Probing exotic states in photon induced interactions at the LHC

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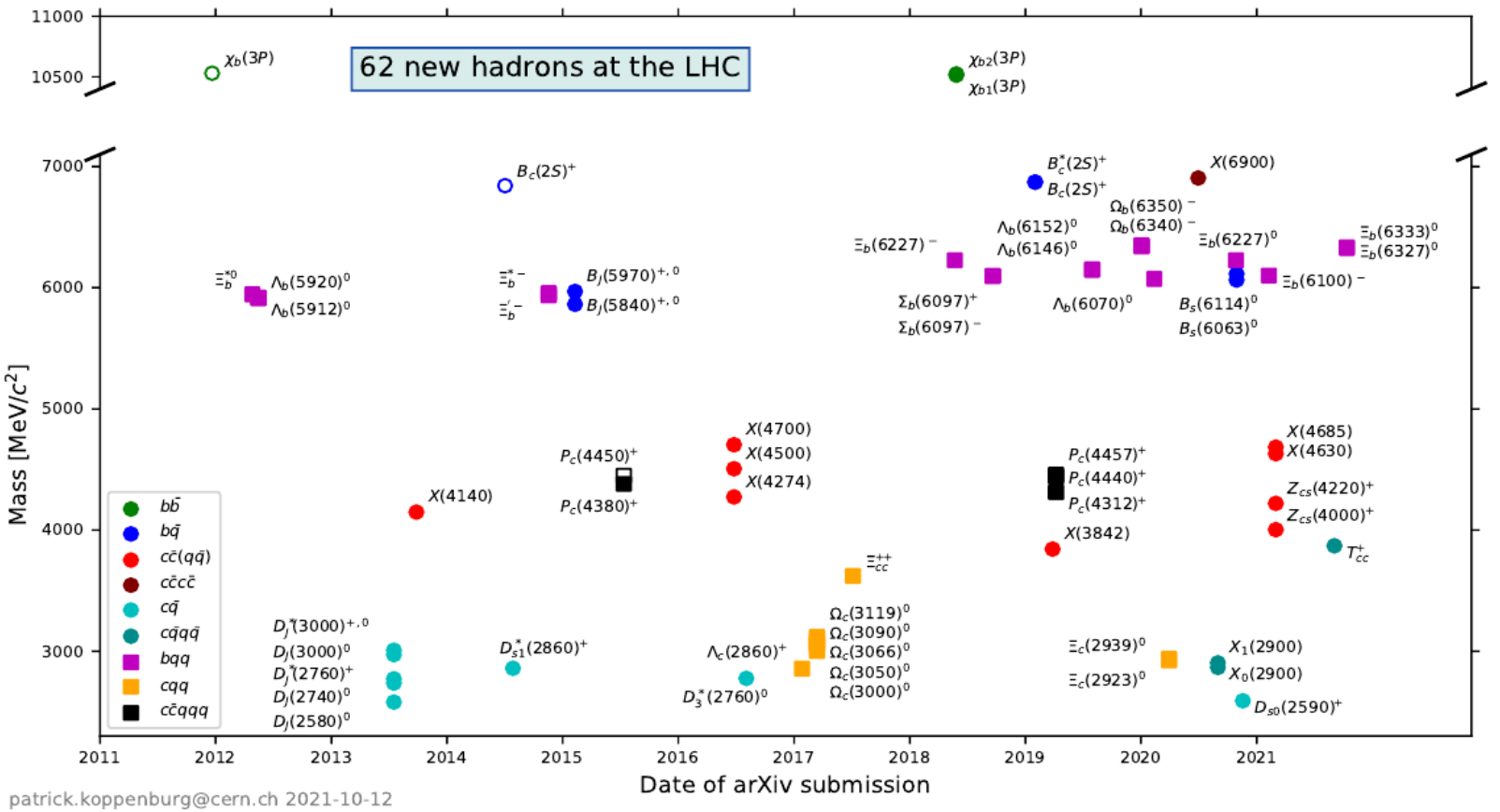
Motivation

EXOTIC STATES: class of hadrons that decay to final states that contain a heavy quark and a heavy antiquark but cannot be easily accommodated in the remaining unfilled states in the $Q\bar{Q}$ level scheme.

Ever since the discovery of X(3872), we have a golden era in the discovery of the exotic states.

Motivation

At the LHC:



