Particle production in photon - photon interactions at hadronic colliders: Recent results and prospects

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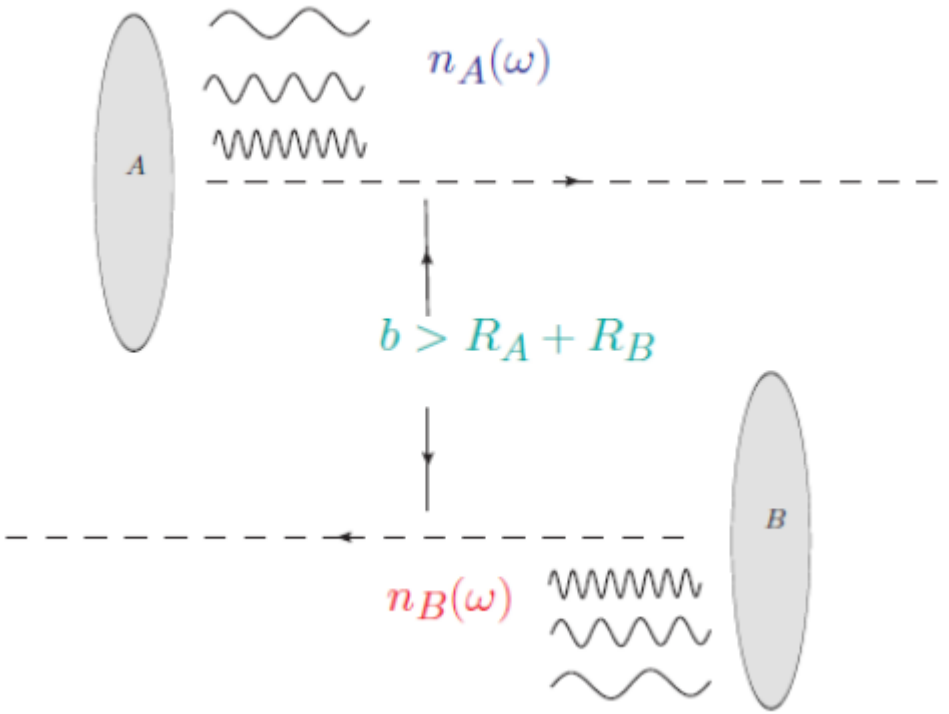
LHC = Photon collider



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: $\sigma(h_1 h_2 \to X) = n_1(\omega) \otimes n_2(\omega) \otimes \sigma^{\gamma\gamma \to X}(W_{\gamma\gamma})$

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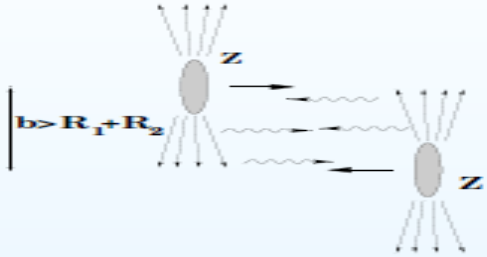

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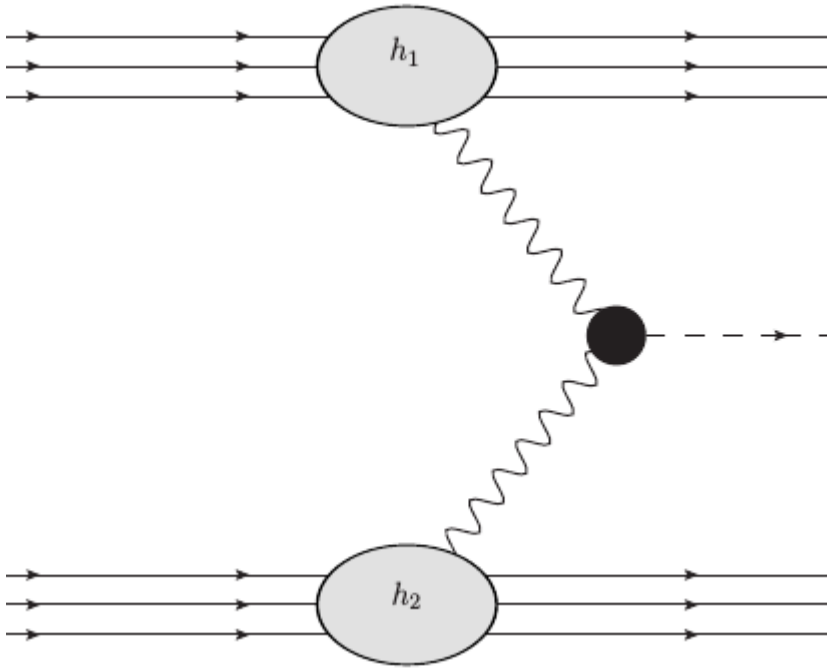
Center of mass energies

LHC	pp	$W_{\gamma p} \lesssim 8390$ GeV	$W_{\gamma\gamma} \lesssim 4504$ GeV
LHC	$pPb(Ar)$	$W_{\gamma A} \lesssim 1500\,(2130)$ GeV	$W_{\gamma\gamma} \lesssim 260\,(480)$ GeV
LHC	$PbPb$	$W_{\gamma A} \lesssim 950$ GeV	$W_{\gamma\gamma} \lesssim 160$ GeV
HERA	ep	$W_{\gamma p} \lesssim 200$ GeV	–

LHC allow us to probe the particle production by photon - photon interactions in a energy range unexplorated by LEP and higher than that proposed for the ILC.

LHC = Photon collider



Intact hadron

Rapidity gap

Rapidity gap

Intact hadron

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

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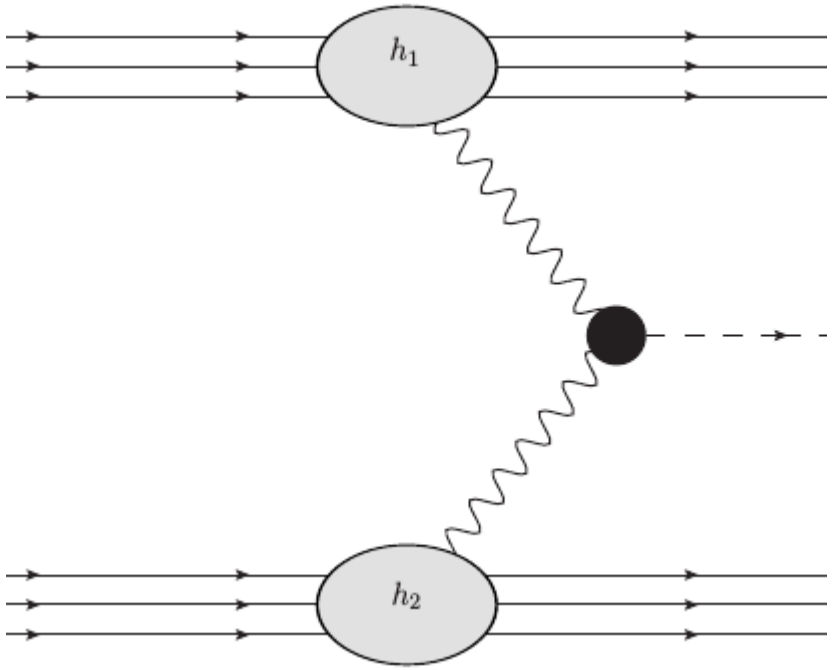

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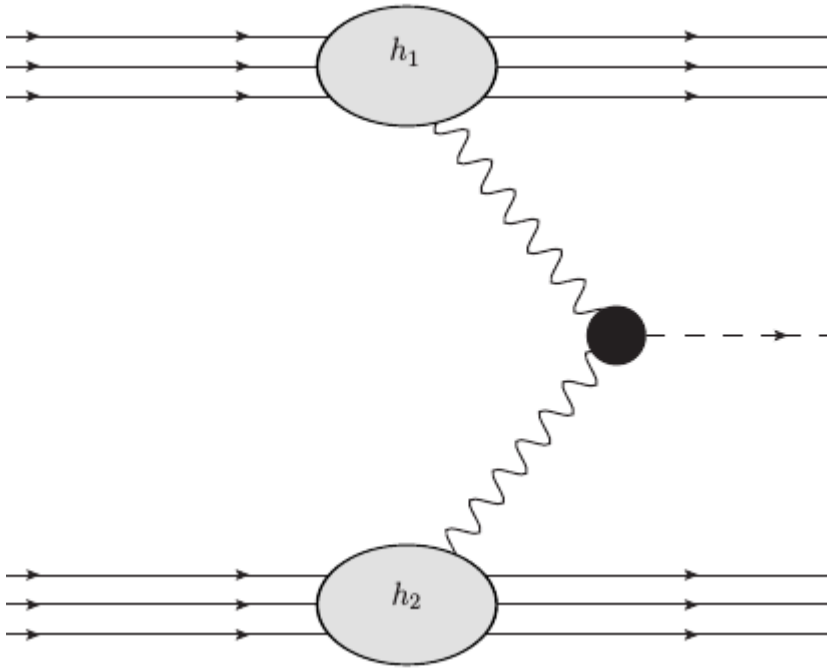
$$\sigma^{PbPb}(\gamma\gamma) \approx Z^2 \sigma^{pPb}(\gamma\gamma) \approx Z^4 \sigma^{pp}(\gamma\gamma)$$

Resonance production



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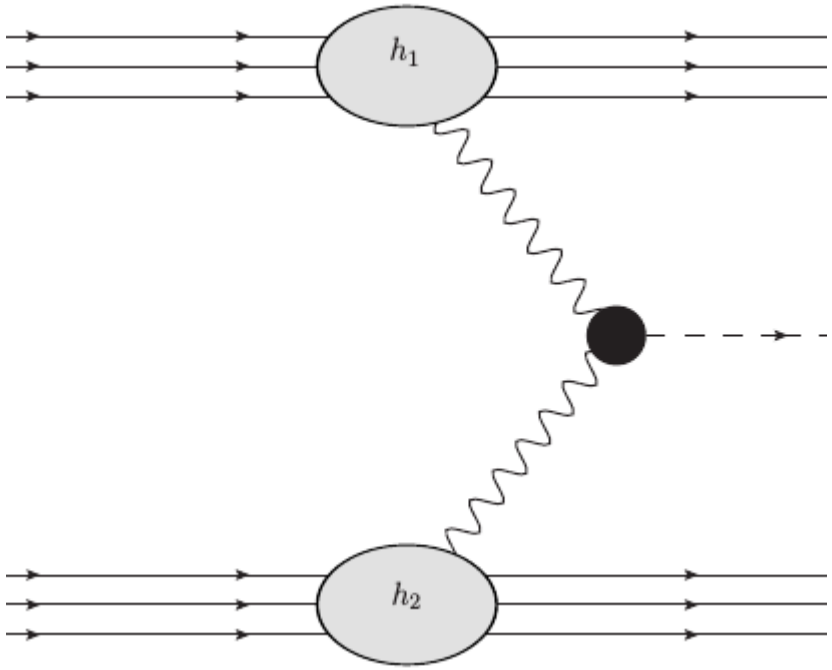
$$\sigma_{\gamma\gamma\to R}(\omega_1, \omega_2) = 8\pi^2(2J+1)\frac{\Gamma_{R\to\gamma\gamma}}{M_R}\delta(4\omega_1\omega_2 - M_R^2)$$

Resonance production



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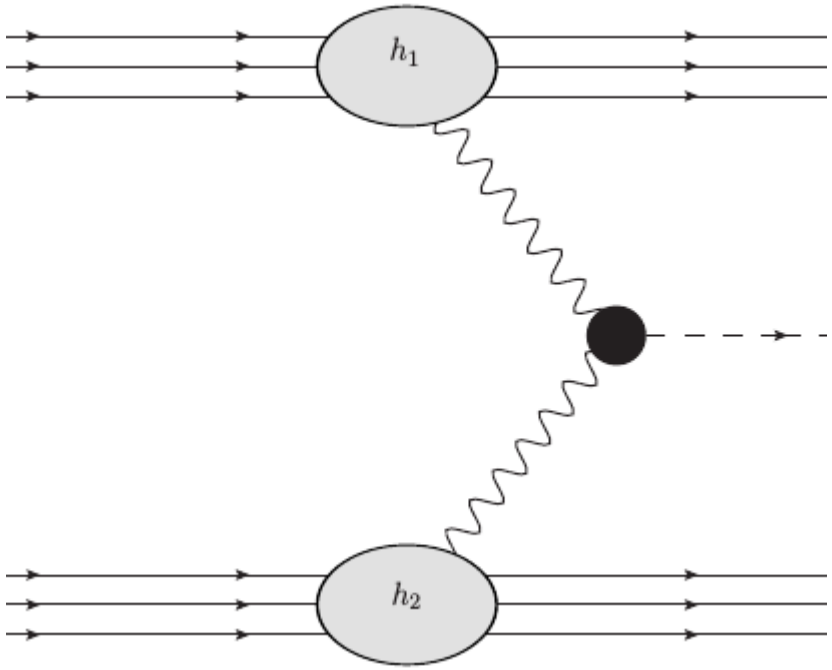
Resonance production



