Exclusive processes in hadronic collisions at the LHC: Improving our understanding of the Standard Model and opening a portal for New Physics

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Webminar
26 April 2022

Outline

This talk:

- Exclusive top pair production in pp collisions at the LHC
- Double photon and ALP production in pA and AA collisions

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This talk:

- Exclusive top pair production in pp collisions at the LHC

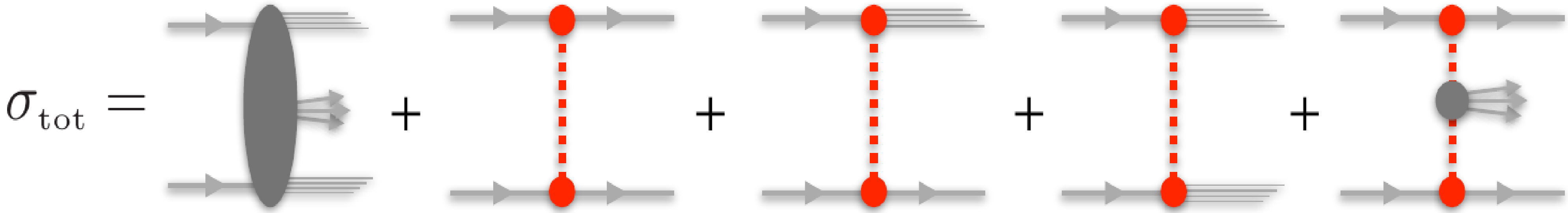
  VPG/Martins/Rangel/Tasevsky – PR D102, 074014 (2020)
  VPG/Martins/Tasevsky – arXiv:2202.01257[hep-ph]

- Double photon and ALP production in pA and AA collisions

  VPG/Martins/Rangel – EPJC81 (2021) 220
  Coelho/VPG/Martins/Rangel – EPJC80 (2020) 488
  Coelho/VPG/Martins/Rangel – PLB806 (2020) 135512

Proton - Proton collisions

$$\sigma_{\text{tot}} = \sigma_{\text{ND}} + \sigma_{\text{elastic}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{CD}}$$



Proton - Proton collisions

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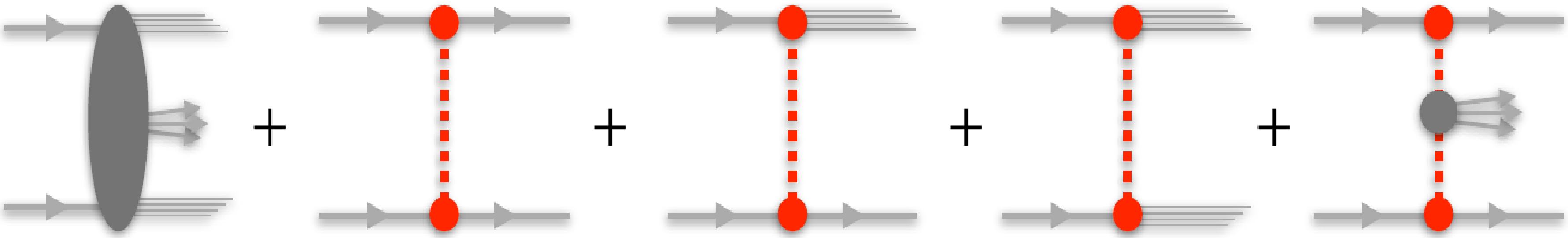
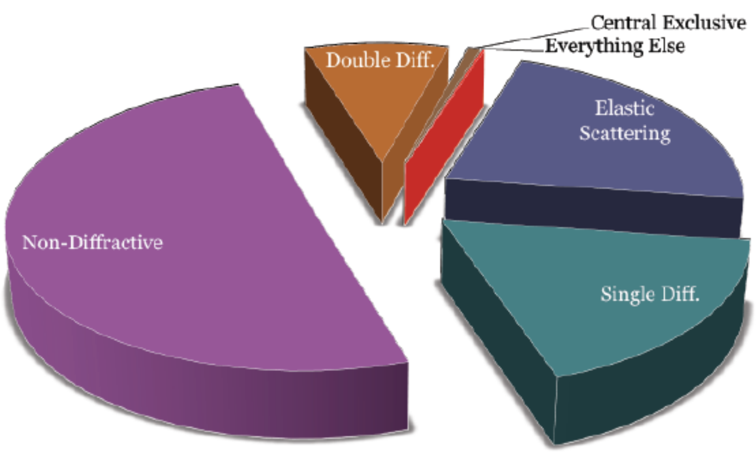
$\sigma_{\text{tot}} =$ 



Proton - Proton collisions

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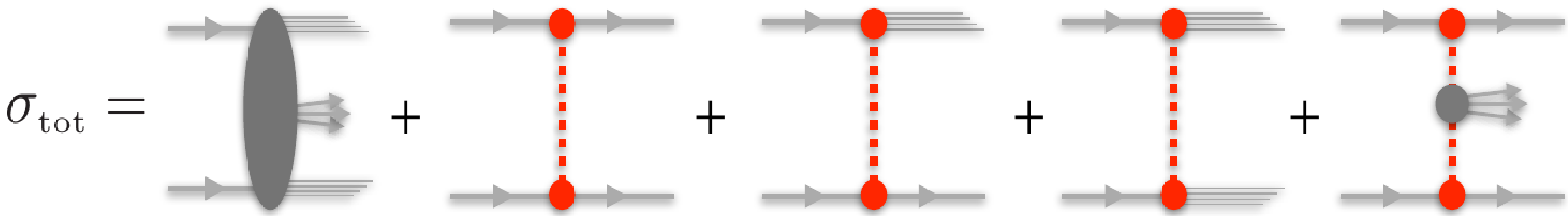
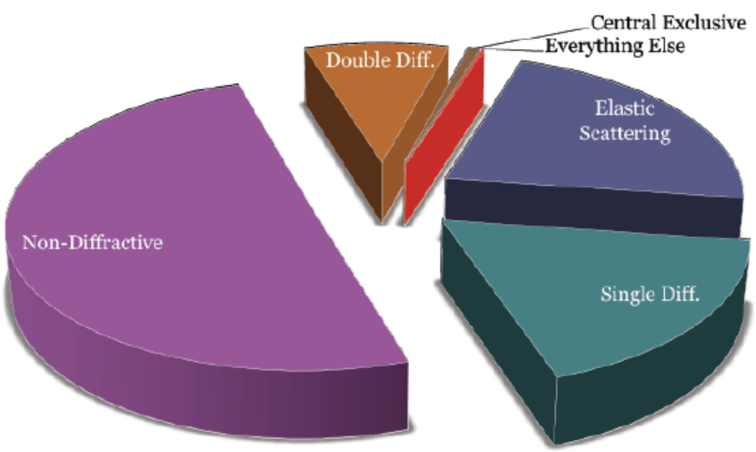




LHC is a:

- Discovery Machine
- QCD machine (QCD is always present!)

