Discussion session:

UPC in fixed target mode at the LHC

Fixed target experiments at LHC - Strong2020 workshop

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Aussois, Friday 6th January 2023

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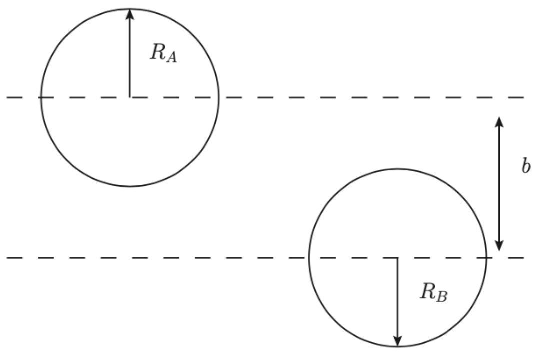
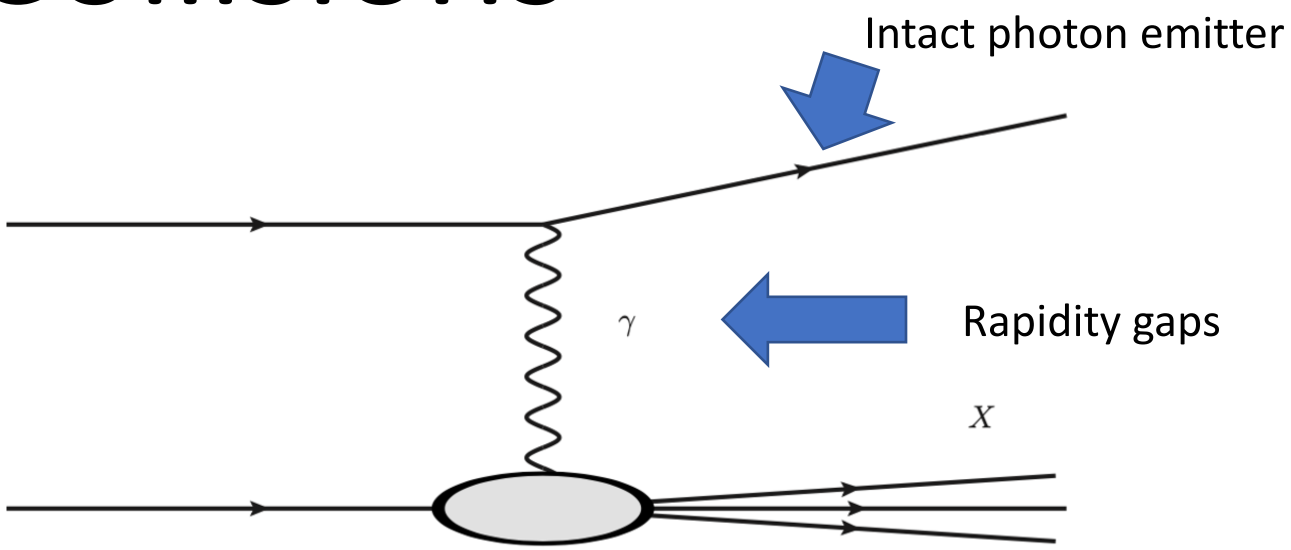
Ultra-peripheral Collisions





- $b > R_A + R_B$
- Photon induced
- Fewer particles produced than in hadronic interactions
- Rapidity gaps
- Photon emitter can remain **intact**
  - $E_{\gamma}^{\max} \approx \frac{\hbar c}{b_{min}}$

LHC UPC results …

Collider Mode

- Exclusive vector meson production

Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}} = 5$ TeV

LHCb collaboration[†]

- Dijet production

Photo-nuclear jet production in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector

The ATLAS Collaboration

- Light-by-light scattering

Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb^{-1} of Pb+Pb data with the ATLAS detector

The ATLAS Collaboration

Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

The CMS Collaboration[*]

Fixed target mode

None!