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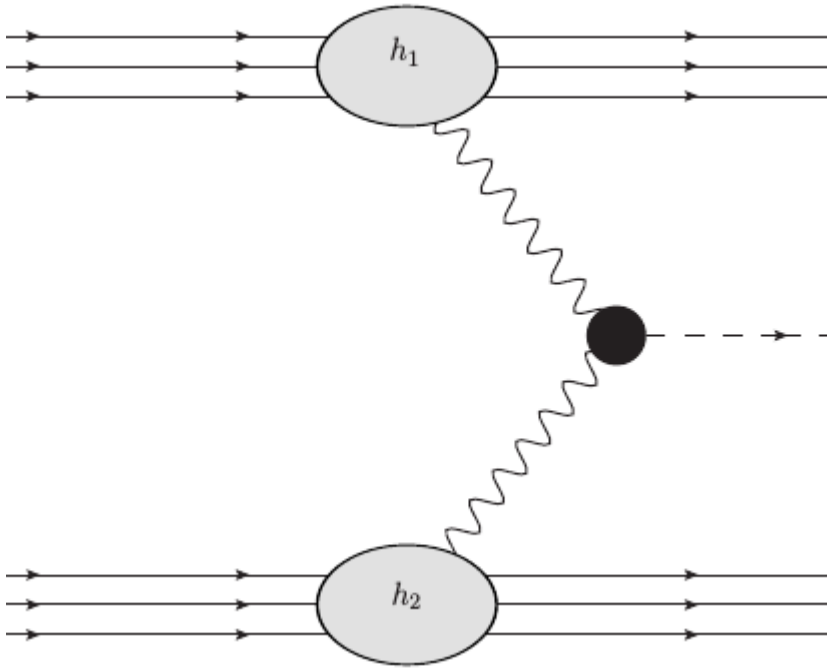
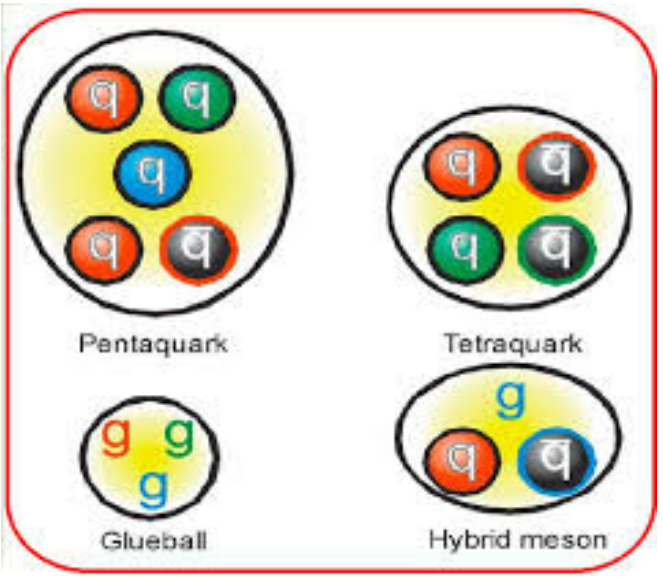
Resonance production





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

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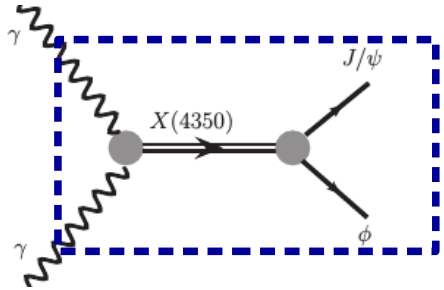
Probing Exotic Charmoniumlike states in photon - photon interactions

Photoproduction of X(4350):



Constrained by Belle Collaboration.

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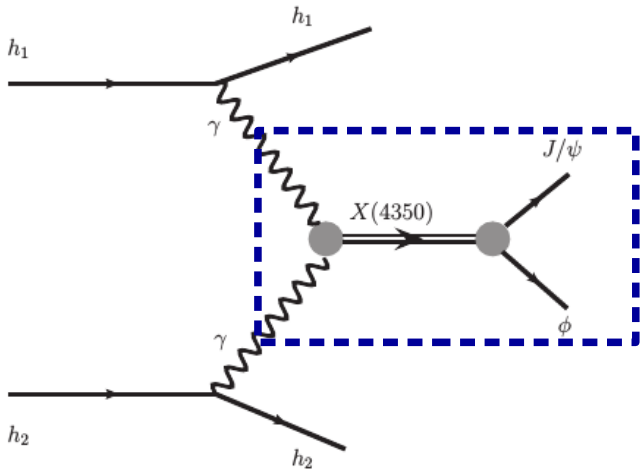

Constrained by Belle Collaboration.

VPG, Moreira, EPJC 79, 7 (2019).

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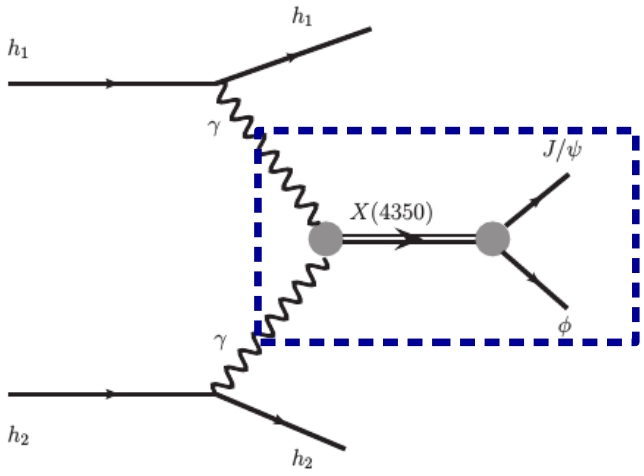

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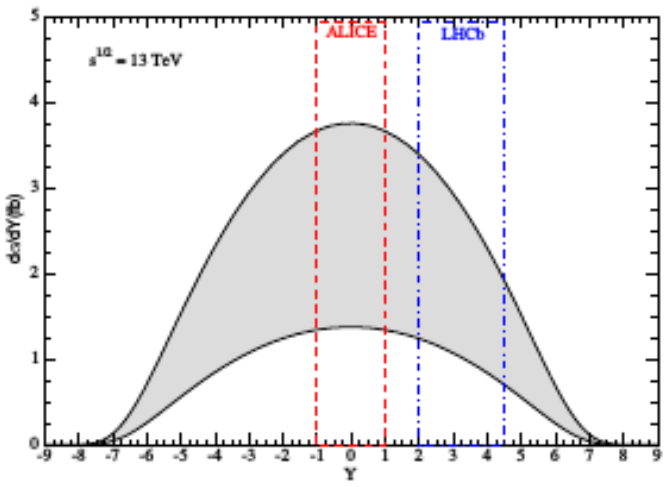
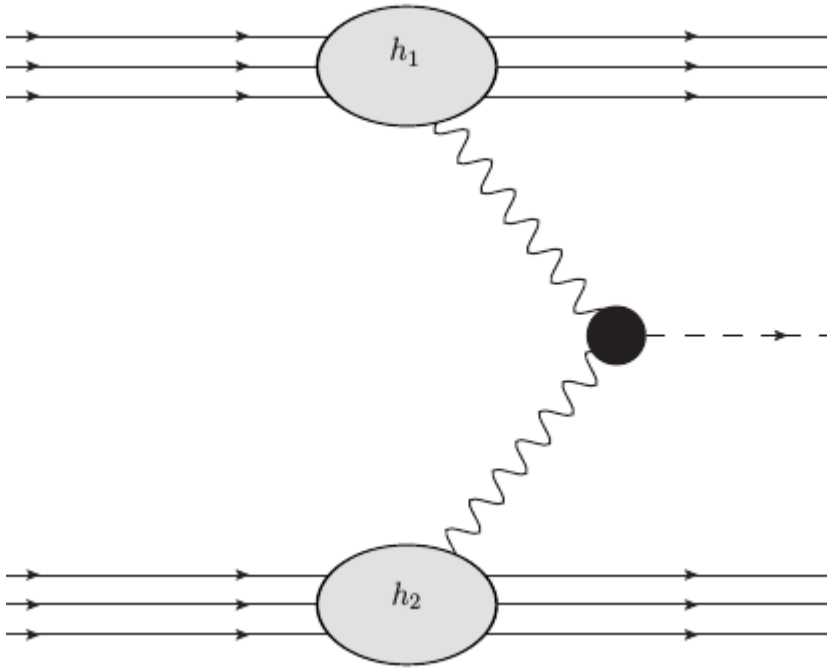
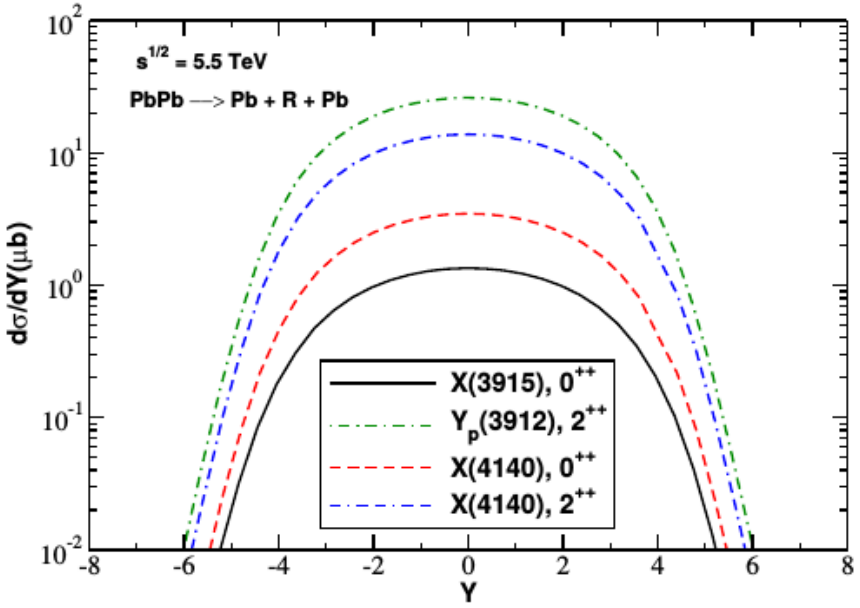


Collision	Resonance	LHCb $2 < Y < 4.5$
pp ($\sqrt{s}$ =13 TeV)	$X(4350)$, 0^{++}	(2.47 – 6.13) fb
	$X(4350)$, 2^{++}	(2.52 – 6.88) fb
pPb ($\sqrt{s}$ =8.1 TeV)	$X(4350)$, 0^{++}	(10.20 – 25.30) pb
	$X(4350)$, 2^{++}	(10.30 – 28.30) pb
$PbPb$ ($\sqrt{s}$ =5.02 TeV)	$X(4350)$, 0^{++}	(14.60 – 36.20) nb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





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

$$\sigma_{\gamma\gamma\to R}(\omega_1, \omega_2) = 8\pi^2(2J+1)\frac{\Gamma_{R\to\gamma\gamma}}{M_R}\delta(4\omega_1\omega_2 - M_R^2)$$

(*) Bertulani, VPG, Moreira, Navarra, PRD94, 094024 (2016)

Probing Exotic Charmoniumlike states in photon - photon interactions

State	Mass	$\Gamma_{\gamma\gamma}^{theor}$(keV)	$\sigma_{b_{min}}$ (μb)			σ_F (μb)			σ_R (μb)		
			2.76 TeV	5.5 TeV	39 TeV	2.76 TeV	5.5 TeV	39 TeV	2.76 TeV	5.5 TeV	39 TeV
X(3940), 0^{++}	3943	0.33	4.2	8.2	31.6	6.5	11.8	40.9	5.7	10.8	39.6
X(3940), 2^{++}	3943	0.27	17.2	33.6	129.2	26.5	48.4	167.4	23.4	44.2	162.0
X(4140), 0^{++}	4143	0.63	6.5	12.9	51.2	10.2	18.7	65.7	9.0	17.1	63.6
X(4140), 2^{++}	4143	0.50	26.0	51.2	201.0	40.3	74.3	260.6	35.5	67.7	252.3
Z(3930), 2^{++}	3922	0.083	5.4	10.5	40.9	8.3	15.2	52.4	7.4	13.9	50.5
X(4160), 2^{++}	4169	0.363	18.4	36.4	144.2	28.6	52.7	185.3	25.2	48.1	178.7
Y_p(3912), 2^{++}	3919	0.774	50.5	98.6	382.4	77.9	142.2	490.1	68.9	129.9	473.7
X(3915), 0^{++}	3919	0.20	2.6	5.1	19.8	4.0	7.3	25.3	3.6	6.7	24.5

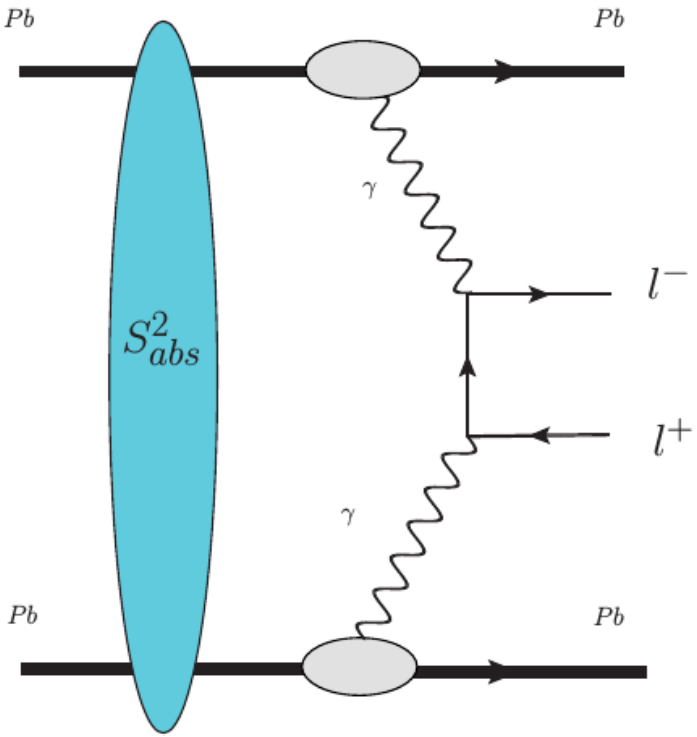
TABLE I: Cross sections for exotic meson production in Pb-Pb collisions using the theoretical decay rates presented in Refs. [34–36].