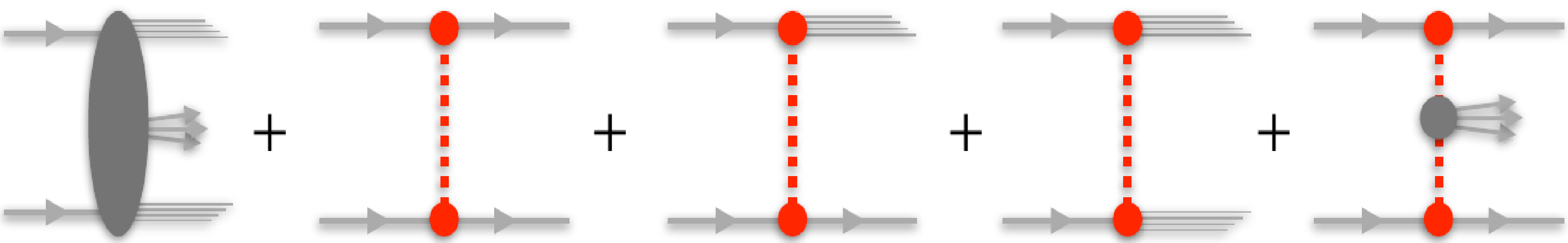
Diffraction is a:

- Vital aspect of QCD
- Place to look for New Physics

Diffractive reactions

- Diffractive reactions at hadron colliders are defined as reactions in which a color singlet object (Pomeron or photon) is exchanged between colliding particles.

$\sigma_{\rm tot} =$



Diffractive reactions

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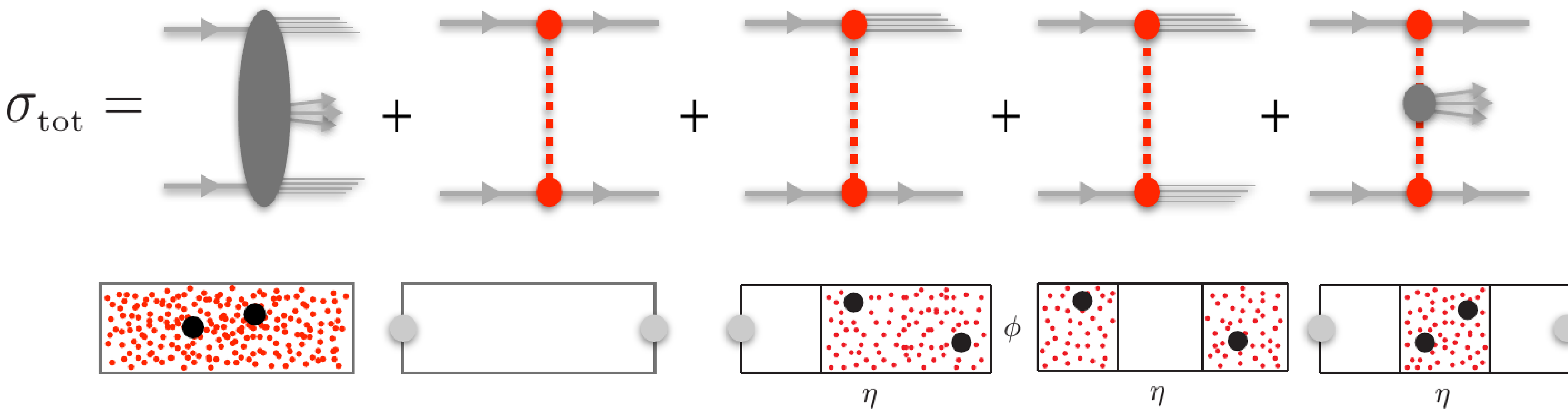
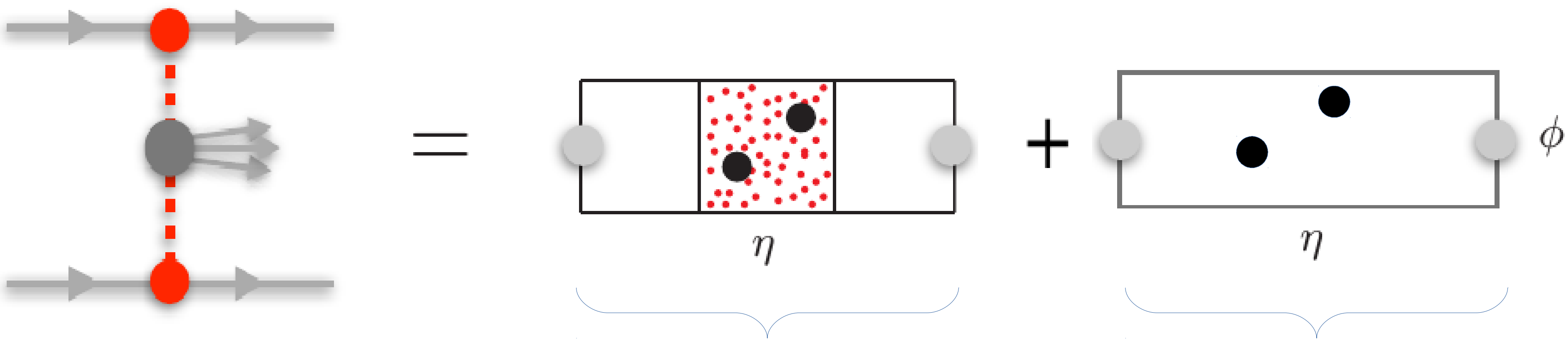


- Identified by the presence of an intact leading particle or a large rapidity gap (LRG).