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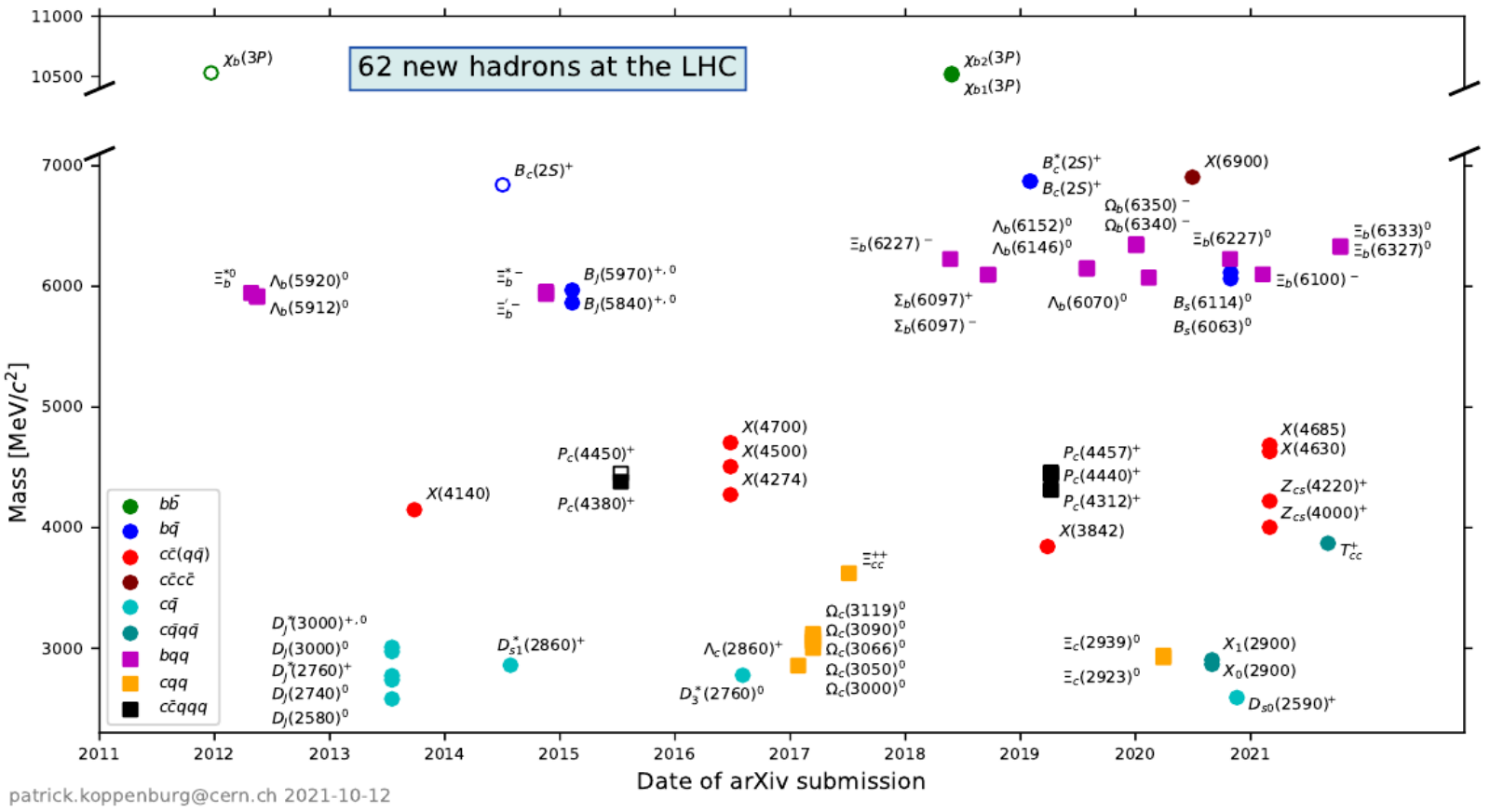

No solid explanation for these states!

This talk:

Main goal: Demonstrate that the study of photon - induced interactions at the LHC can be useful to demonstrate the existence and to probe the properties of exotic states.

Focus on:

- Production of exotic tetraquark states in photon - photon interactions;

- Production of exotic pentaquark states in photon - hadron interactions.

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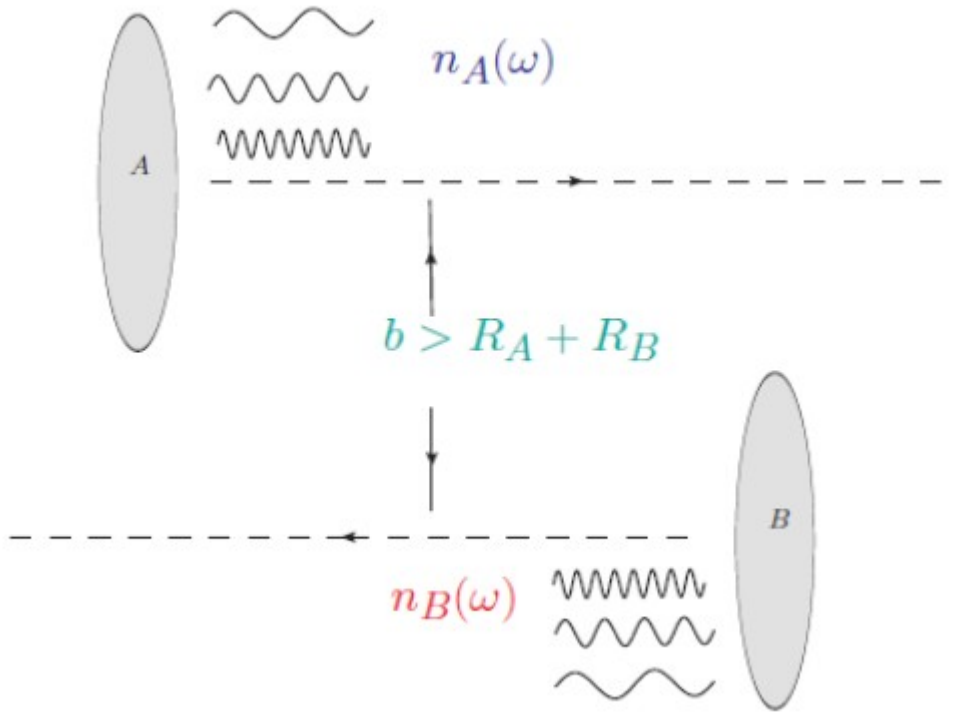
VPG, Moreira EPJC79 (2019) 7; PLB816 (2021) 136249

- Production of exotic pentaquark states in photon - hadron interactions.