State	Mass	$\Gamma_{\gamma\gamma}^{theor}$(keV)	$\sigma_{b_{min}}$ (pb)			σ_F (pb)		
			7 TeV	14 TeV	100 TeV	7 TeV	14 TeV	100 TeV
X(3940), 0^{++}	3943	0.33	0.98	1.3	2.8	1.0	1.5	2.8
X(3940), 2^{++}	3943	0.27	4.0	5.6	11.4	4.1	5.7	11.6
X(4140), 0^{++}	4143	0.63	1.6	2.2	4.5	1.6	2.2	4.6
X(4140), 2^{++}	4143	0.50	6.2	8.7	18.0	6.4	8.9	18.3
Z(3930), 2^{++}	3922	0.083	1.2	1.7	3.6	1.3	1.8	3.6
X(4160), 2^{++}	4169	0.363	4.4	6.1	12.8	4.5	6.3	13.0
Y_p(3912), 2^{++}	3919	0.774	11.7	16.3	33.4	12.0	16.7	34.0
X(3915), 0^{++}	3919	0.20	0.60	0.84	1.7	0.62	0.86	1.8

TABLE III: Cross sections for exotic meson production in pp collisions using the theoretical decay rates presented in Refs. [34–36].

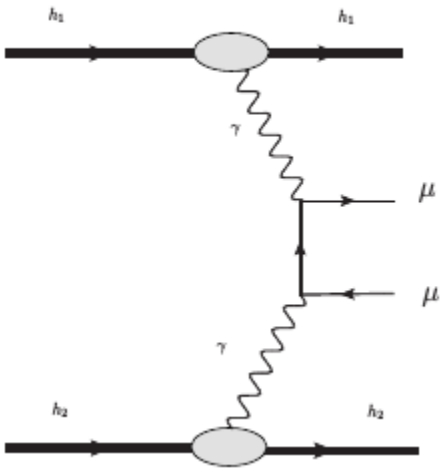
(*) Bertulani, VPG, Moreira, Navarra, PRD94, 094024 (2016)

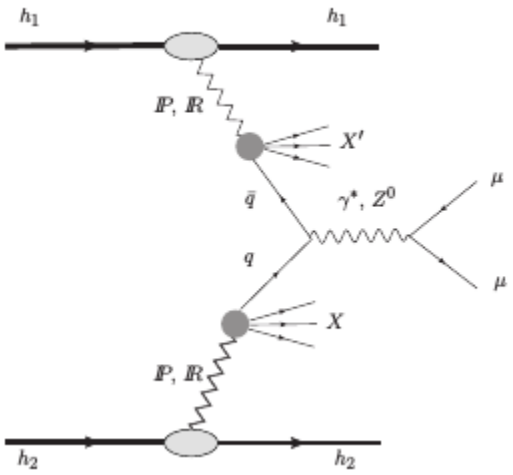
Dilepton production

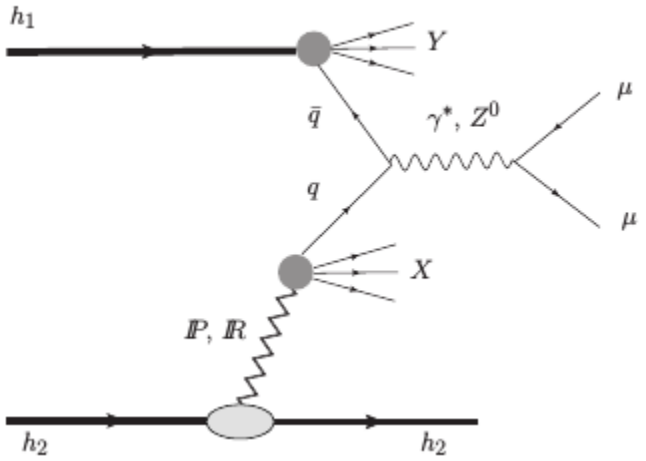


$$\sigma\left(PbPb \to Pb \otimes l^+l^- \otimes Pb; s\right) = \int \mathrm{d}^2\mathbf{b}_1 \mathrm{d}^2\mathbf{b}_2 \mathrm{d}\omega_1 \mathrm{d}\omega_2 \; \hat{\sigma}\left(\gamma\gamma \to l^+l^-; W\right) N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) S^2_{abs}(\mathbf{b})$$

Dilepton production
– pp collisions –





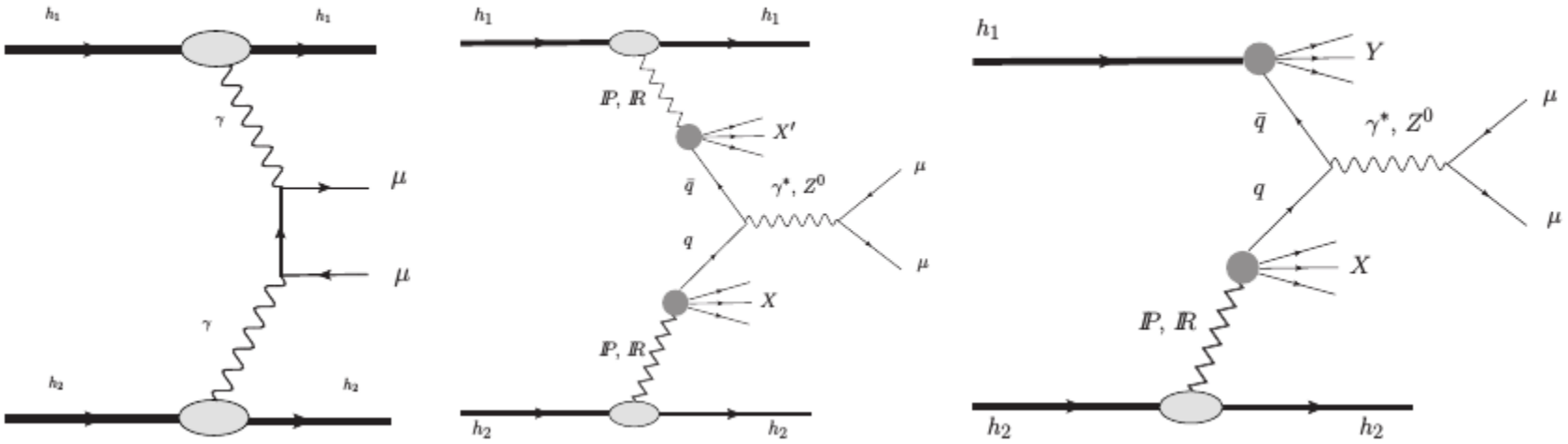


DOUBLE DIFFRACTION

SINGLE DIFFRACTION

(*) VPG, Jaime, Martins, Rangel, PRD97, 074024 (2018)

Dilepton production
– pp collisions –



DOUBLE DIFFRACTION

$$\sigma(h_1 h_2 \to h_1 \otimes X \mu^+ \mu^- X' \otimes h_2) = \int dx_1 \int dx_2 \; [\; q_1^D(x_1, Q^2) \cdot \bar{q}_2^D(x_2, Q^2) + \bar{q}_1^D(x_1, Q^2) \cdot q_2^D(x_2, Q^2)\,] \cdot \hat{\sigma}(q\bar{q} \to \mu^+ \mu^-)$$

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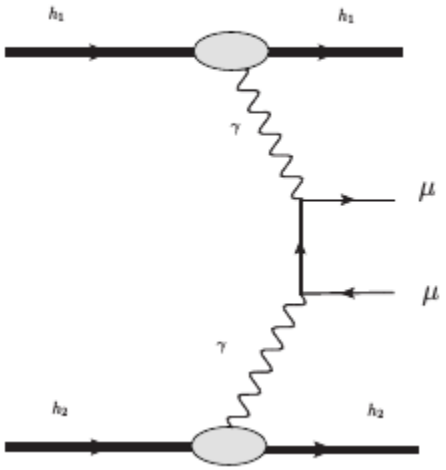
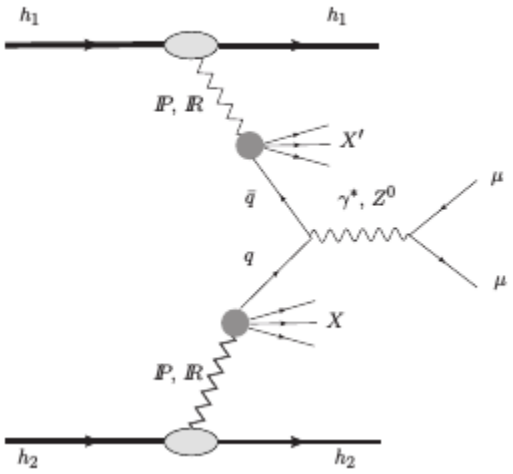
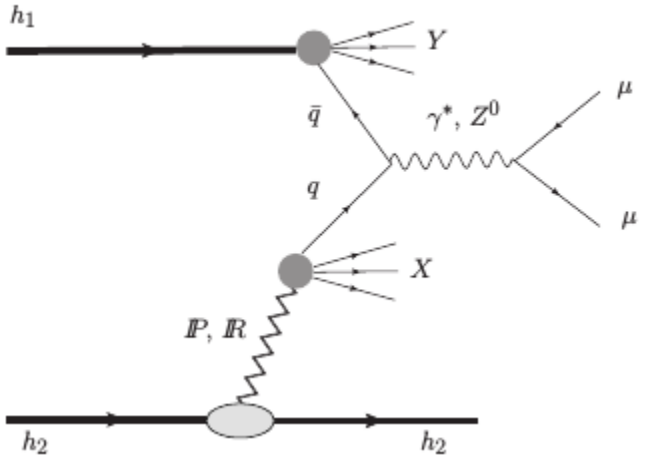
Dilepton production
– pp collisions –







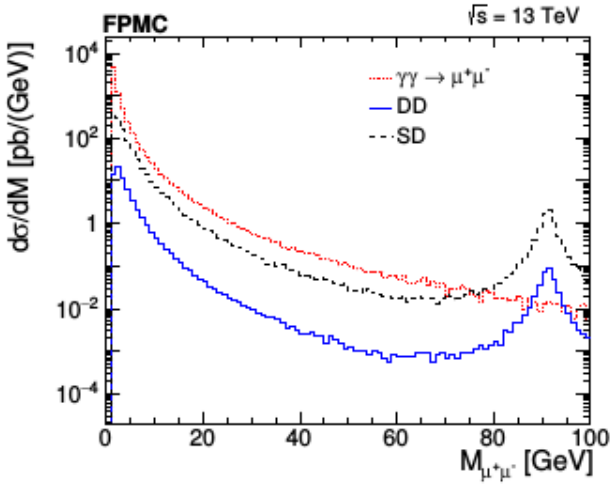
SINGLE DIFFRACTION

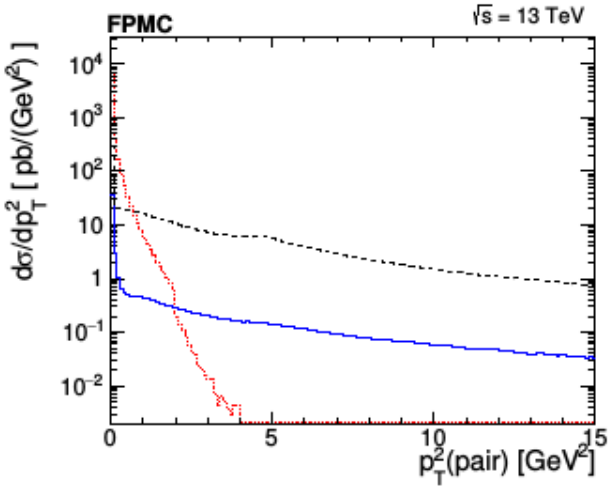
$$\sigma(h_1 h_2 \to Y \mu^+ \mu^- X \otimes h_i) = \int dx_1 \int dx_2 \, [q_1^D(x_1, Q^2) \cdot \bar{q}_2(x_2, Q^2) \; + \; q_1(x_1, Q^2) \cdot \bar{q}_2^D(x_2, Q^2) \; + \; (q \leftrightarrow \bar{q})] \cdot \hat{\sigma}(q\bar{q} \to \mu^+ \mu^-)$$