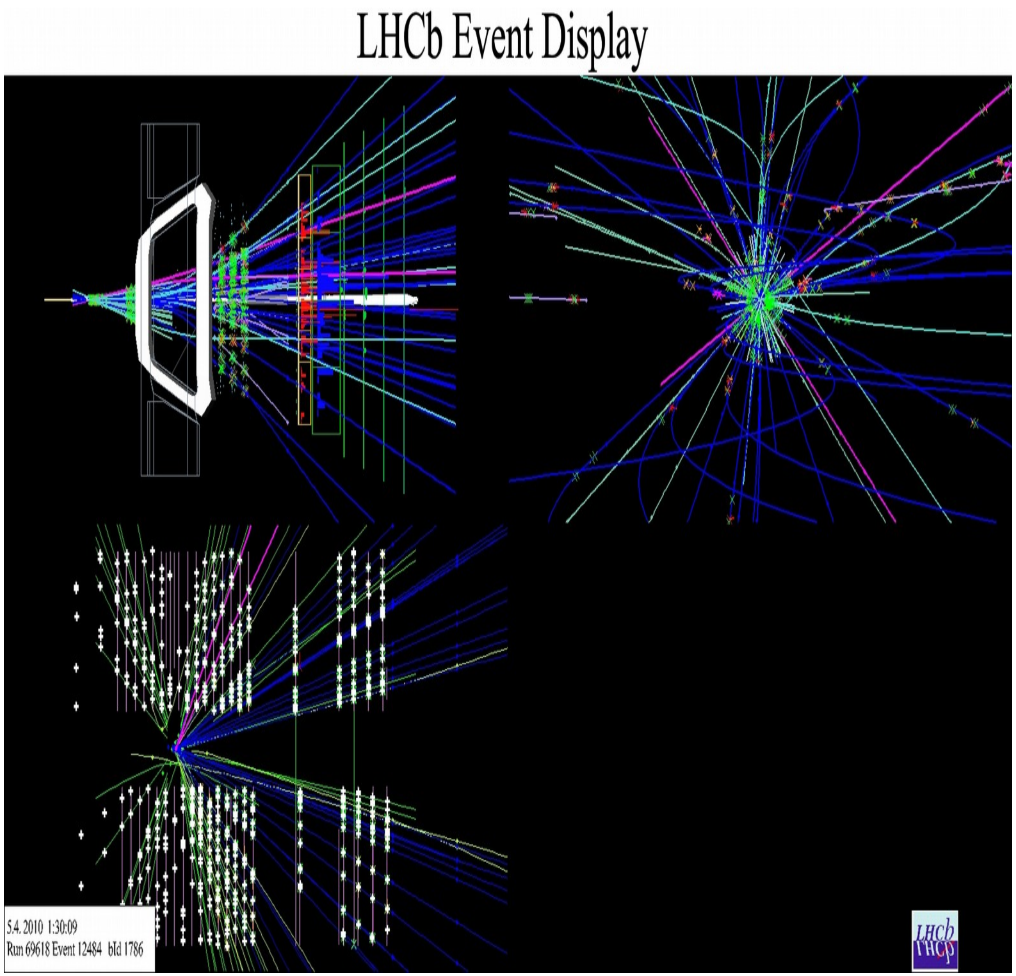
Exclusive processes



- Semiexclusive production
- Exclusive production

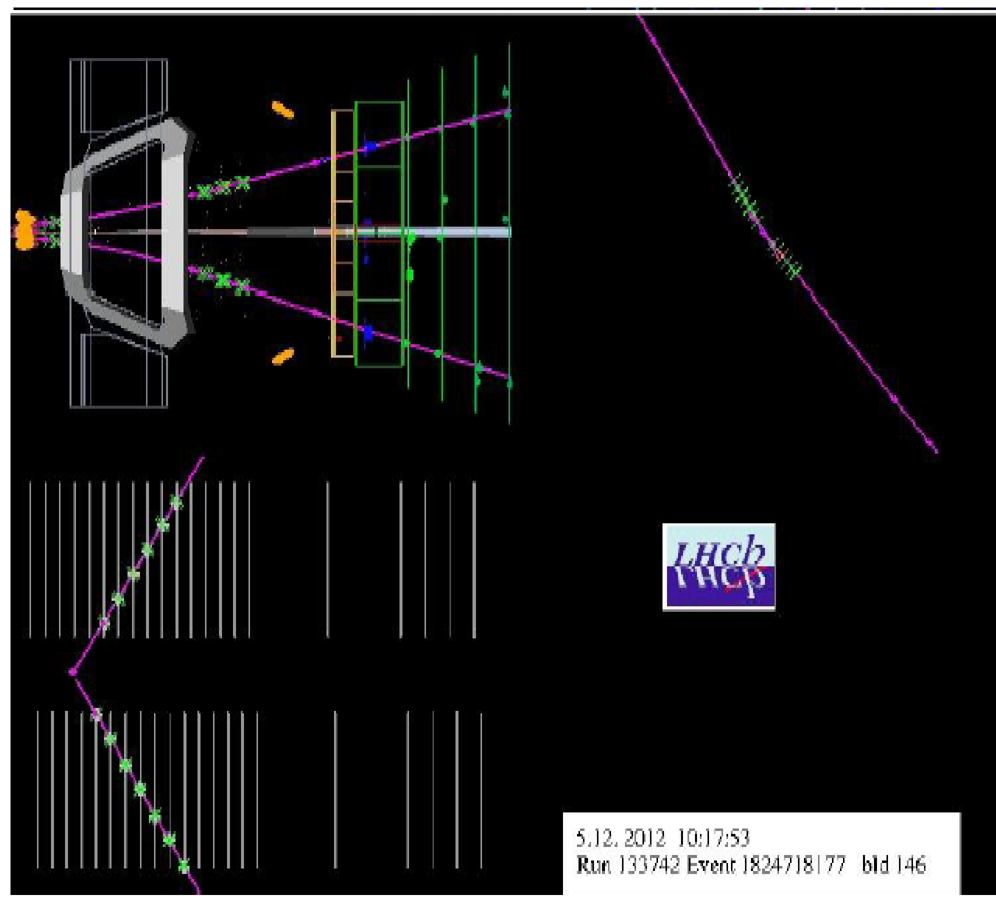
Exclusive processes

- Typical pp events:



Many tracks + high p_T particles

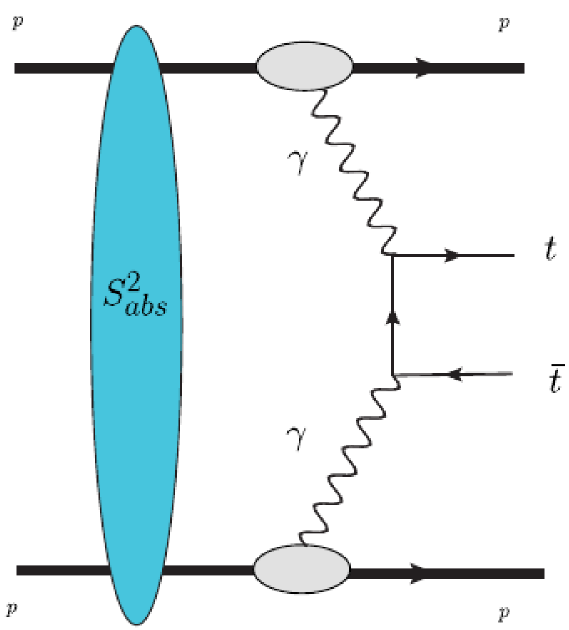
- Exclusive events:



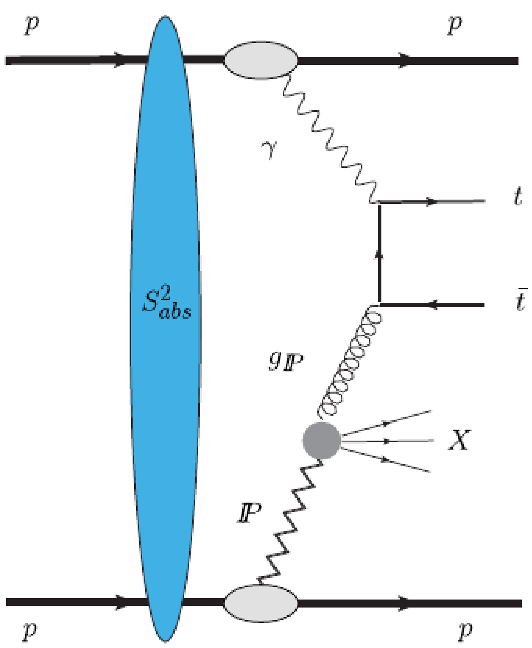
Few tracks + low p_T particles

Top pair production in diffractive and exclusive processes

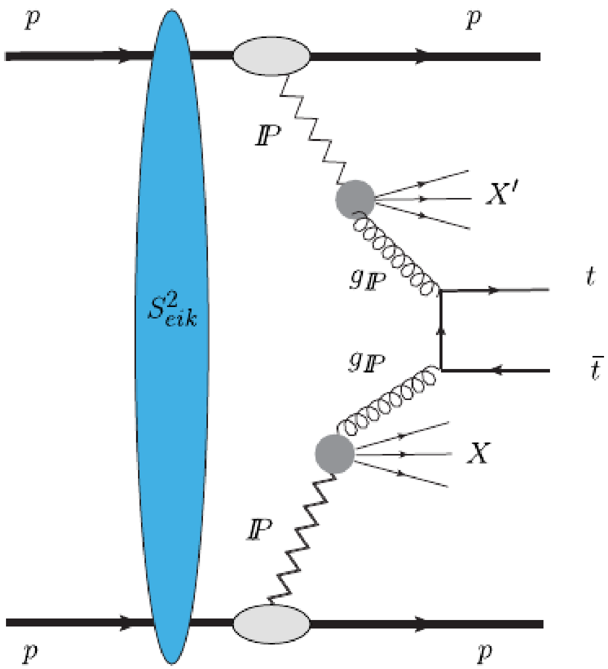
Photon - photon interactions:



Photon - Pomeron interactions:



Pomeron - Pomeron interactions:



Top pair production in diffractive and exclusive processes

❑ First analysis (*):

- Signal:
  - Top pair production in photon – photon, photon – Pomeron and Pomeron – Pomeron interactions.