VPG, Jaime PLB805 (2020) 135447; VPG, Xie PLB814 (2021) 136121

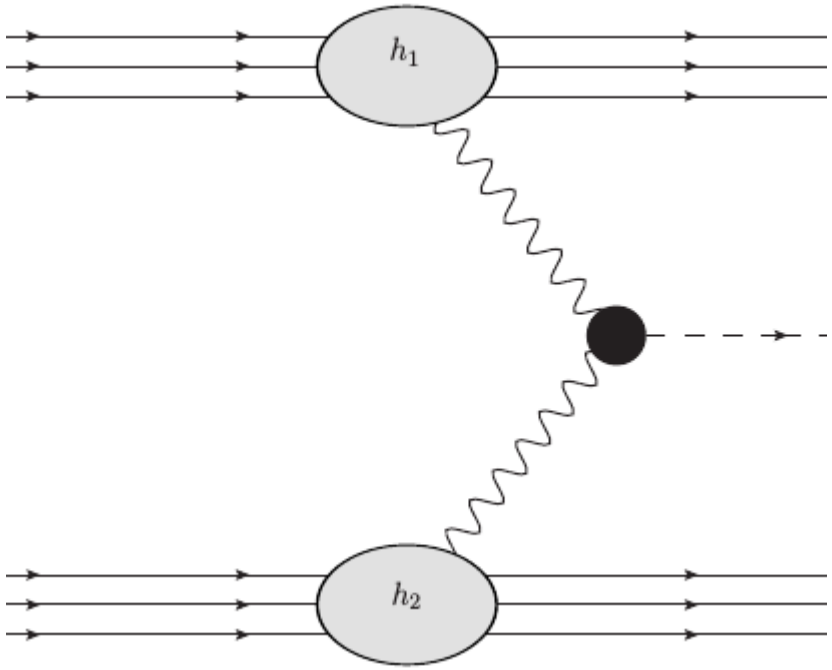
LHC = Photon collider



1. γh Processes: $\sigma(h_1 h_2 \to X) = n_h(\omega) \otimes \sigma^{\gamma h \to X}(W_{\gamma h})$
2. $\gamma\gamma$ Processes: $\sigma(h_1 h_2 \to X) = n_1(\omega) \otimes n_2(\omega) \otimes \sigma^{\gamma\gamma \to X}(W_{\gamma\gamma})$

LHC = Photon collider

– Photon – Photon interactions –



Intact hadron

Rapidity gap

Rapidity gap

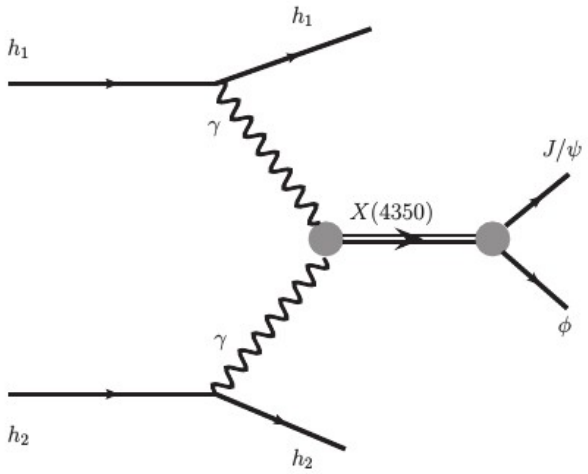
Intact hadron

$$\sigma\left(h_1 h_2 \to h_1 \otimes R \otimes h_2; s\right) = \int \hat{\sigma}\left(\gamma\gamma \to R; W\right) N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) S^2_{abs}(\mathbf{b}) \mathrm{d}^2\mathbf{b}_1 \mathrm{d}^2\mathbf{b}_2 \mathrm{d}\omega_1 \mathrm{d}\omega_2$$

$$\sigma^{PbPb}(\gamma\gamma) \approx Z^2 \sigma^{pPb}(\gamma\gamma) \approx Z^4 \sigma^{pp}(\gamma\gamma)$$

Probing Tetraquarks in photon - photon interactions

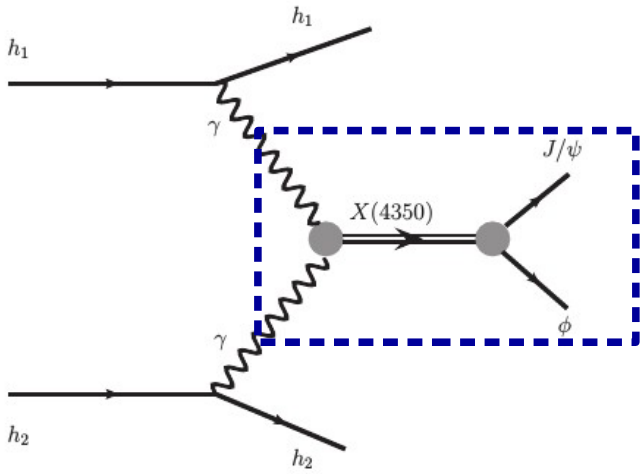
X(4350)



VPG, Moreira, EPJC 79 (2019) 7.

Probing Tetraquarks in photon - photon interactions

X(4350)

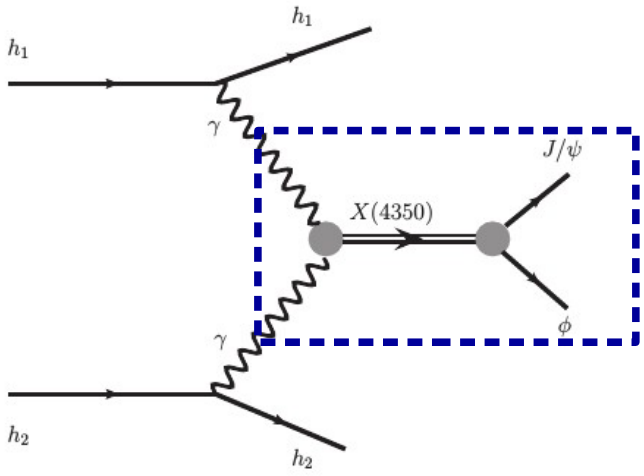


Constrained by Belle Collaboration.