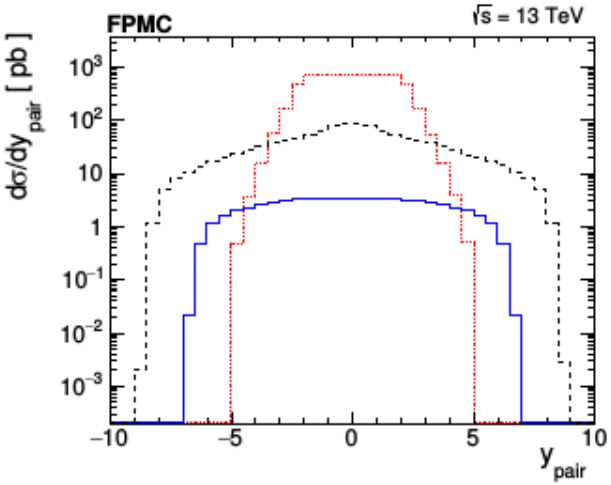
(*) VPG, Jaime, Martins, Rangel, PRD97, 074024 (2018)

Dilepton production
– pp collisions –

W/o cuts:







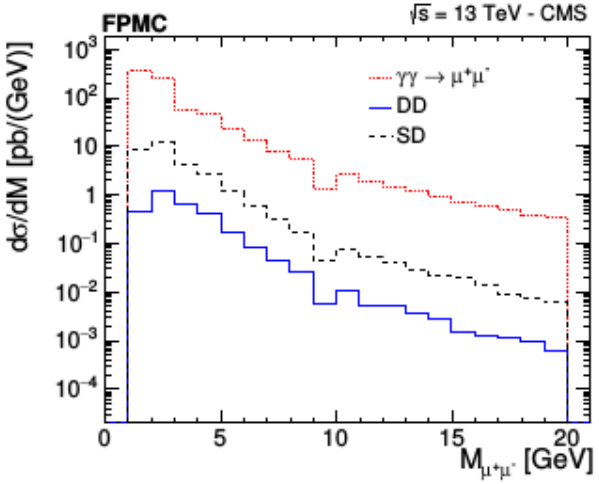
Process	$\mathbb{PP}$	$\mathbb{PR}+\mathbb{RP}$	$\mathbb{RR}$	**DD**	$\mathbb{P}p$	$\mathbb{R}p$	**SD**	$\gamma\gamma$
Total Cross Section [pb]	31.0	27.0	6.1	64.1	694.0	425.0	1119.0	7101.1

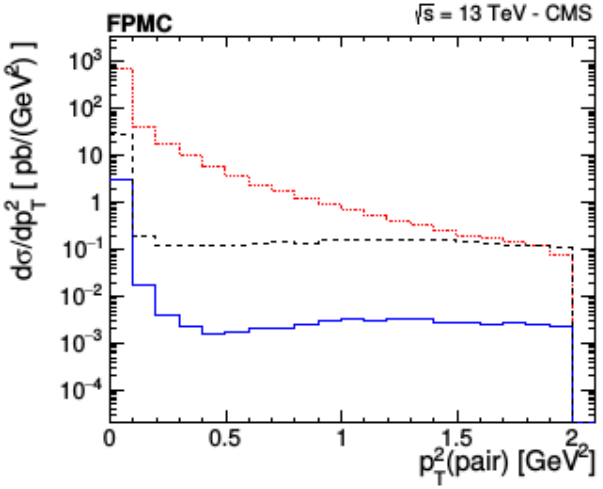
(*) VPG, Jaime, Martins, Rangel, PRD97, 074024 (2018)

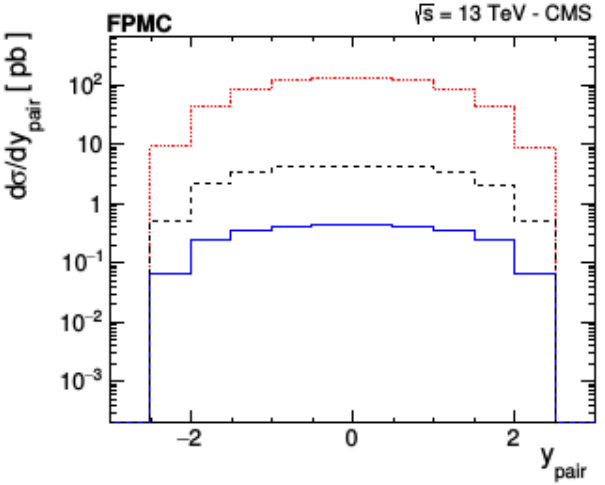
Dilepton production
– pp collisions –

Including cuts:

Cut\Process	$\mathbb{PP}$	$\mathbb{PR}+\mathbb{RP}$	$\mathbb{RR}$	**DD**	$\mathbb{P}p$	$\mathbb{R}p$	**SD**	$\gamma\gamma$
No cut	31.0	27.0	6.1	**64.1**	694.0	425.0	**1119.0**	7101.1
1. $p_T(\mu^\pm) > 0.4\,\text{GeV}$	28.6	23.9	4.5	**57.3**	616.4	310.3	**926.7**	2601.3
2. Inv. mass range $1.0 \le M_{\mu^+\mu^-} \le 20$ GeV	23.3	19.3	2.6	**45.2**	499.6	189.5	**689.1**	1531.1
3. $p_T^2(\mu^+\mu^-) < 2\,\text{GeV}^2$	16.5	13.0	1.5	**31.0**	236.1	82.2	**318.2**	1529.5
4. η in the CMS acceptance	5.7	3.4	0.8	**9.8**	66.6	46.9	**113.5**	775.3
η in the LHCb acceptance	1.7	1.4	0.1	**3.2**	20.8	6.2	**27.0**	46.6
5. Exclusivity: CMS	1.3	1.2	0.5	**3.0**	16.4	12.3	**28.7**	775.3
Exclusivity: Backward and forward LHCb	0.1	0.1	0.01	**0.2**	0.9	0.6	**1.4**	46.6





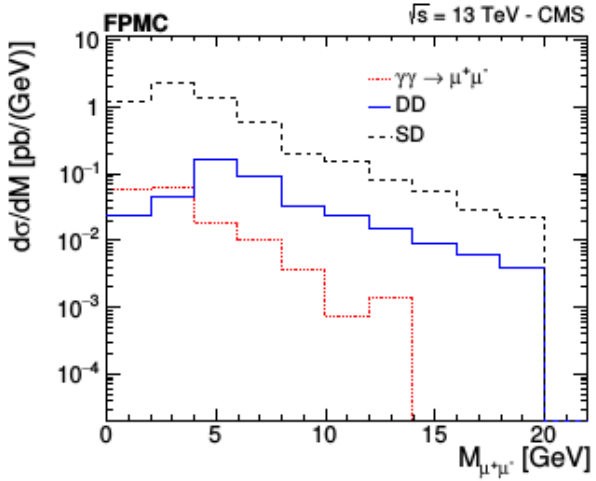


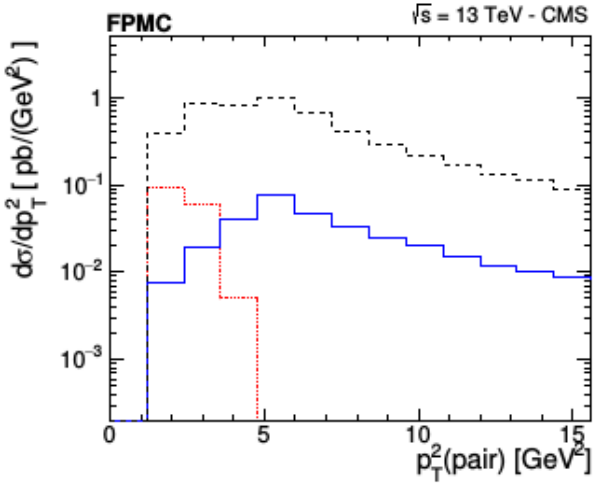
Dominated by photon – photon interactions!

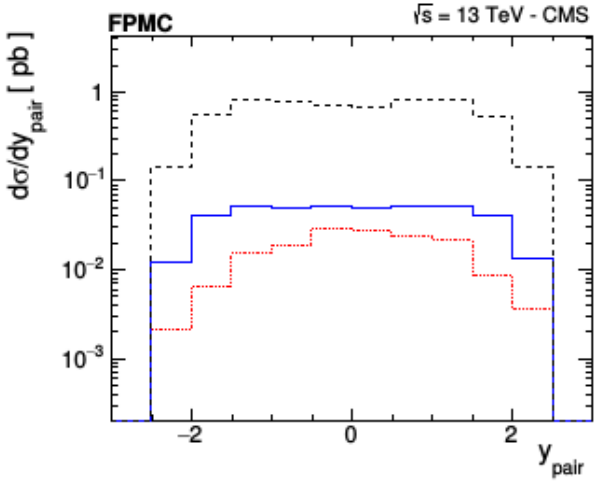
Dilepton production
– pp collisions –

Including cuts:

Cut\Process	$\mathbb{PP}$	$\mathbb{PR}+\mathbb{RP}$	$\mathbb{RR}$	**DD**	$\mathbb{P}p$	$\mathbb{R}p$	**SD**	$\gamma\gamma$
No cut	31.0	27.0	6.1	**64.1**	694.0	425.0	**1119.0**	7101.1
1. $p_T(\mu^\pm) > 0.4\,\text{GeV}$	28.6	23.9	4.5	**57.0**	616.4	310.3	**926.7**	2601.3
2. Inv. mass range $1.0 \le M_{\mu^+\mu^-} \le 20$ GeV	23.3	19.3	2.6	**45.2**	499.6	189.5	**689.1**	1531.1
3. $p_T^2(\mu^+\mu^-) > 2\,\text{GeV}^2$	4.7	4.2	0.6	**9.6**	166.8	63.3	**230.1**	0.1
4. η in the CMS acceptance	2.2	1.7	0.3	**4.3**	70.4	38.5	**108.9**	0.04
η in the LHCb acceptance	0.6	0.6	0.1	**1.2**	17.6	5.8	**23.4**	0.005
5. Exclusivity: CMS	0.04	0.2	0.08	**0.3**	1.5	2.1	**3.6**	0.04
Exclusivity: Backward and forward LHCb	8×10^{-4}	0.002	5×10^{-4}	**0.004**	0.01	0.01	**0.02**	0.005

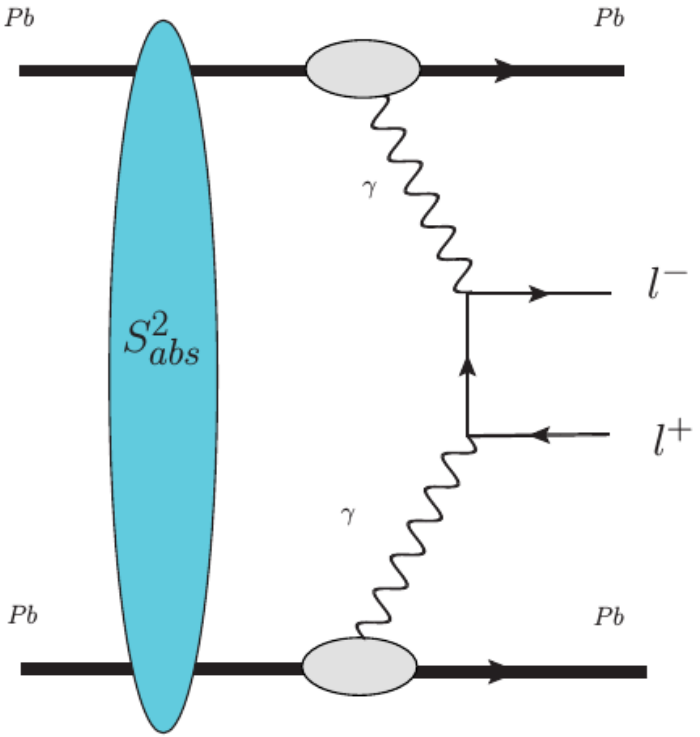






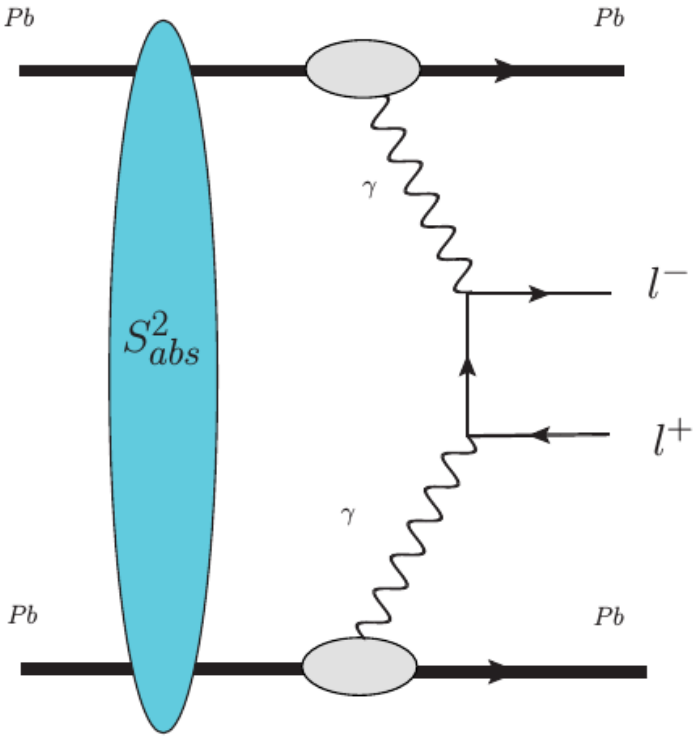
Dominated by diffractive interactions!