- Final state: $t\bar{t} \rightarrow jjbl\nu_l\bar{b}$ (Semileptonic decays)

- Backgrounds:
  - Irreducible: $\gamma\mathbb{P} \rightarrow Wt$ and $\gamma\gamma \rightarrow WW$
  - Reducible: Inclusive top pair production + pileup

(*) Goncalves, Martins, Rangel, and Tasevsky, PRD102, 074014 (2020)

Top pair production in diffractive and exclusive processes

❑ Cuts:

TABLE I. Cuts used in this analysis.

Cut
$N_{\text{jet}} \geq 4(E_T > 25\ \text{GeV}, \lvert\eta\rvert < 2.5)$
$N_{e/\mu} \geq 1(E_T > 25\ \text{GeV}, \lvert\eta\rvert < 2.5)$
$\Delta R(\text{e}/\mu, \text{jet}) > 0.2$
$N_{b\text{-jet}} \geq 2$
$0.015 < \xi_{1,2} < 0.15$
$N_{\text{trk}}(p_{\text{T}} > 0.2\ \text{GeV}, \lvert\eta\rvert < 2.5, \lvert\Delta z\rvert < 1\ \text{mm}) \leq X$

- Events:
  - Signal: Forward Physics MC (FPMC)
  - Background: FPMC, Madgraph5, Pythia8
  - Detector effects and pileup mixing: DELPHES

Results:

❑ Zero pileup scenario:

TABLE II. Cut flow for the exclusive signal processes and inclusive background with zero pileup. The values marked as ∼0 correspond to numbers which are sufficiently below 10^{-4}.

Process	$\gamma\gamma$	$\gamma\mathbb{P}$	$\mathbb{P}\mathbb{P}$	Incl. $t\bar{t}$ + PU	$\gamma\gamma \to WW$	$\gamma\mathbb{P} \to Wt$
Generated cross section (fb)	0.34	52.0	28.4	390000	75.6	12.0
$N_{e/\mu} \geq 1(E_T > 25$ GeV, $\|\eta\| < 2.5)$	0.09	14.1	7.4	89991	0.06	2.0
$N_{\text{jet}} \geq 4(E_T > 25$ GeV, $\|\eta\| < 2.5)$	0.02	3.9	2.0	36412	4.7	0.4
$\Delta R(\text{e}/\mu, \text{jet}) > 0.2$	0.02	3.9	2.0	36412	0.003	0.4
$N_{b\text{-jet}} \geq 2$	0.02	3.9	2.0	36412	10^{-4}	0.4
$0.015 < \xi_{1,2} < 0.15$	0.014	2.3	0.74	∼0	∼0	0.1

Results:

❑ Nonzero pileup scenario:

TABLE III. Cut flow for the effective cross sections in femtobarns for the exclusive signal processes and inclusive background with pileup overlaid with $\langle\mu\rangle = 5$, 10, and 50. The effect of the ξ cut for the inclusive background with pileup is evaluated as a combinatorial background coming from the rate of fake double-tagged events. Suppression of pileup effects from using TOF information is based on [38,39].

Process	$\gamma\mathbb{P}(\langle\mu\rangle = 5/10/50)$	$\mathbb{PP}(\langle\mu\rangle = 5/10/50)$	Incl. $t\bar{t}$ + PU$(\langle\mu\rangle = 5/10/50)$
Generated cross section (fb)	52.0	28.4	390000
$N_{e/\mu} \geq 1(E_T > 25$ GeV, $\lvert\eta\rvert < 2.5)$	14.1/14.2/13.4	7.4/7.3/6.7	90057/90042/82994
$N_{\text{jet}} \geq 4(E_T > 25$ GeV, $\lvert\eta\rvert < 2.5)$	4.2/4.4/5.4	2.1/2.2/2.6	38157/38928/42821
$\Delta R(\text{e}/\mu, \text{jet}) > 0.2$	4.2/4.4/5.4	2.1/2.2/2.6	38157/38928/42821
$N_{b\text{-jet}} \geq 2$	4.2/4.4/5.4	2.1/2.2/2.6	38157/38928/42821
$0.015 < \xi_{1,2} < 0.15$	2.4/2.6/3.2	0.8/0.8/1.0	118.2/423.3/10534
$m_{t\bar{t}} < 1000$ GeV, $m_X > 400$ GeV	2.4/2.6/3.1	0.8/0.8/1.0	97.6/349.6/9107
TOF suppression	2.4/2.6/2.4	0.8/0.8/0.8	5.3/20.2/843.2
$N_{\text{trk}} \leq 10$	0.45/0.44/0.14	0.002/0.02/0.02	0.006/0.35/2.7
$N_{\text{trk}} \leq 15$	1.12/1.12/0.60	0.10/0.10/0.10	0.12/1.39/15.4
$N_{\text{trk}} \leq 20$	1.73/1.76/1.20	0.11/0.26/0.25	0.29/3.94/52.8
$N_{\text{trk}} \leq 25$	2.11/2.16/1.80	0.30/0.45/0.44	0.81/7.49/123.9

Top pair production in diffractive and exclusive processes

❑ Second analysis (*):

- Focus:
  - Separation of the individual channels in a high – luminosity LHC environment.

- Final state: $t\bar{t} \rightarrow jjbl\nu_l\bar{b}$ (Semileptonic decays)

- Improvements:

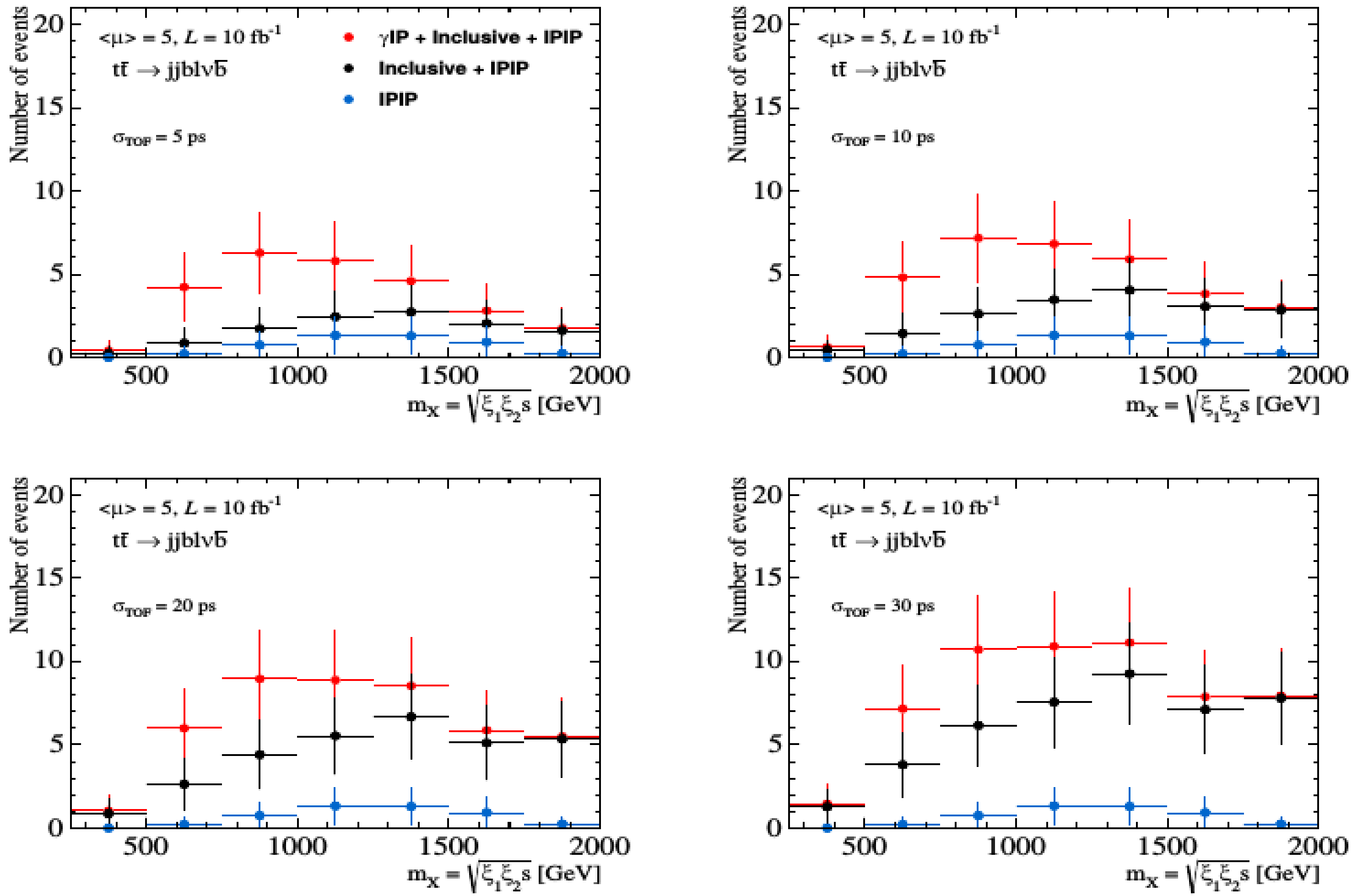
  – Inclusion of H.L scenario with pileup (<mu> = 200);

  – Up-to-date delphes detector card for low and high luminosity;

  – Study of each channel in different ToF resolutions

(*) Goncalves, Martins, and Tasevsky, arXiv: 2202.01257

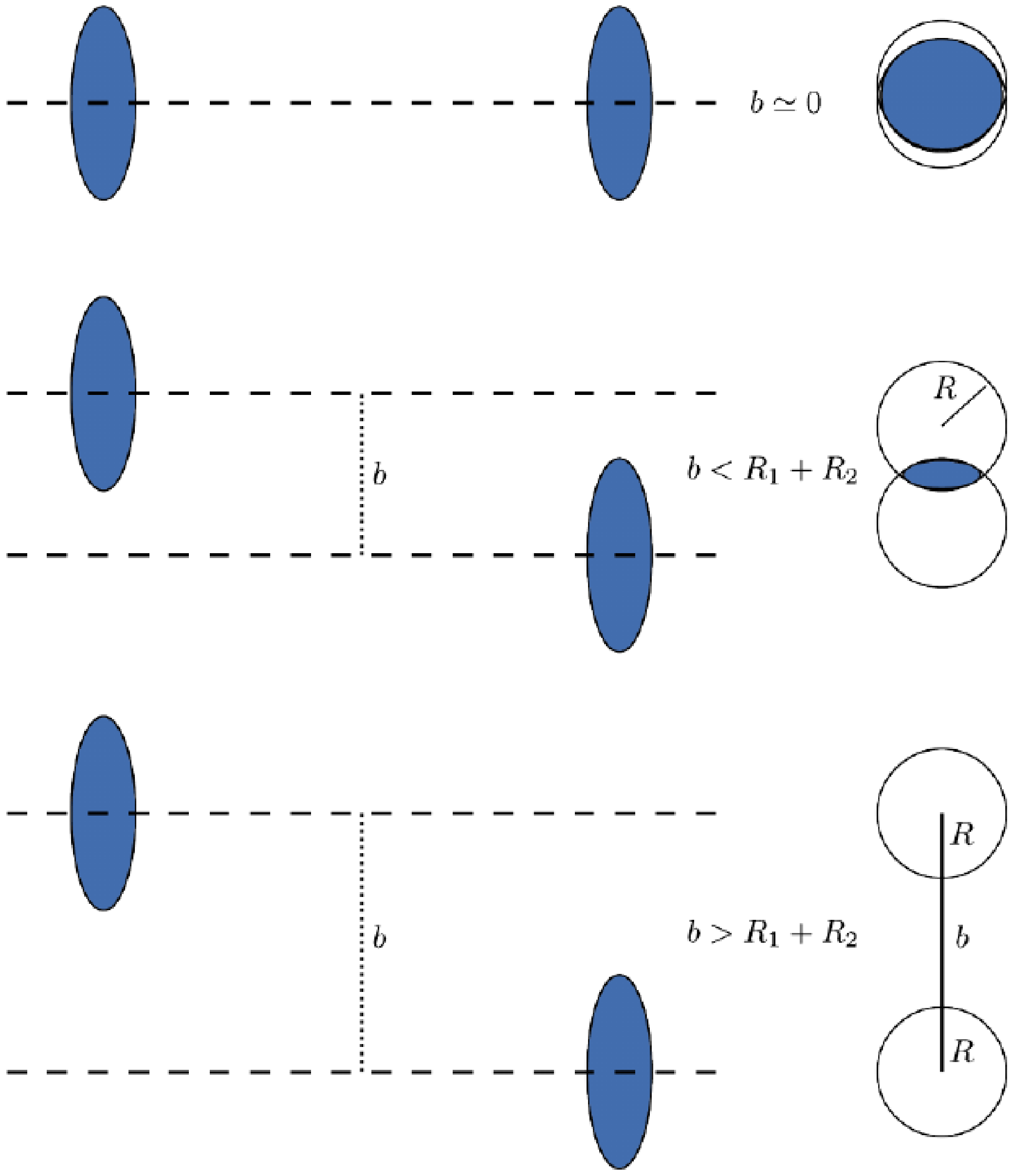
Results:



Main conclusions:

- Photon – pomeron interactions can be separated;
- Elastic top pair production can be discovered at the LHC.