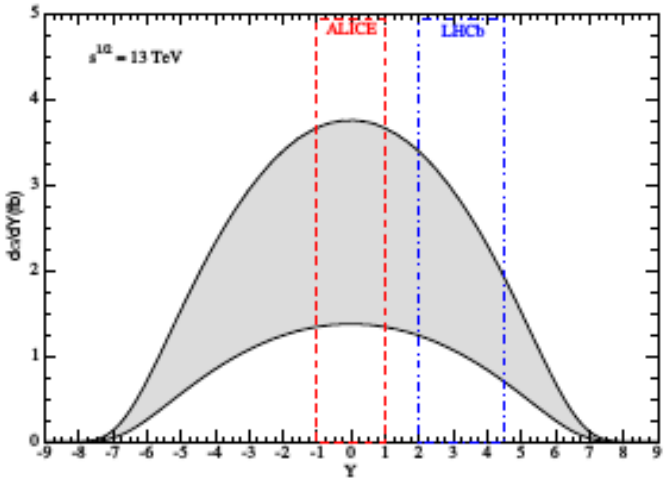
VPG, Moreira, EPJC 79 (2019) 7.

Probing Tetraquarks in photon - photon interactions

X(4350)



Constrained by Belle Collaboration.

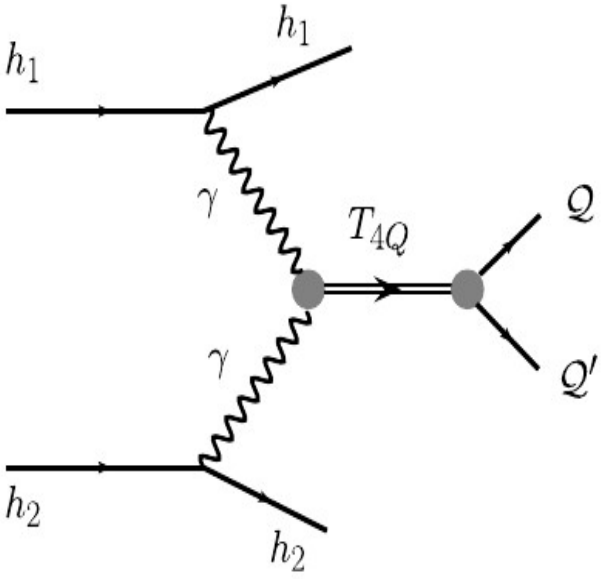


Collision	Resonance	LHCb $2 < Y < 4.5$
pp ($\sqrt{s}$ =13 TeV)	$X(4350)$, 0^{++}	(2.47 – 6.13) fb
	$X(4350)$, 2^{++}	(2.52 – 6.88) fb
pPb ($\sqrt{s}$ =8.1 TeV)	$X(4350)$, 0^{++}	(10.20 – 25.30) pb
	$X(4350)$, 2^{++}	(10.30 – 28.30) pb
$PbPb$ ($\sqrt{s}$ =5.02 TeV)	$X(4350)$, 0^{++}	(14.60 – 36.20) nb
	$X(4350)$, 2^{++}	(14.90 – 40.60) nb

Such channel can be used to confirm (or not) the existence of resonances observed in e^+e^- colliders.

Probing Tetraquarks in photon - photon interactions

Fully - heavy tetraquark:



Total cross section:

$$\sigma\left(h_1 h_2 \to h_1 \otimes T_{4Q} \otimes h_2; s\right) = \int \hat{\sigma}\left(\gamma\gamma \to T_{4Q}; W\right) N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) S^2_{abs}(\mathbf{b}) \frac{W}{2} \times \mathrm{d}^2\mathbf{b}_1 \mathrm{d}^2\mathbf{b}_2 \mathrm{d}W \mathrm{d}Y \ ,$$

where:

$$\hat{\sigma}_{\gamma\gamma\to T_{4Q}}(\omega_1, \omega_2) = 8\pi^2 (2J+1) \frac{\Gamma_{T_{4Q}\to\gamma\gamma}}{M_{T_{4Q}}} \delta(4\omega_1\omega_2 - M^2_{T_{4Q}})$$

Main assumption:

$$\Gamma_{T_{4Q}\to\gamma\gamma} \simeq \Gamma_{\chi_Q\to\gamma\gamma}$$

VPG, Moreira, PLB816 (2021) 136249.

Probing Tetraquarks in photon - photon interactions

X(6900):

Table 1
Total cross sections for the $X(6900)[J^P] \to J/\psi J/\psi$ production by $\gamma\gamma$ interactions in pp, pPb and $PbPb$ collisions for different center - of - mass energies considering the full LHC rapidity range as well as the rapidity ranges covered by the ALICE and LHCb detectors.

Collision	Resonance	LHC Full rapidity range	LHCb $2.0 \leq Y \leq 4.5$	ALICE $-1.0 \leq Y \leq 1.0$
pp ($\sqrt{s} = 13$ TeV)	$X(6900)$, 0^{++}	26.3 fb	5.53 fb	6.34 fb
	$X(6900)$, 2^{++}	31.9 fb	6.71 fb	7.71 fb
pPb ($\sqrt{s} = 8.1$ TeV)	$X(6900)$, 0^{++}	76.3 pb	21.6 pb	22.4 pb
	$X(6900)$, 2^{++}	92.4 pb	26.2 pb	27.2 pb
$PbPb$ ($\sqrt{s} = 5.02$ TeV)	$X(6900)$, 0^{++}	171.0 nb	22.3 nb	70.0 nb
	$X(6900)$, 2^{++}	206.0 nb	26.7 nb	84.7 nb