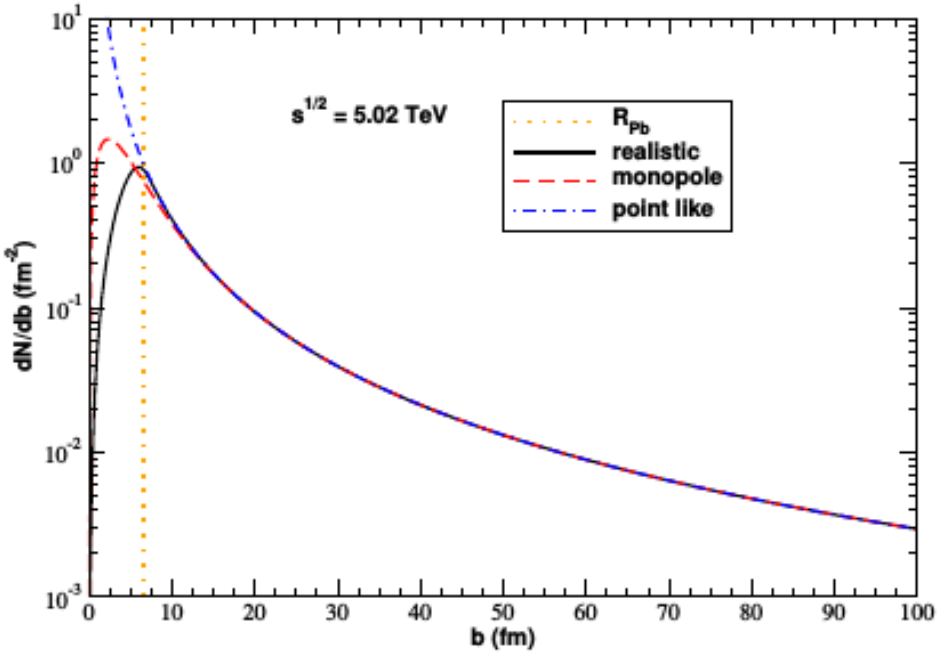
Dilepton production
– PbPb collisions –



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

Dilepton production
- PbPb collisions -

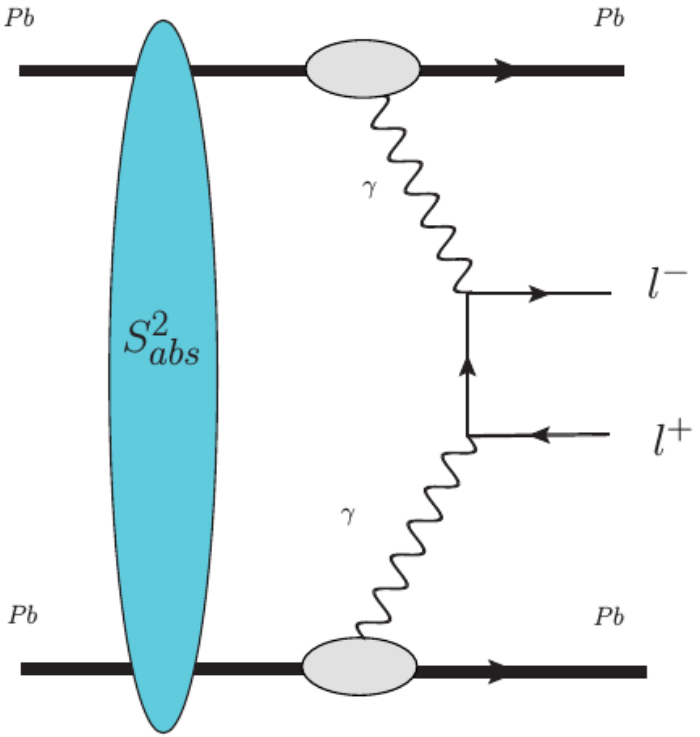


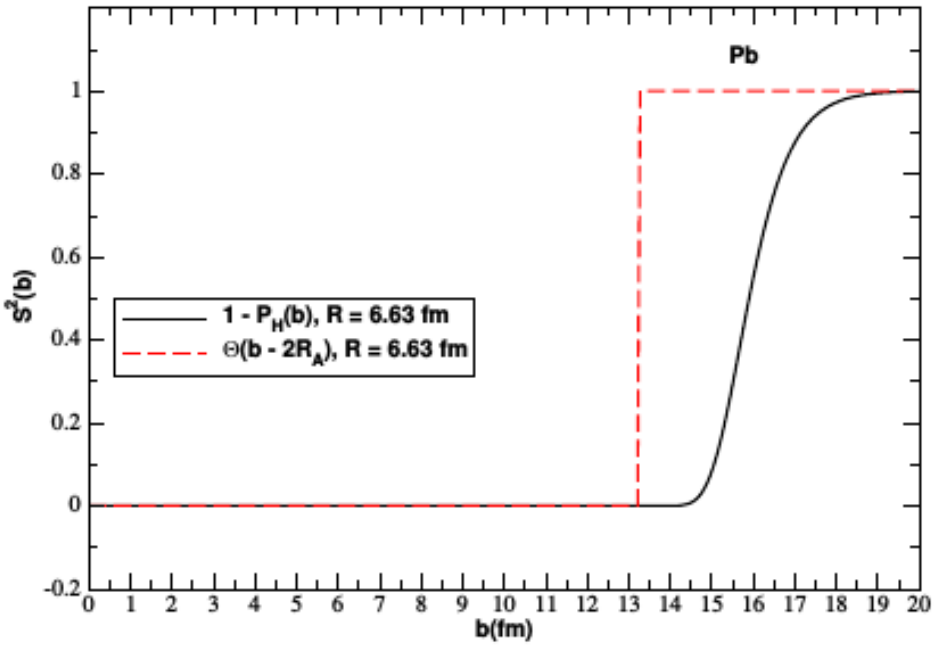


$$\sigma\left(PbPb \to Pb \otimes l^+l^- \otimes Pb; s\right) = \int \mathrm{d}^2\mathbf{b}_1\mathrm{d}^2\mathbf{b}_2\mathrm{d}\omega_1\mathrm{d}\omega_2\, \hat{\sigma}\left(\gamma\gamma \to l^+l^-; W\right) N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) S^2_{abs}(\mathbf{b})$$

(*) Azevedo, VPG, Moreira, EPJC79, 432 (2019)

Dilepton production
– PbPb collisions –





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

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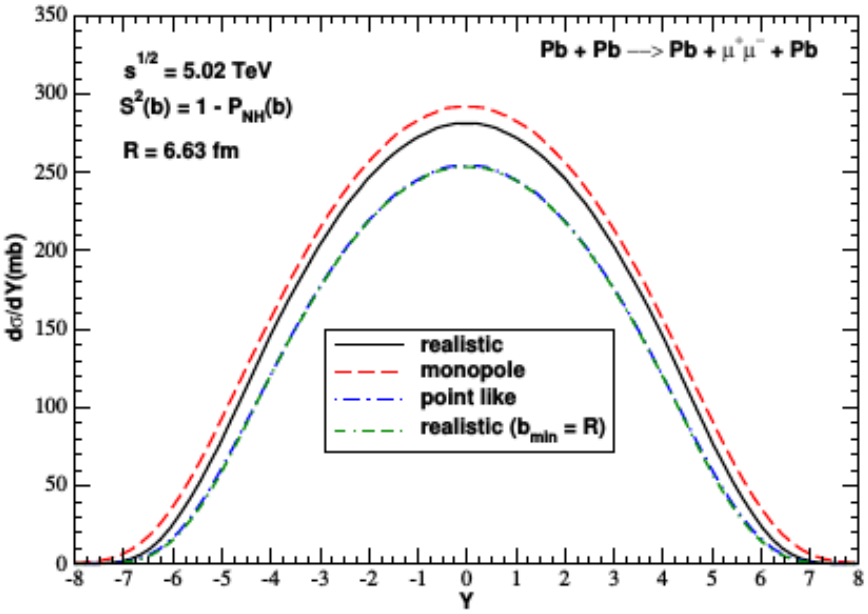

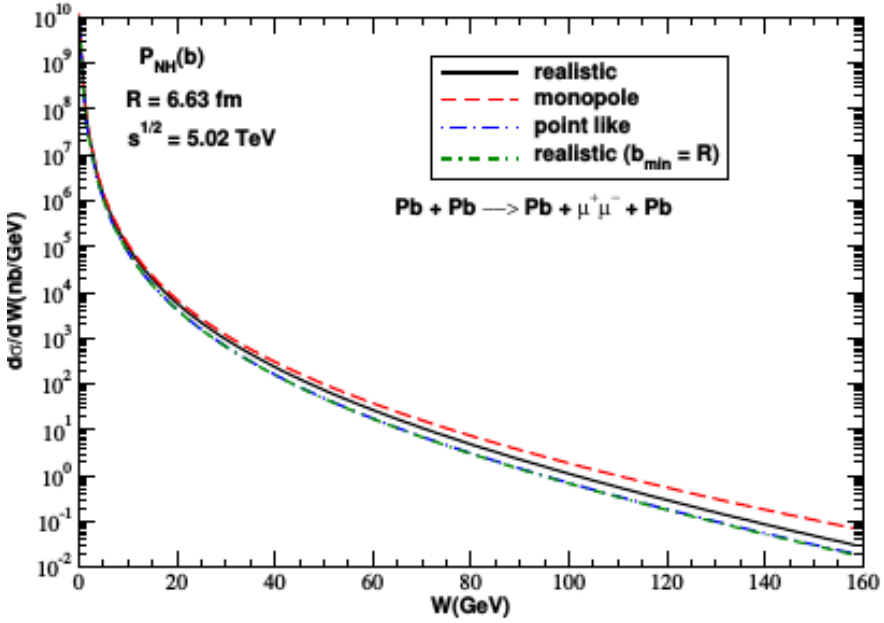

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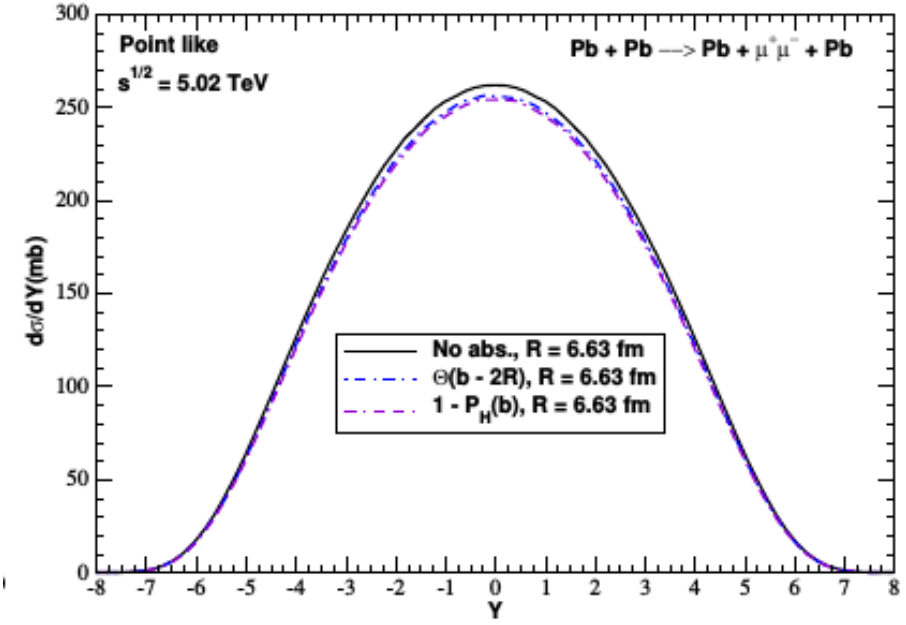