Nuclear collisions

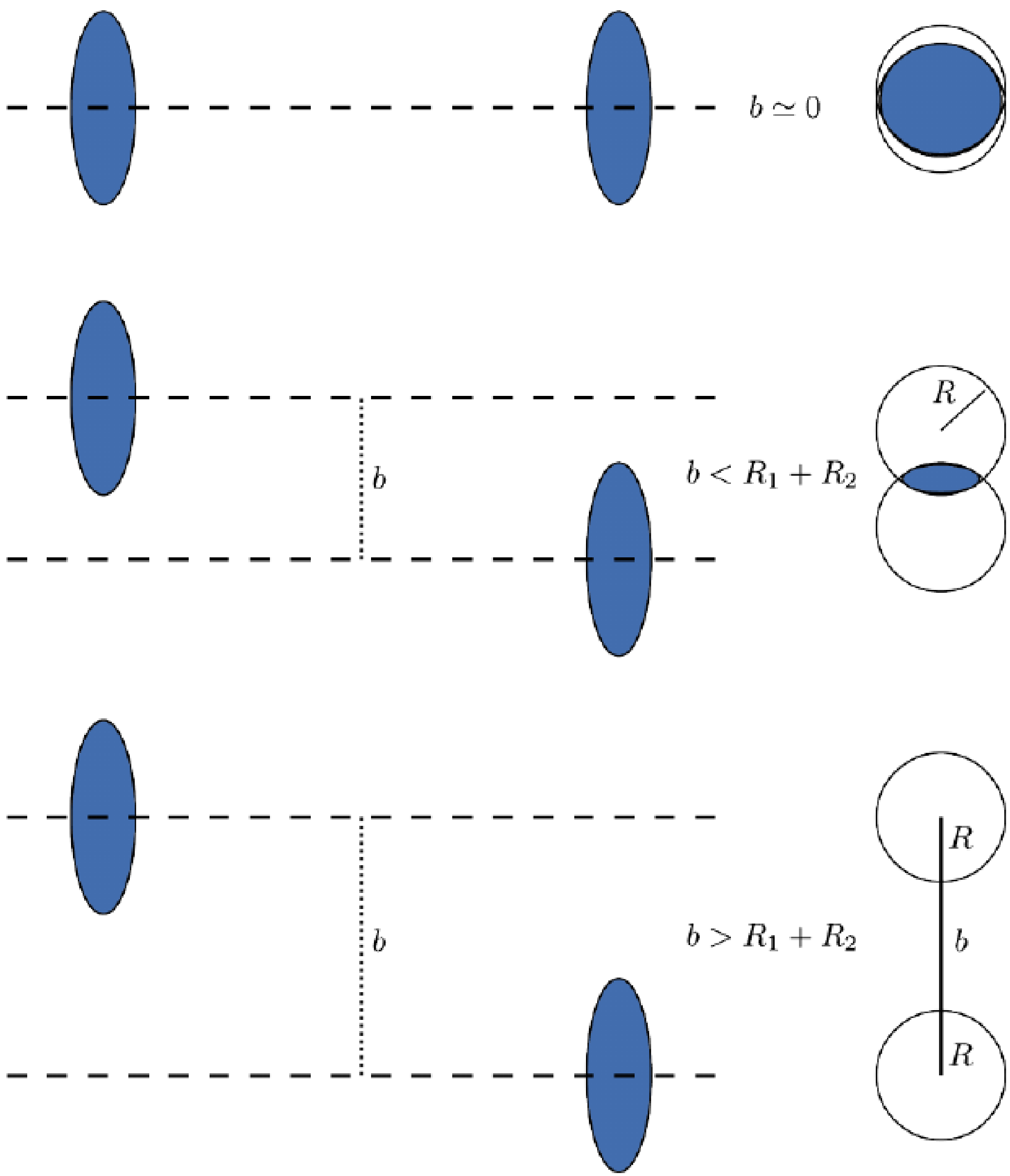


Central Collisions

Peripheral Collisions

Ultraperipheral Collisions

Nuclear collisions



Central Collisions

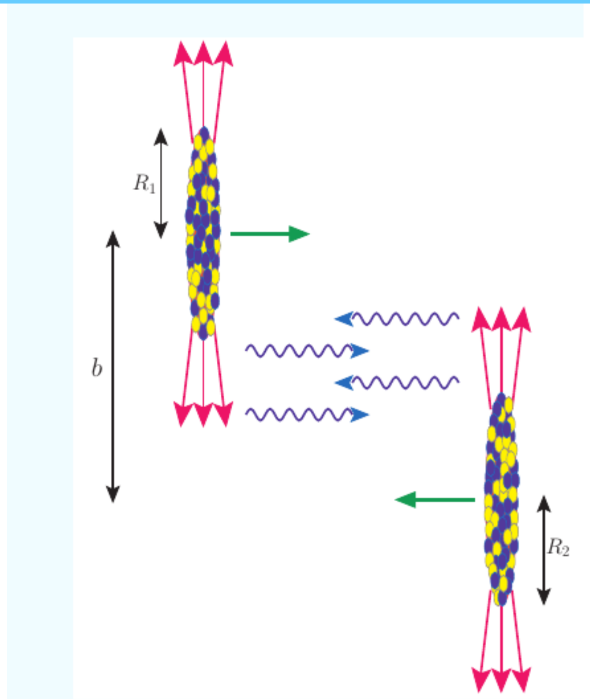
Peripheral Collisions

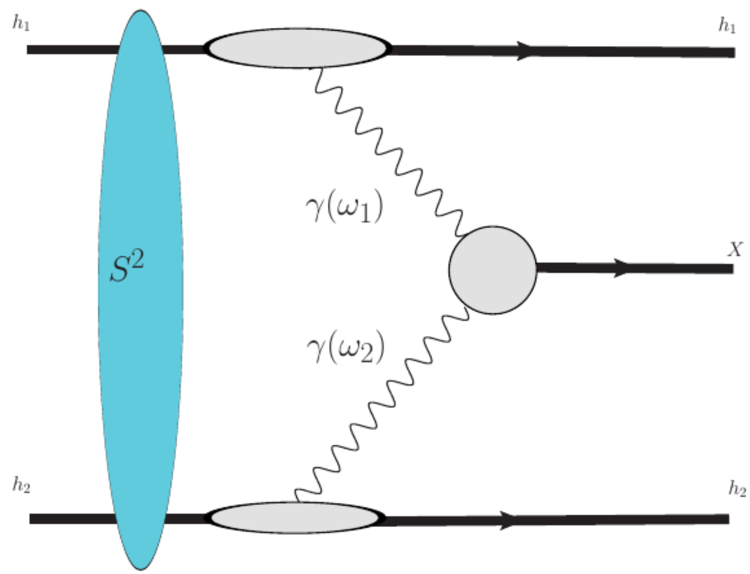
Dominated by strong interactions

Ultraperipheral Collisions

Dominated by electromagnetic interactions

LHC as a photon collider





$$\sigma(h_1 h_2 \to h_1 \otimes X \otimes h_2) = \int \hat{\sigma}(\gamma\gamma \to X, W) S^2_{abs}(\mathbf{b}) \times N(\omega_1, \mathbf{r}_1) N(\omega_2, \mathbf{r}_2) d^2\mathbf{r}_1 d^2\mathbf{r}_2 d\omega_1 d\omega_2 .$$

System	$\sqrt{s_{NN}}$ (TeV)	γ	R_A (fm)	ω_{max} (GeV)	$\sqrt{s_{\gamma\gamma}^{max}}$ (GeV)
p-p	14	7455	0.7	2450	4500
p-Pb	8.8	4690	7.1	130	260
Pb-Pb	5.5	2930	7.1	80	160