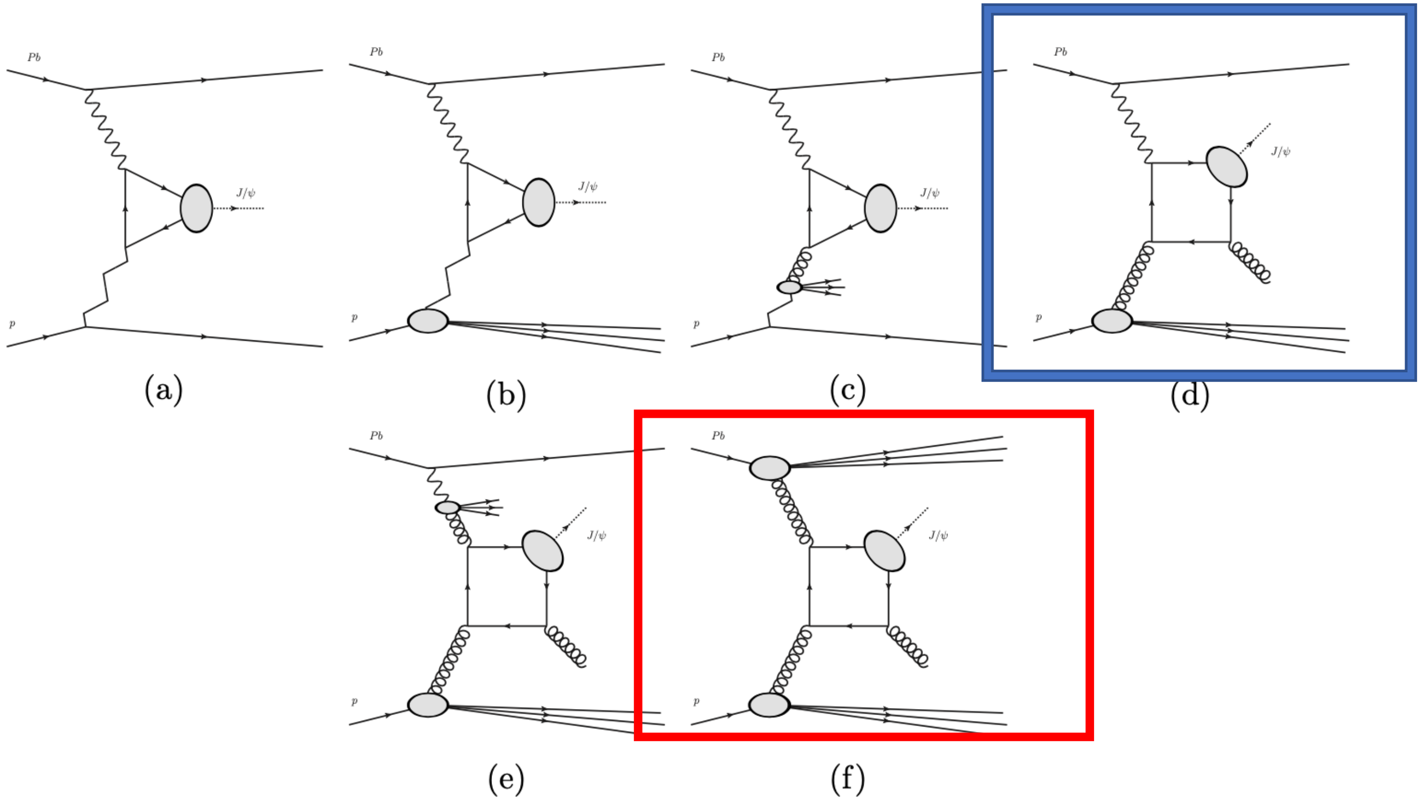
Attempt…

Dimuon Production

"In-In Ultra Peripheral Collisions in NA60", P.Ramalhete (PhD) 2009

No signal!

