \to Xp)$, $\sigma(\gamma A \to VA)$, ratio $2\pi^+ 2\pi^- / \pi^+ \pi^-$ and nuclear cross section
- The usage of $\rho(1570)$ resonance more accurate than incoherent sum of $\rho(1450)$ & $\rho(1700)$
- Future:
  - Gluon saturation
  - $1 \to 4\pi$ exact kinematics
  - new experimental data for UPC

Gracias!

[1] H1 Collaboration, S. Schmitt, Exclusive Photoproduction of $2\pi^+ 2\pi^-$ at HERA. (DIS 2018): Port Island, Kobe, Japan, April 16-20, 2018