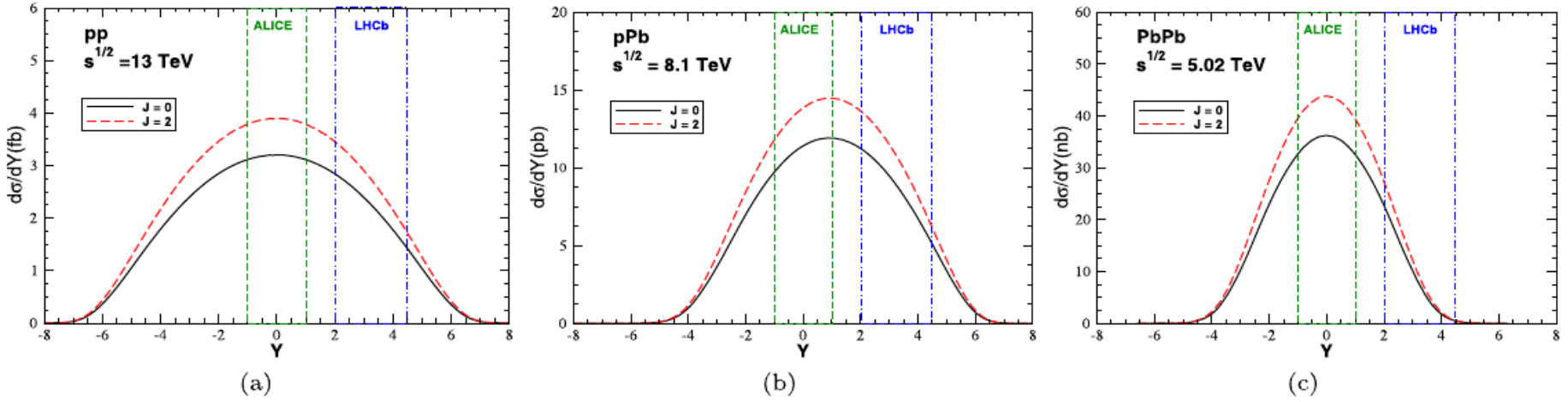
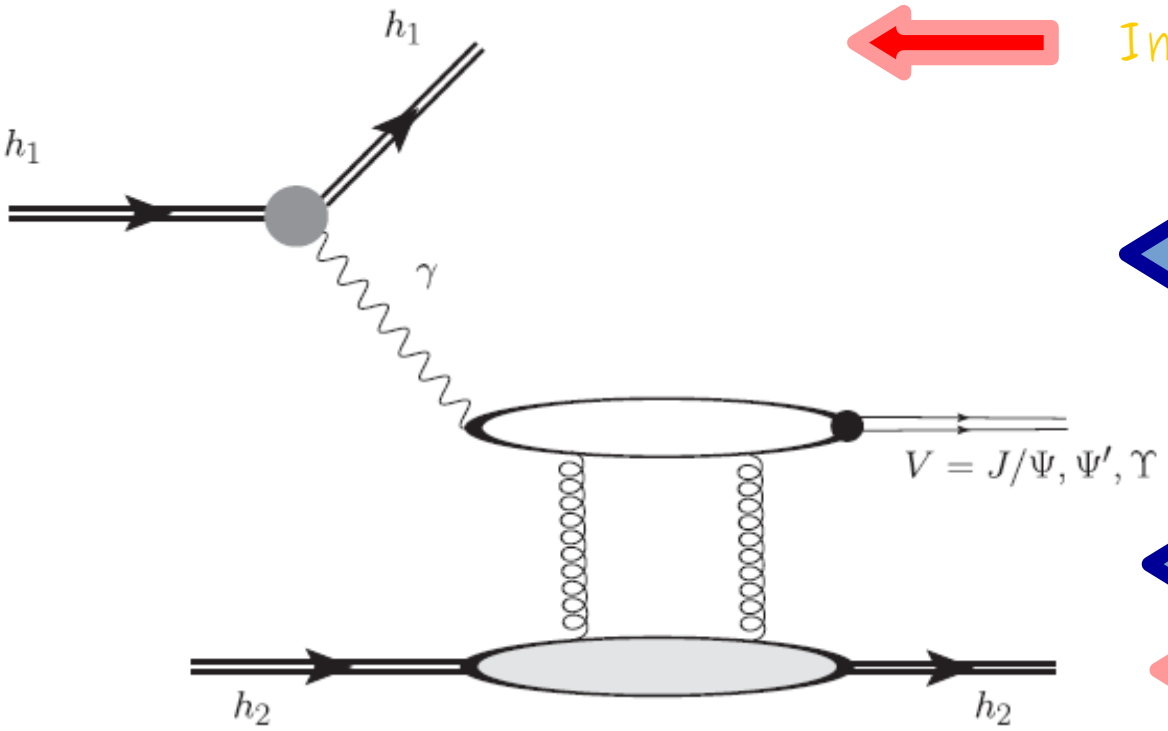


Fig. 2. Rapidity distributions for the $X(6900) \to J/\psi J/\psi$ production by $\gamma\gamma$ interactions in (a) pp ($\sqrt{s} = 13$ TeV), (b) pPb ($\sqrt{s} = 8.1$ TeV) and (c) $PbPb$ ($\sqrt{s} = 5.02$ TeV) collisions at the LHC.

LHC = Photon collider

– Photon – Hadron interactions –

Exclusive vector meson photoproduction in hadronic collisions:



Intact hadron

Rapidity gap

Rapidity gap

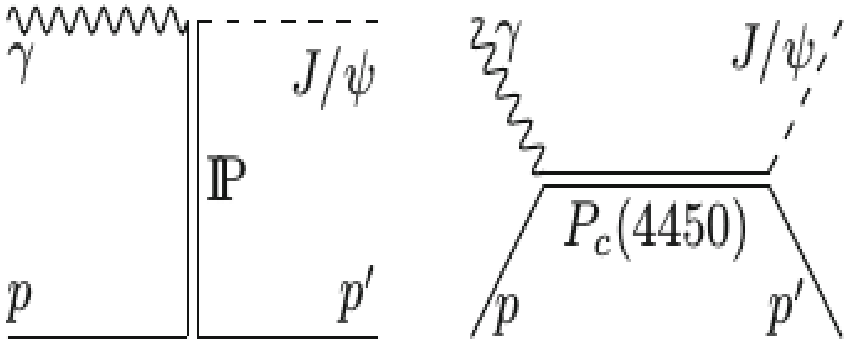
Intact hadron

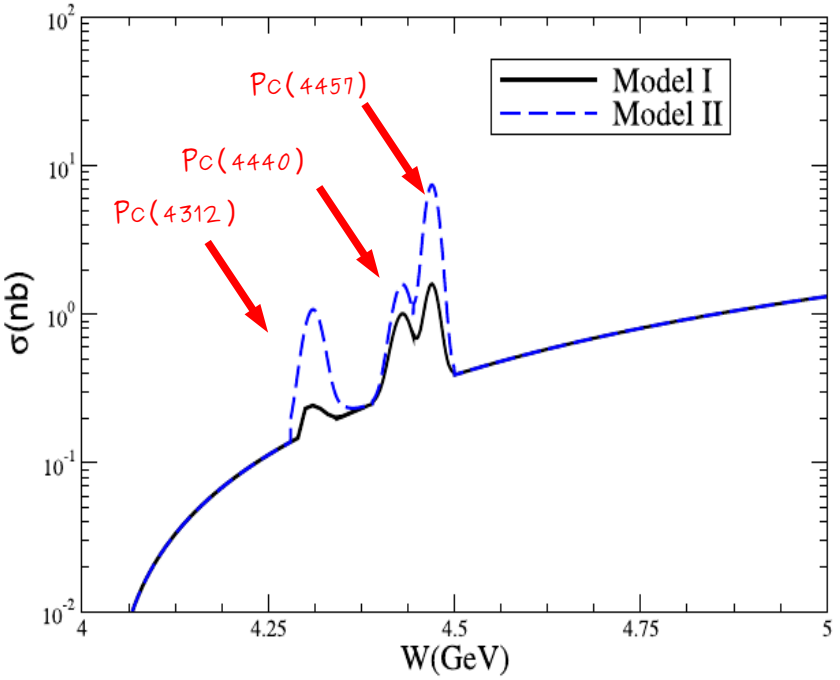
$$\frac{d\sigma\ [h_1 + h_2 \to h_1 \otimes V \otimes h_2]}{d^2b dy} = [\omega N_{h_1}(\omega, b)\, \sigma_{\gamma h_2 \to V \otimes h_2}\ (\omega)]_{\omega_L} + [\omega N_{h_2}(\omega, b)\, \sigma_{\gamma h_1 \to V \otimes h_1}\ (\omega)]_{\omega_R}$$

[a] VPG, Bertulani, PRC65, 054905 (2002)

Probing Pentaquarks in photon - hadron interactions

Hidden-charm pentaquark:



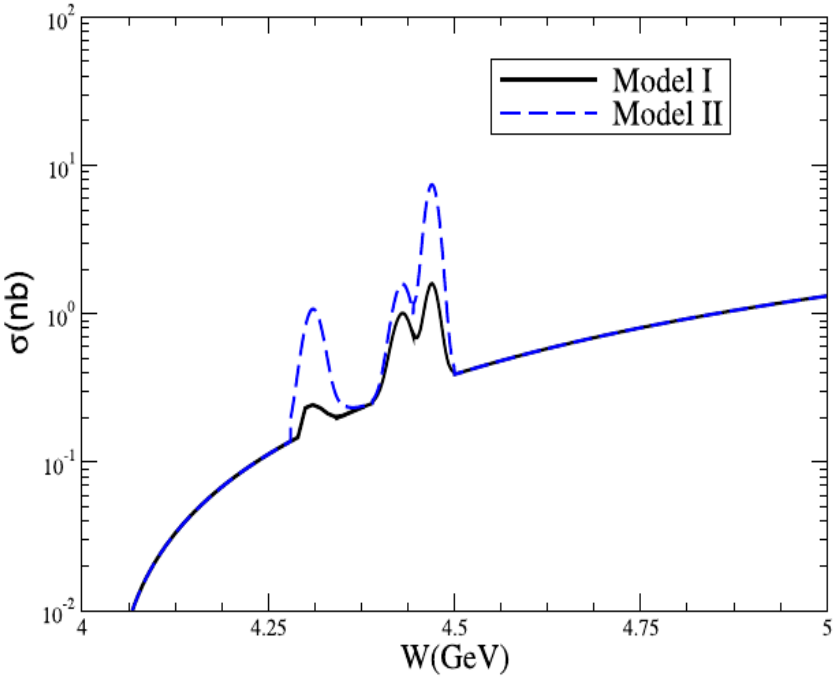


* VPG, Medina EPJC78, 693 (2018): Vector meson photoproduction at low energies can be studied in fixed - target collisions at the LHC.

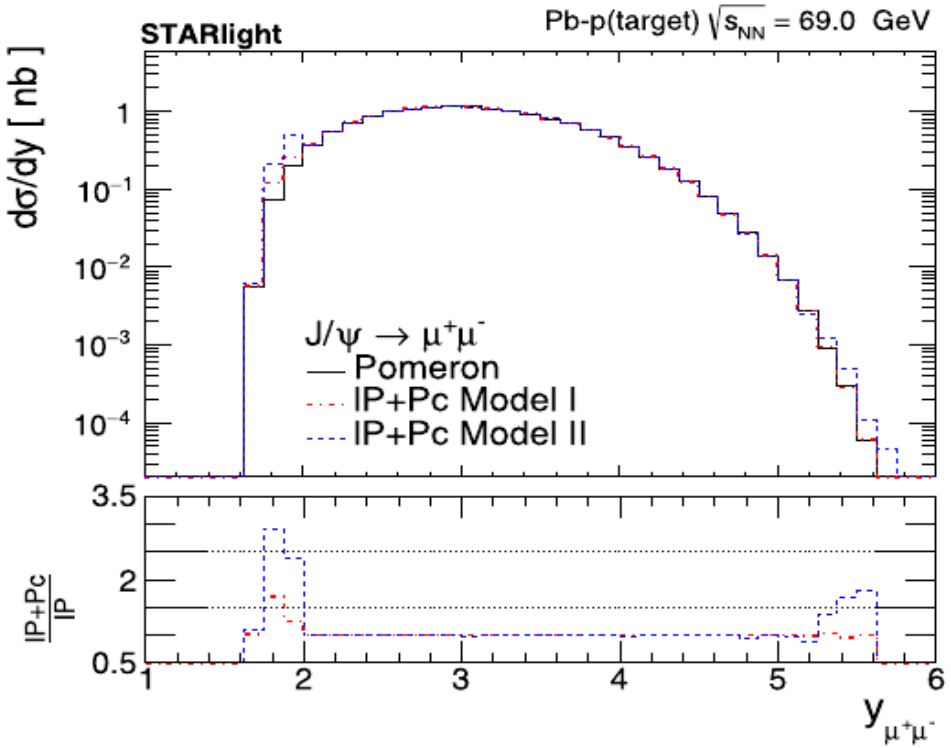
*Beam - gas collisions have been studied by the LHCb Collaboration and a similar programme can be developed by the AFTER@LHC experiment;