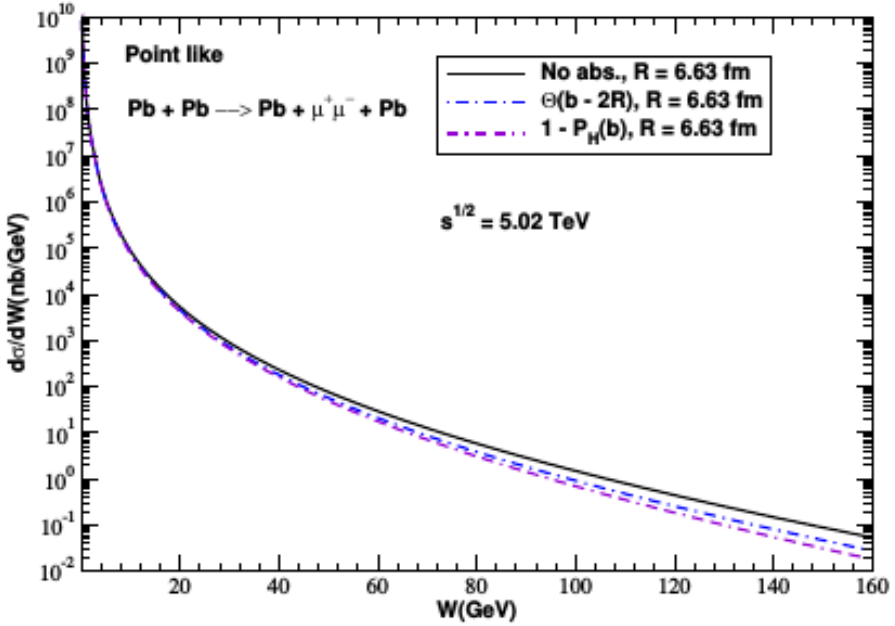

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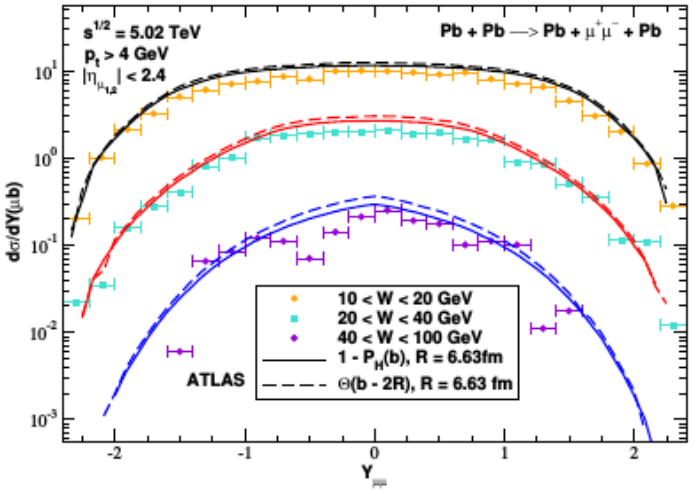
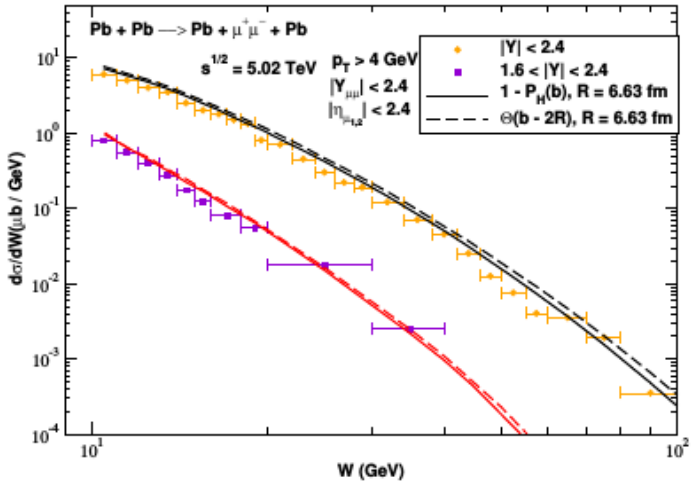
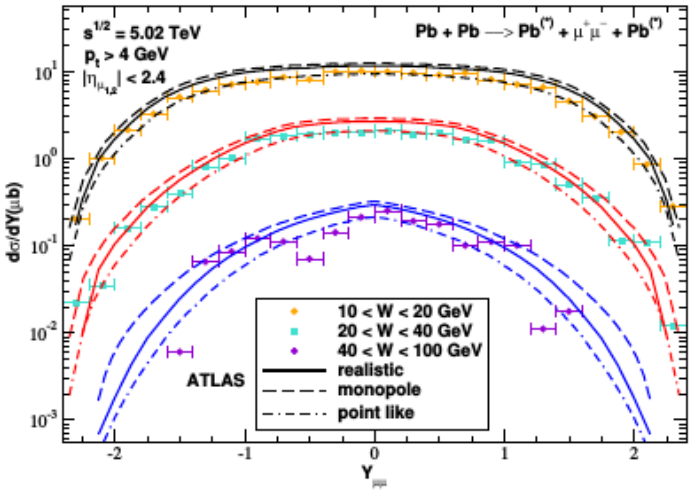
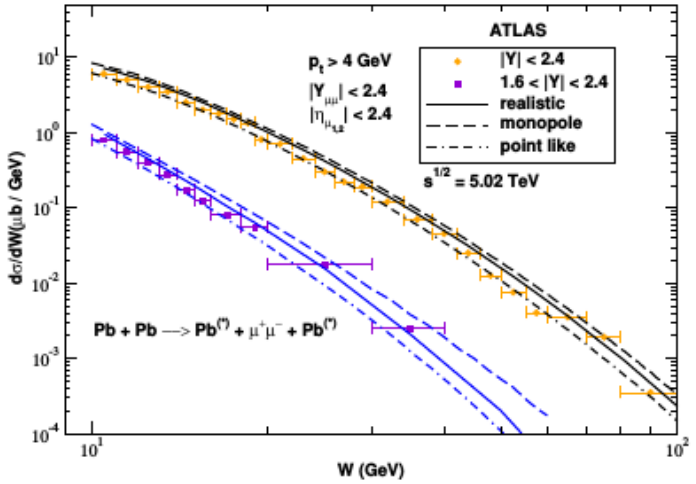
Dilepton production
– PbPb collisions –

Including experimental cuts:









Dilepton production
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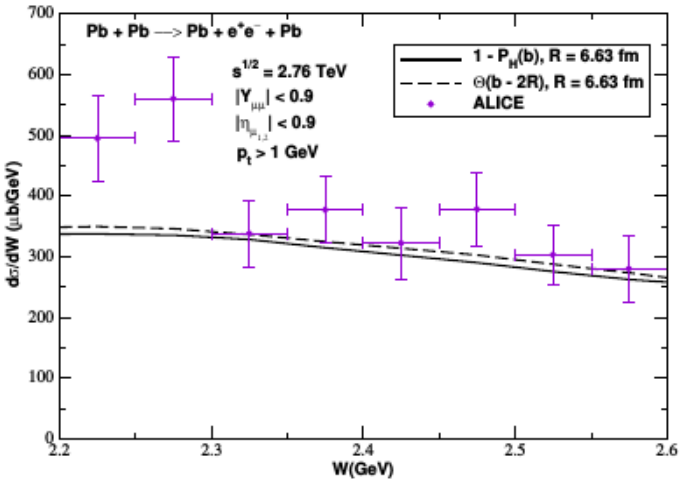
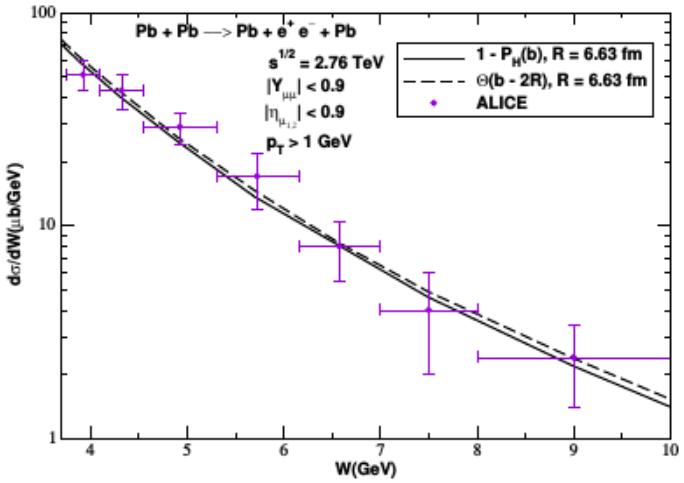
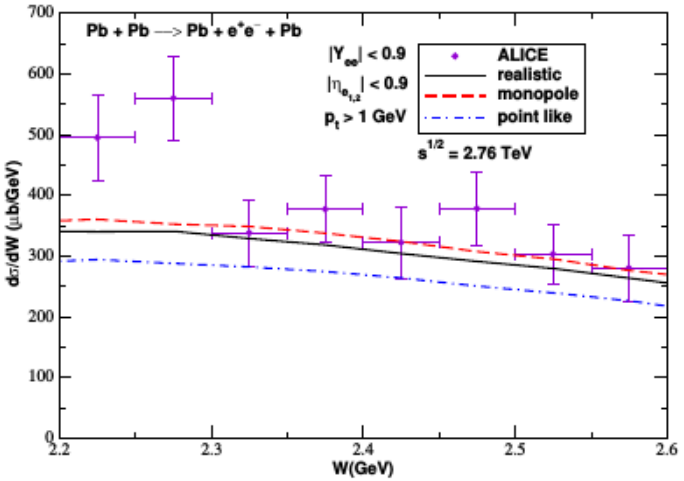
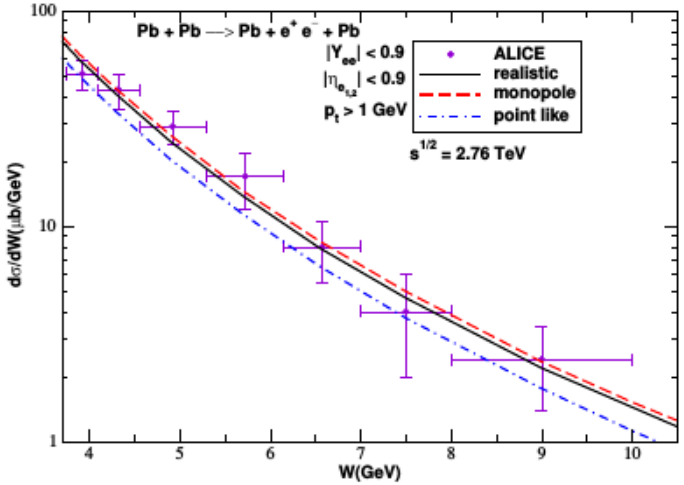




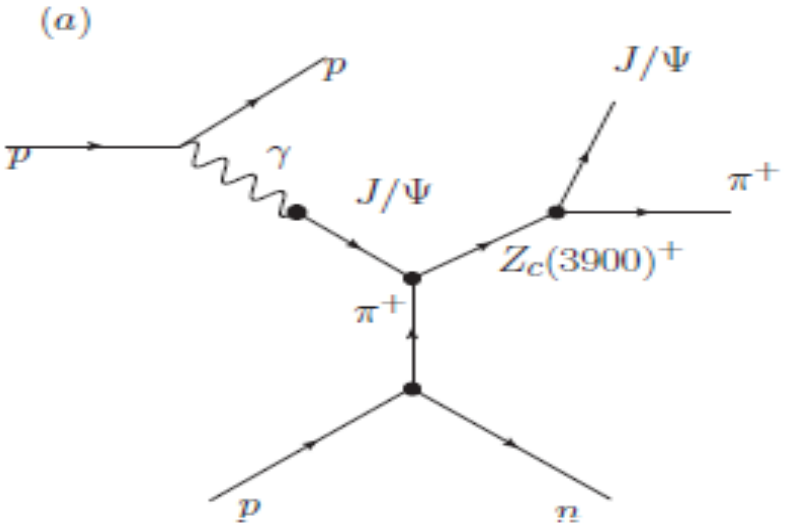


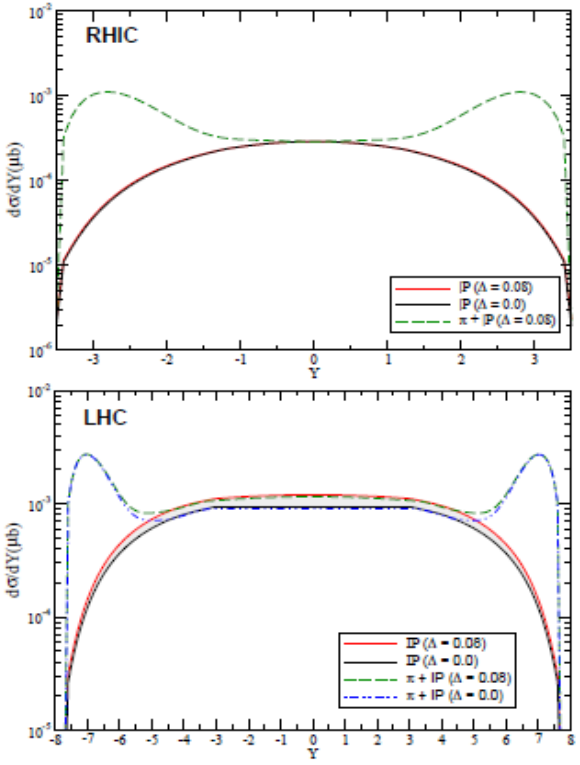


Prospects

Probing Exotic Charmoniumlike states in photon - hadron interactions

Photoproduction of $Z_c(3900)^+$:





Reaction	Ressonance	Contribution	σ [nb] ($\sqrt{s} = 0.2$ TeV)	σ [nb] ($\sqrt{s} = 7$ TeV)	σ [nb] ($\sqrt{s} = 14$ TeV)
$\sigma(pp \to pJ/\Psi\pi n)$	–	$\mathbb{P}$	1.15	8.18 – 9.64	10.33 – 12.65
	$Z_c(3900)$	$\mathbb{P} + \pi$	3.83	14.13 – 15.52	16.89 – 19.12

⇒ Cross sections are enhanced by a factor Z^2 in pPb collisions.