Light - by - Light Scattering

Eur. Phys. J. C (2020) 80:488
https://doi.org/10.1140/epjc/s10052-020-8006-7

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

Exclusive and diffractive $\gamma\gamma$ production in $PbPb$ collisions at the LHC, HE-LHC and FCC

R. O. Coelho[1,a], V. P. Gonçalves[1,b], D. E. Martins[2,c], M. Rangel[2,d]

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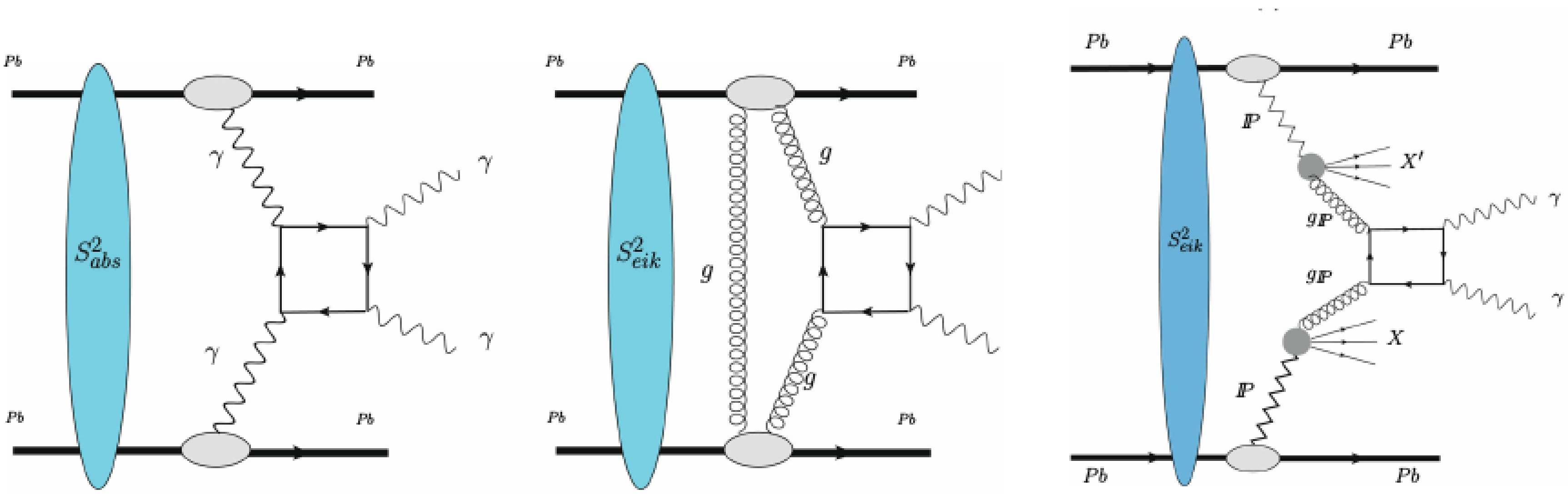

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THE EUROPEAN PHYSICAL JOURNAL C

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Table 1 Predictions for the diphoton production cross sections in $PbPb$ collisions at LHC, HE-LHC and FCC. The results in the parenthesis are the predictions after the inclusion of soft survival factor S^2_{eik}

Process	$\sqrt{s}$ (TeV)	$\sigma[Pb\,Pb \to Pb + \gamma\gamma + Pb]$
LbL	5.5	1.8×10^4 nb
	10.6	2.7×10^4 nb
	39	5.2×10^4 nb
Durham	5.5	4.9×10^6 nb (0.280 nb)
	10.6	9.8×10^6 nb (0.570 nb)
	39	3.8×10^7 nb (0.980 nb)
DDP	5.5	5.2×10^5 nb (17.7 nb)
	10.6	9.7×10^5 nb (22.3 nb)
	39	3.0×10^6 nb (30.0 nb)

	LbL	Durham	DDP
$PbPb$ collisions at $\sqrt{s} = 5.5$ TeV			
Total cross section [nb]	18000.0	0.28	17.7
$m_X > 1$ GeV, $p_T(\gamma,\gamma) > 0.2$ GeV	13559.0	0.24	17.6
$1 - (\Delta\phi/\pi) < 0.01$	8834.0	0.09	0.2
$p_T(\gamma\gamma) < 0.1$ GeV	8826.0	0.08	0.0
$2.0 < \eta(\gamma,\gamma) < 4.5$ and 0 extra tracks	616.0	0.006	0.0

ALP production

Physics Letters B 806 (2020) 135512

Contents lists available at ScienceDirect

Physics Letters B

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Production of axionlike particles in $PbPb$ collisions at the LHC, HE–LHC and FCC: A phenomenological analysis

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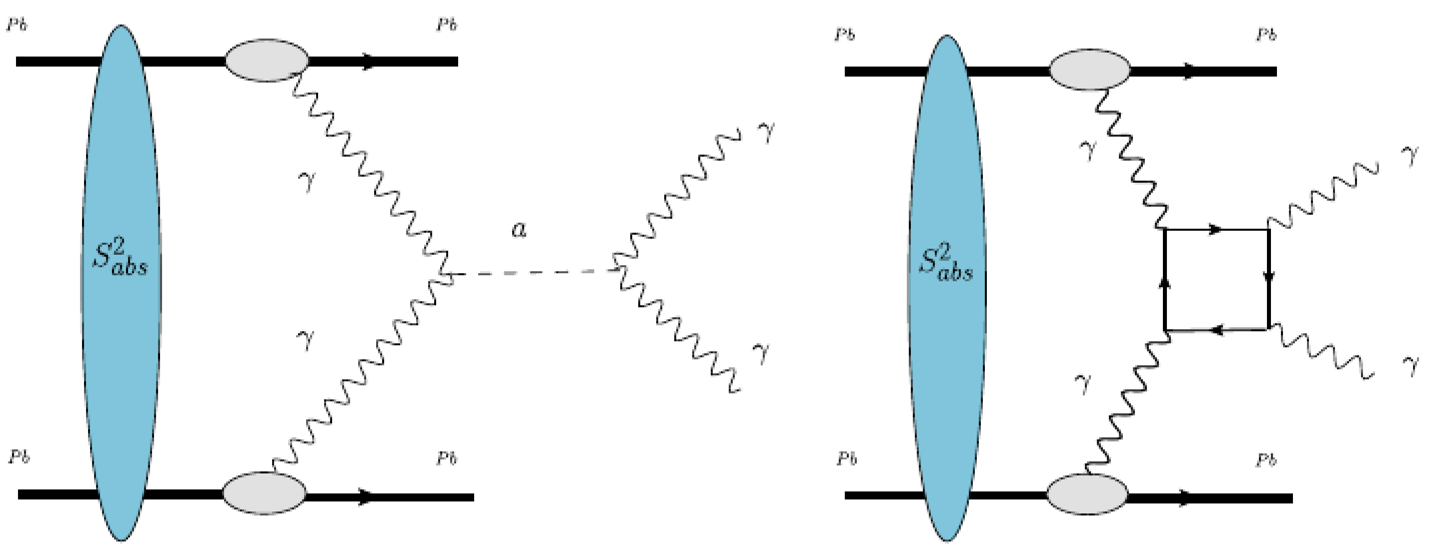
$$\mathcal{L} = \frac{1}{2}\partial^{\mu}a\partial_{\mu}a - \frac{1}{2}m_a^2a^2 - \frac{1}{4}g_a a F^{\mu\nu}\tilde{F}_{\mu\nu}$$