Probing Pentaquarks in photon - hadron interactions

Hidden-charm pentaquark:



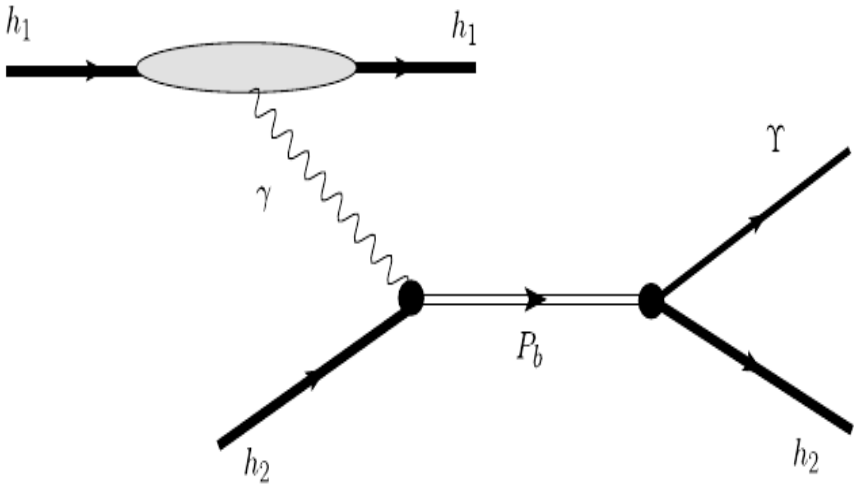
Fixed - target mode:



VPG, Medina, PLB805 (2020) 135447.

Probing Pentaquarks in photon - hadron interactions

Hidden-bottom pentaquark:



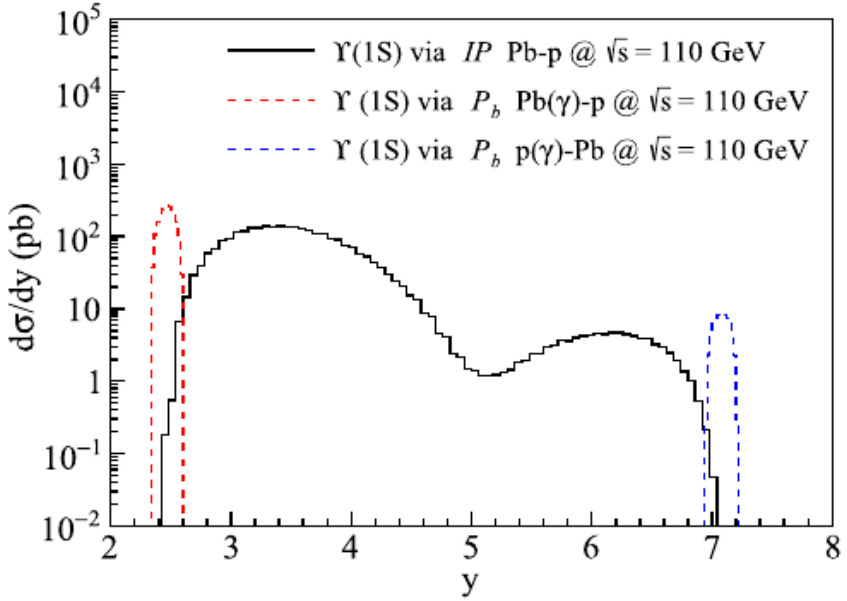


Table 1
Total cross sections (in pb) for the exclusive Υ photoproduction in fixed - target collisions at the LHC considering different rapidity ranges and $\sqrt{s} = 110\,(69)$ GeV.

	Pb - p	Pb - He	Pb - Ar	Ar - p
$\sigma^{I\!P}$ (Full rapidity range)	168.0 (13.0)	1000.0 (140.0)	8400.0 (870.0)	22.0 (2.9)
σ^{P_b} (Full rapidity range)	46.0 (12.0)	75.0 (24.0)	380.0 (80.0)	3.6 (1.3)
$\sigma^{I\!P}$ $(2.0 \leq y \leq 4.5)$	160.0 (12.0)	860.0 (100.0)	5100.0 (370.0)	18.0 (2.6)
σ^{P_b} $(2.0 \leq y \leq 4.5)$	45.0 (11.0)	72.0 (22.0)	300.0 (58.0)	3.3 (1.2)
$\sigma^{I\!P}$ $(2.0 \leq y \leq 2.7)$	2.2 (0.52)	10.0 (2.7)	78.0 (16.0)	0.16 (0.058)
σ^{P_b} $(2.0 \leq y \leq 2.7)$	45.0 (11.0)	72.0 (22.0)	300.0 (58.0)	3.3 (1.2)

Xie, VPG, PLB805 (2020) 135447.