VPG, Silva, PRD 89, 114005 (2014).

Probing Exotic Charmoniumlike states in photon - hadron interactions

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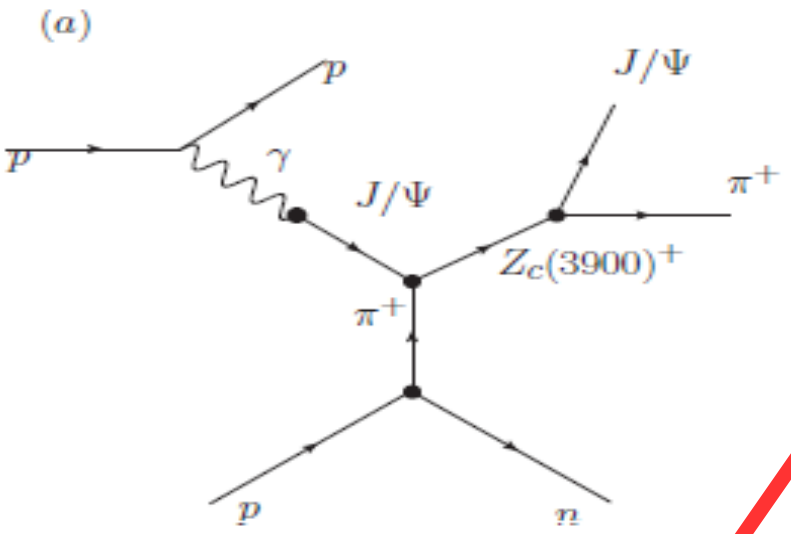
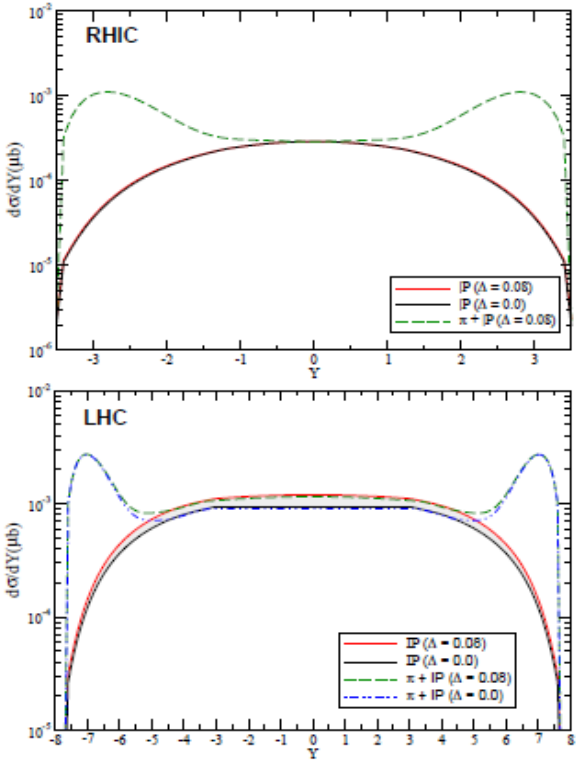




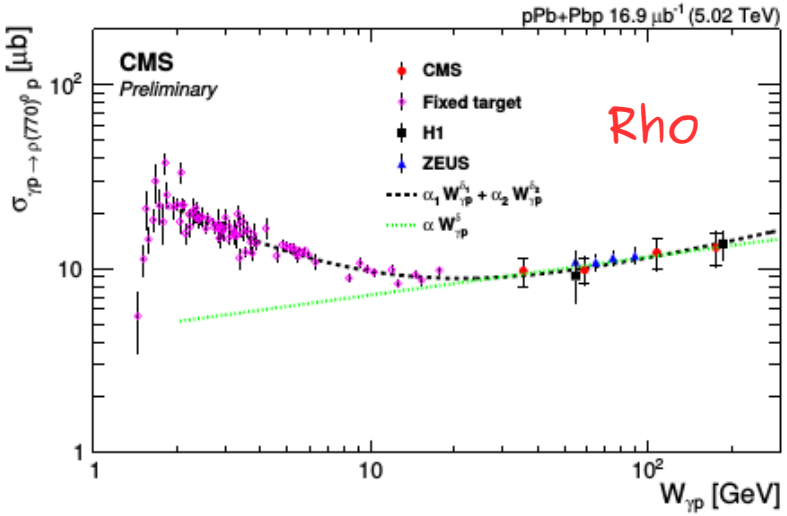
The enhancement occurs at very large rapidities (small photon - proton center - of - mass energies)!

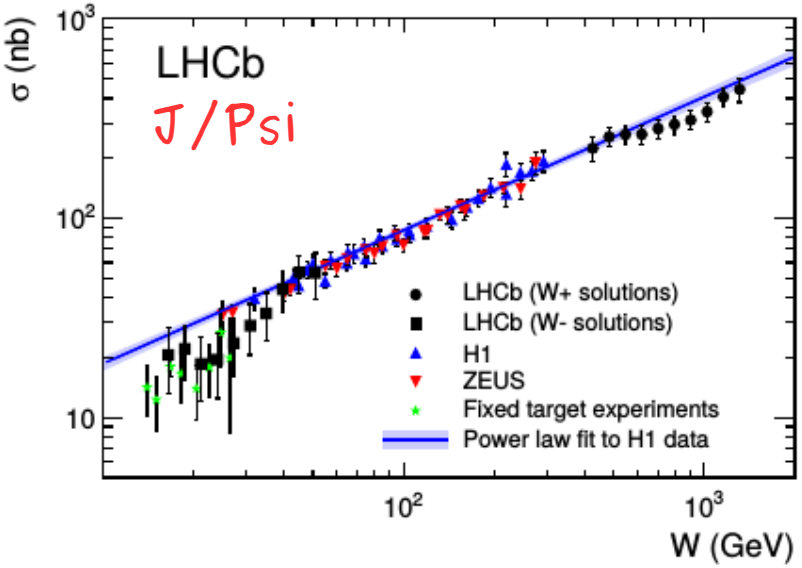
VPG, Silva, PRD 89, 114005 (2014).

Exclusive VM photoproduction 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;

* Such collisions allows to study the vector meson photoproduction at low energies.





(*) VPG, Medina EPJC78, 693 (2018)

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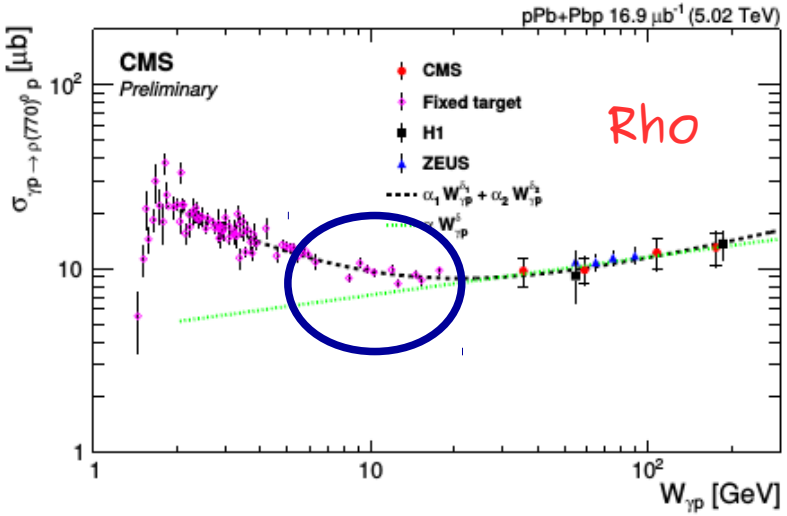

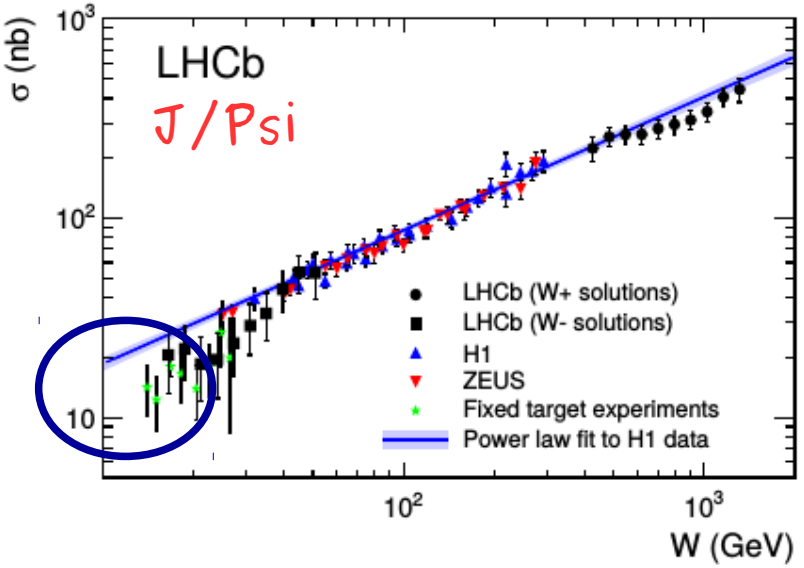

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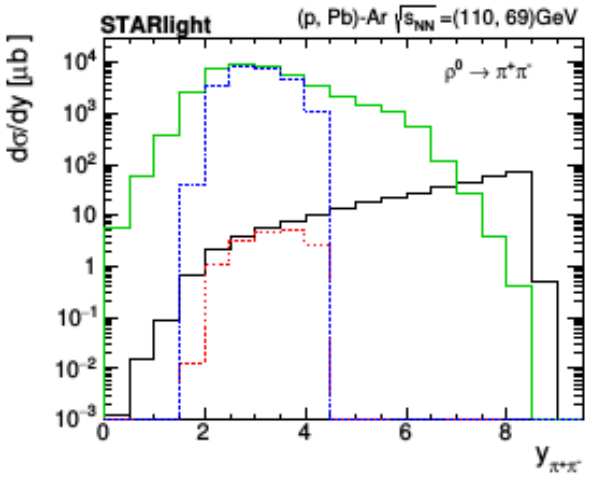
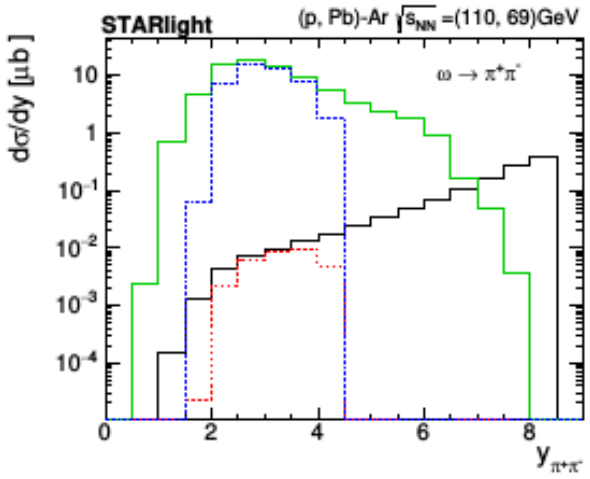
Exclusive VM photoproduction in fixed target collisions at the LHC