ALP production

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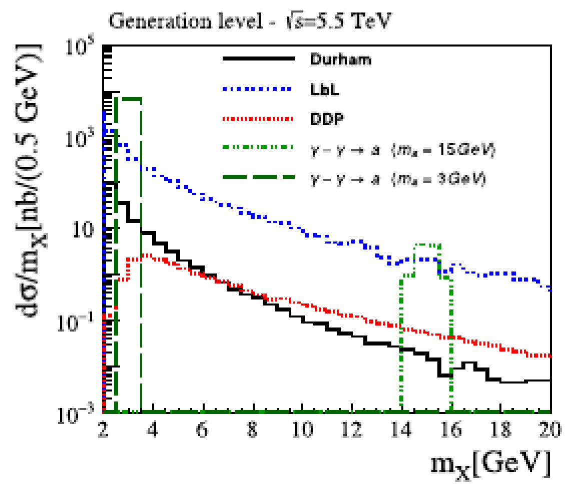

	LbL	Durham	DDP	$m_a = 3$ GeV	$m_a = 5$ GeV	$m_a = 15$ GeV	$m_a = 40$ GeV
PbPb at $\sqrt{s_{NN}}$ = 5.5 TeV							
Total Cross section [nb]	18000.0	167.0	17.7	13000.0	363.0	11.0	13.0
$m_X > 1$ GeV, $p_T(\gamma,\gamma) > 0.2$ GeV	13559.0	142.0	17.6	12873.0	360.0	11.0	13.0
$1-(\Delta\phi/\pi) < 0.01$	8834.0	51.0	0.2	11033.0	335.0	11.0	13.0
$p_T(\gamma\gamma) < 0.1$ GeV	8826.0	47.0	0.0	11019.0	334.7	10.8	13.0
$2.0 < \eta(\gamma,\gamma) < 4.5$	616.0	3.7	0.0	974.0	23.4	0.2	0.02
$2 < m(\gamma\gamma) < 4$	83.7	3.2	0.0	974.0	–	–	–
$5 < m(\gamma\gamma) < 7$	32.0	1.0	0.0	–	23.4	–	–
$13 < m(\gamma\gamma) < 17$	0.0	0.0	0.0	–	–	0.2	–
$38 < m(\gamma\gamma) < 42$	0.0	0.0	0.0	–	–	–	0.02

ALP production

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THE EUROPEAN PHYSICAL JOURNAL C

Letter

Searching for axionlike particles with low masses in pPb and $PbPb$ collisions

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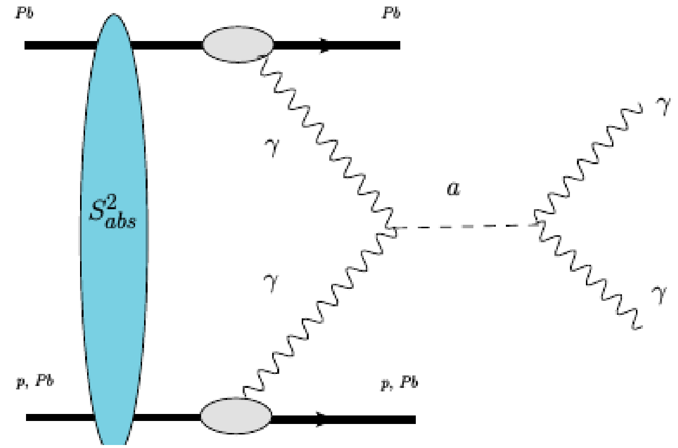

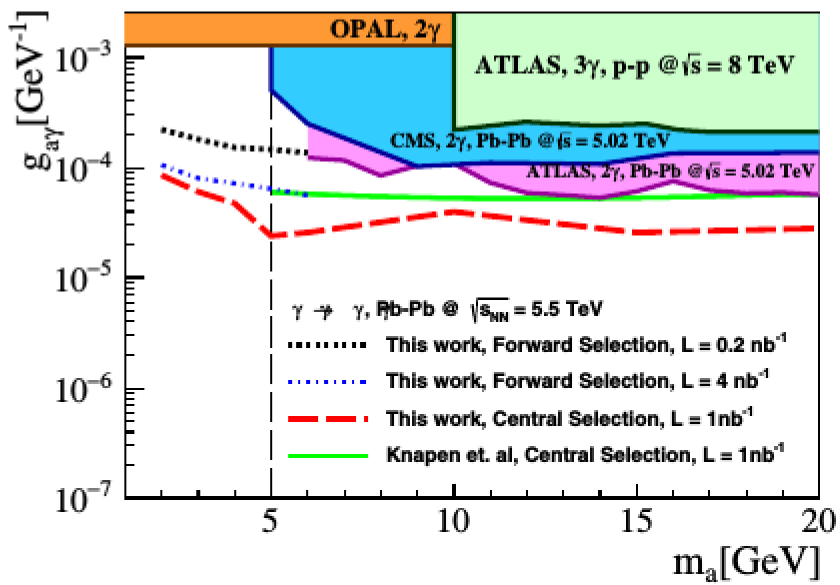

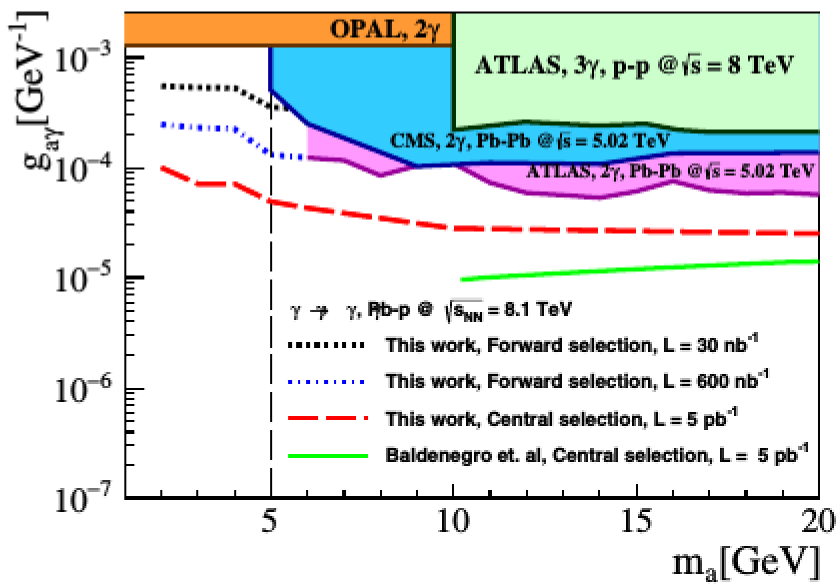

Summary

* The LHC is the world´s most powerful collider not only for protons but also for photon - photon and photon - hadron collisions;

* The study of exclusive processes in photon and pomeron induced interactions at LHC can be useful to probe the top pair production as well to search for signals of BSM physics in this final state;

* Good prospects for searching New Physics in Ultraperipheral collisions.

Summary

* The LHC is the world´s most powerful collider not only for protons but also for photon – photon and photon – hadron collisions;

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Thank you for your attention !