Summary

- ✓ Photon – induced interactions can be used to constrain the physics in unexplorated energy regime.
- ✓ We can learn a lot of physics by studying the HE regime. However, the analysis of the low energy regime is also very important to constrain some important aspects of hadronic physics.
- ✓ The RHIC and LHC data for the photoproduction of exotic states will be fundamental to constrain and/or discriminate between different models.

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Thank you for your attention!

T4Q STATES

X(19000):

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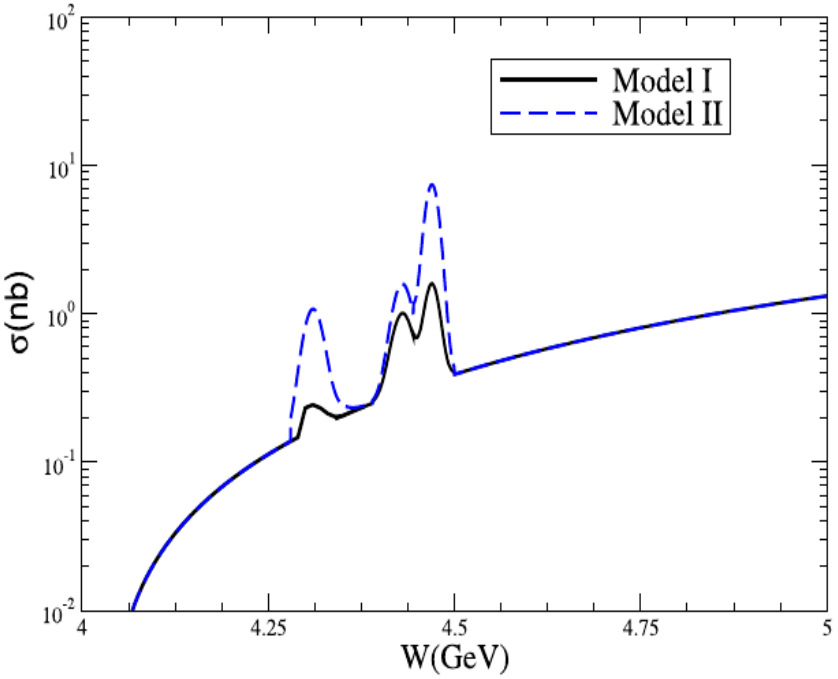
Total cross sections for the $X(19000)[J^P] \to \Upsilon\Upsilon$ production by $\gamma\gamma$ interactions in pp, pPb and $PbPb$ collisions for different center - of - mass energies considering the full LHC rapidity range as well as the rapidity ranges covered by the ALICE and LHCb detectors.

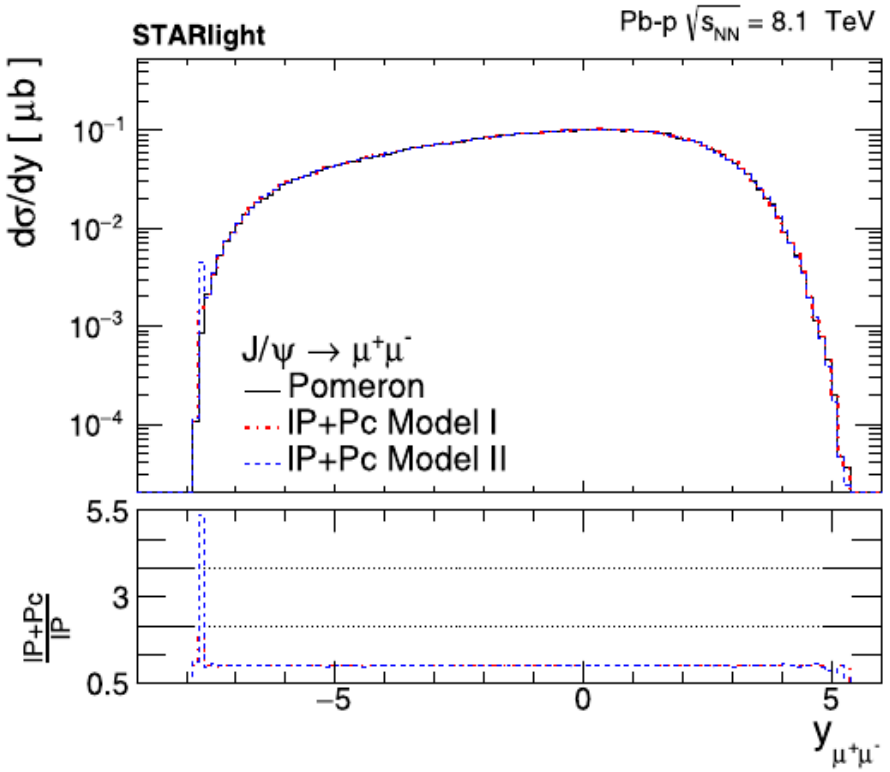
Collision	Resonance	LHC Full rapidity range	LHCb $2.0 \leq Y \leq 4.5$	ALICE $-1.0 \leq Y \leq 1.0$
pp ($\sqrt{s} = 13$ TeV)	$X(19000)$, 0^{++}	2.40×10^{-3} fb	4.90×10^{-4} fb	6.88×10^{-4} fb
	$X(19000)$, 2^{++}	5.91×10^{-3} fb	1.21×10^{-3} fb	1.70×10^{-3} fb
pPb ($\sqrt{s} = 8.1$ TeV)	$X(19000)$, 0^{++}	5.60 fb	1.62 fb	1.96 fb
	$X(19000)$, 2^{++}	13.80 fb	3.99 fb	4.83 fb
$PbPb$ ($\sqrt{s} = 5.02$ TeV)	$X(19000)$, 0^{++}	8.33 pb	0.564 pb	4.32 pb
	$X(19000)$, 2^{++}	20.5 pb	1.38 pb	10.6 pb

Probing Pentaquarks in photon - hadron interactions

Photoproduction of P_c:



Collider mode:



VPG, Medina, PLB805 (2020) 135447.