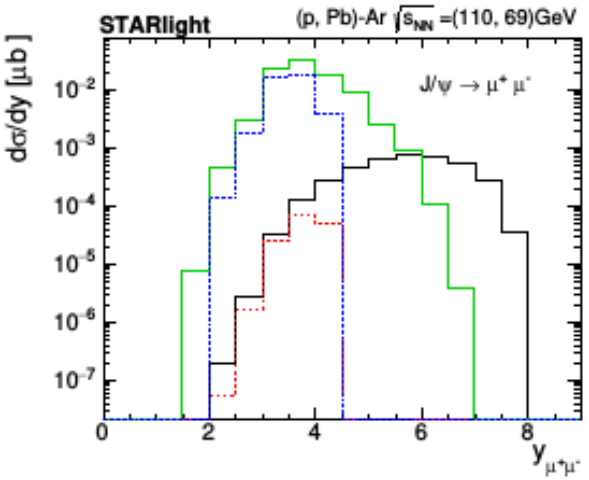
Rho



Omega



J/Psi



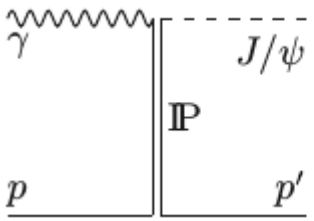
—p-Ar
---p-Ar LHCb
—Pb-Ar
····Pb-Ar LHCb

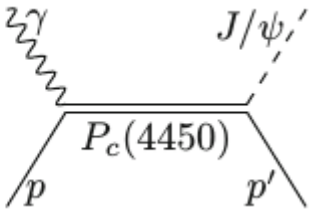
Final State	p-Ar		p-He		Pb-Ar		Pb-He	
$\rho^0 \to \pi^+\pi^-$	318.60	(16.50) μb	6.97	(1.09) μb	42.50	(24.50) mb	5.60	(2.44) mb
$\omega \to \pi^+\pi^-$	1160.12	(30.71) nb	21.86	(2.29) nb	76.32	(46.21) μb	12.81	(5.35) μb
$J/\psi \to \mu^+\mu^-$	3.88	(0.14) nb	118.41	(14.29) pb	88.67	(39.68) nb	13.31	(7.15) nb

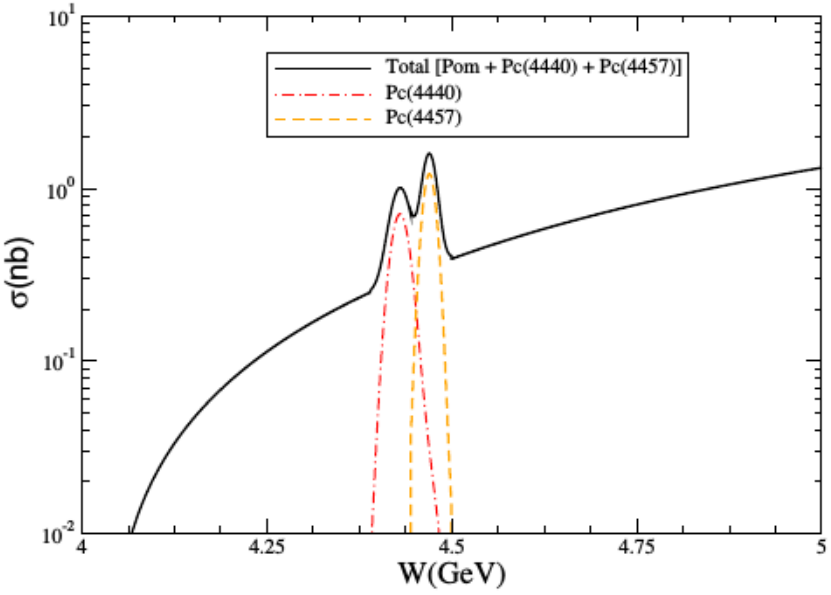
(*) VPG, Medina EPJC78, 693 (2018)

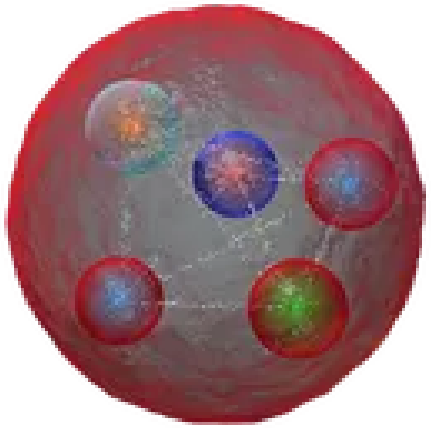
Probing Pentaquarks in photon - hadron interactions

Photoproduction of P_c:









Cao, Dai, ArXiv:1904.06015[hep-ph].

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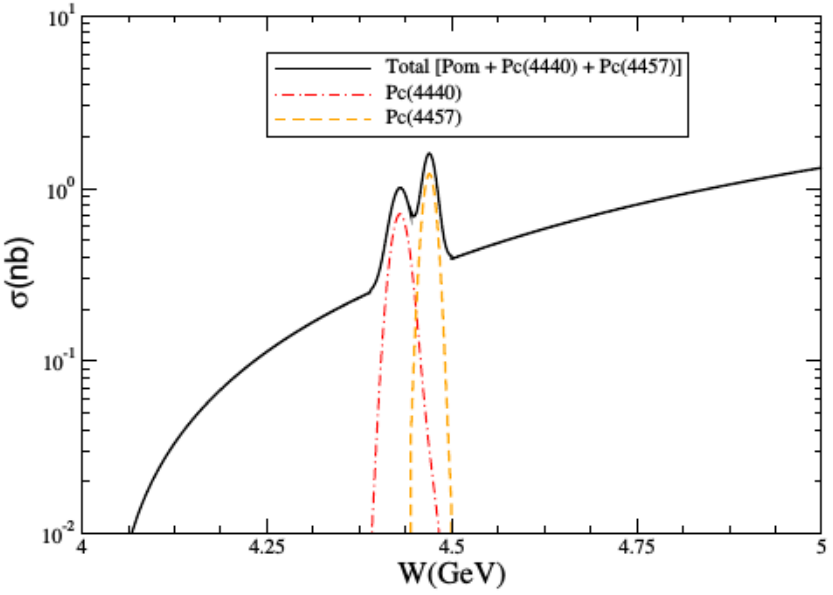
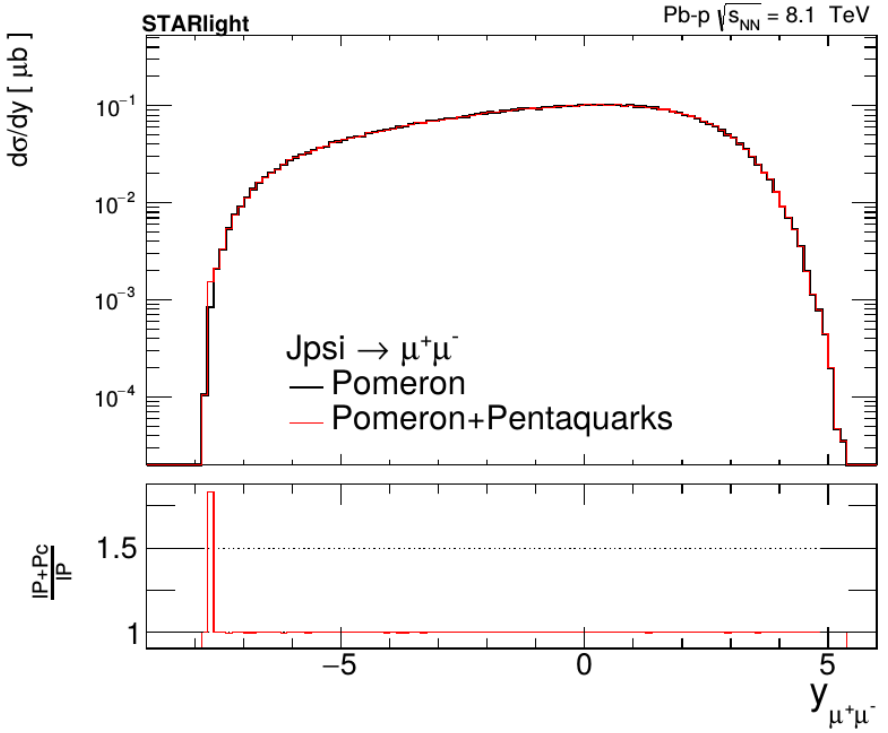


Collider mode:



VPG, Medina, work in progress.

Probing Pentaquarks in photon - hadron interactions

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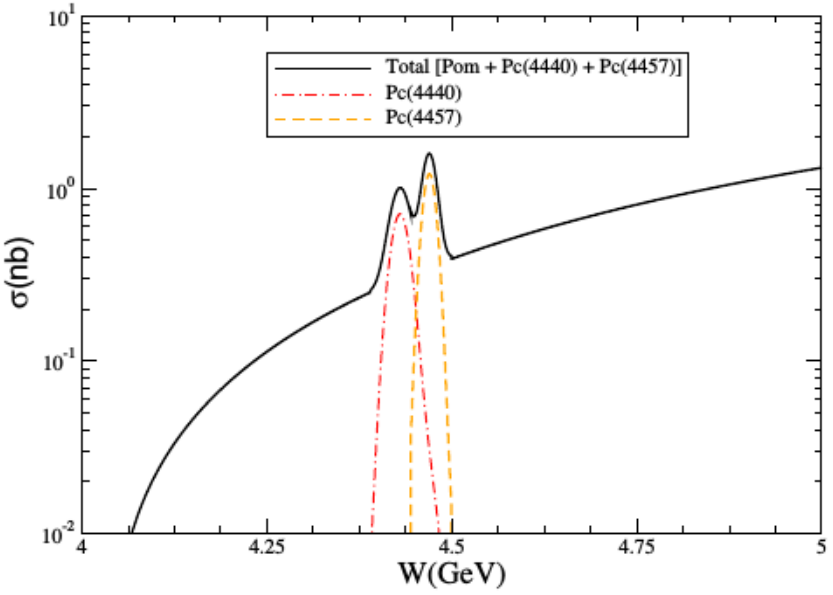
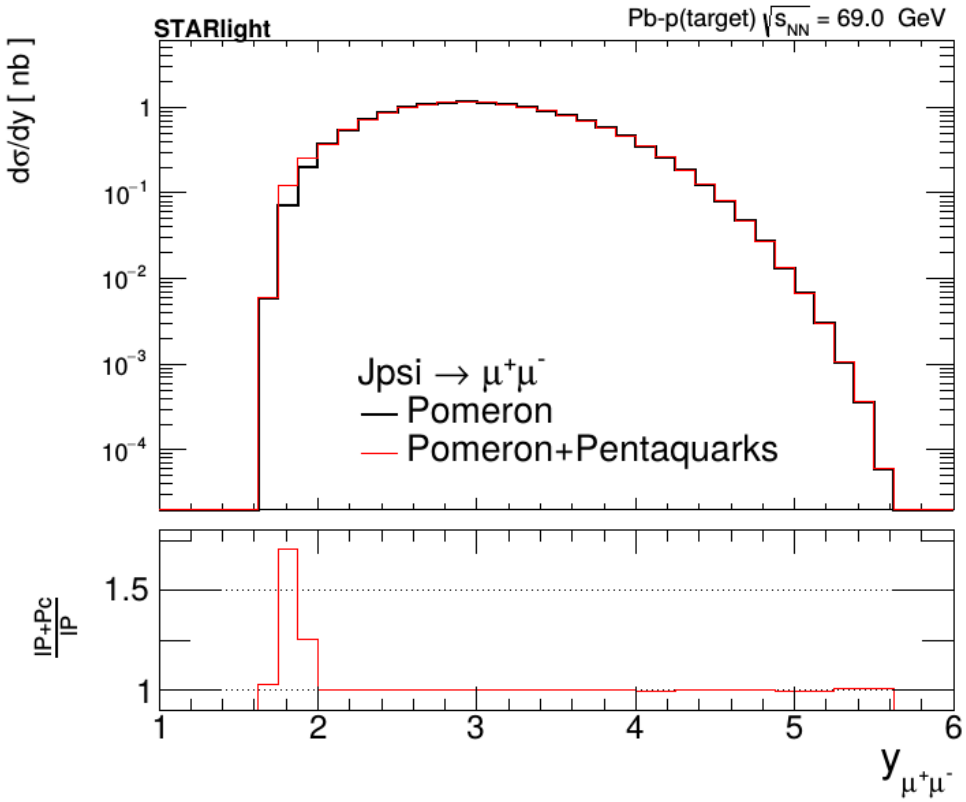


Fixed - target mode:



VPG, Medina, work in progress.

Summary

Summary

- ✓ Photon – induced interactions can be used to constrain the physics in unexplorated energy regime.
- ✓ We can learn a lot of physics 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 different final states will be fundamental to constrain and/or discriminate between different models.
- ✓ Complementary studies can be performed by the analysis of the exclusive vector meson photoproduction in polarized hadronic collisions and in fixed – target collisions at the LHC.

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Summary

- ✓ Photon – induced interactions can be used to constrain the physics in unexplorated energy regime.
- ✓ We can learn a lot of physics 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 different final states will be fundamental to constrain and/or discriminate between different models.
- ✓ Complementary studies can be performed by the analysis of the exclusive vector meson photoproduction in polarized hadronic collisions and in fixed – target collisions at the LHC.

Thank you for your attention!