UPC tagging in collider mode – inclusive quarkonium production



Hadronic cross section greater than photoproduction cross section

Must impose experimental cuts to isolate the signal

	diffractive		γg-fusion		background
	exclusive (p break-up)	resolved-Pomeron	direct-photon	resolved-photon	gg fusion
J/ψ	67 μb (134 μb)	2 μb (4 μb)	52 μb	8 μb	642 μb
Υ	104 nb (208 nb)	5 nb (10 nb)	108 nb	54 nb	95 μb

cross section in full acceptance

work in preparation

UPC tagging in collider mode – inclusive quarkonium production

LHCb	CMS typical	CMS low p_T
$2 < y^\psi < 4.5$	$\lvert y^\psi \rvert < 2.1$	$1.2 > \lvert y^\psi \rvert,\ p_T^\psi > 6.5$
$p_T^\mu > 0.4$	$p_T^\psi > 6.5$	$1.2 < \lvert y^\psi \rvert < 1.6,\ p_T^\psi > 2$
		$1.6 < \lvert y^\psi \rvert < 2.4,\ p_T^\psi > 0$

- LHCb Ap: $\mathcal{L}= 17.4\ \mathrm{nb}^-1$
- LHCb pA: $\mathcal{L}= 12.5\ \mathrm{nb}^-1$
- CMS: $\mathcal{L}= 180\ \mathrm{nb}^-1$

	Background	Signal	$\frac{background}{signal}$
Cross section	38330 ± 12 nb	3154 ± 27 nb	~ 12
LHCb *Pbp*	1,600	49,200	~ 30
HeRSCheL	1,600	975	0.6
$\sum \Delta\eta_\gamma < 2.5$	1,600	1,100	0.7
HeRSCheL $+\sum \Delta\eta_\gamma < 2.5$	1,600	22	0.01
LHCb *pPb*	5,800	48,000	~ 8
HeRSCheL	5,800	920	0.15
$\sum \Delta\eta_\gamma < 1.5$	3,500	12,700	3.4
HeRSCheL $+\sum \Delta\eta_\gamma < 1.5$	3,500	240	0.04
CMS low p_T	36,700	436,000	~ 12
ZDC	36,700	1,090	0.03
$\sum \Delta\eta_\gamma < 4.5$	34,900	100,500	2.9
ZDC $+\sum \Delta\eta_\gamma < 4.5$	34,900	250	0.007

- Combination of **rapidity gap cuts** and cuts based on the **far-forward detectors** show **inclusive quarkonium photoproduction** can be measured in LHCb and CMS

work in preparation

Collider mode vs. fixed target mode

Ann.Rev.Nucl.Part.Sci. 70 (2020) 323-354

Facility	System	$\sqrt{s_{NN}}$ or $\sqrt{s_{eN}}$	Max. E_γ	Max. $W_{\gamma p}$	Max $\sqrt{s_{\gamma\gamma}}$
RHIC	AuAu	200 GeV	320 GeV	25 GeV	6 GeV
	pAu	200 GeV	1.5 TeV	52 GeV	30 GeV
	pp	500 GeV	20 TeV	200 GeV	150 GeV
LHC (17)	PbPb	5.1 TeV	250 TeV	700 GeV	170 GeV
	pPb	8.16 TeV	1.1 PeV	1.5 TeV	840 GeV
	pp	14 TeV	16 PeV	5.4 TeV	4.2 TeV
FCC-hh (18)	PbPb	40 TeV	13 PeV	4.9 TeV	1.2 TeV
SPPC (7)	pPb	57 TeV	58 PeV	10 TeV	6.0 TeV
	pp	100 TeV	800 PeV	39 TeV	30 TeV
eRHIC (19)	eAu	89 GeV	4.0 TeV	89 GeV	15 GeV
LHeC (20)	ePb	820 GeV	360 TeV	820 GeV	146 GeV

In fixed target mode…

- Polarised targets (spin studies)
- Probe large x region (cannot be measured in collider mode)
- Large luminosity (dense target)
- Different target species
- Lower center-of-mass energy

Physics Objectives:

1. Explore large x region
2. QGP studies
3. Spin structure of nucleon

- $\sqrt{s_{\gamma N}^{max.}} = \sqrt{2m_N E_\gamma^{max.}}$
- $E_\gamma^{max.} = \left[\gamma_{lab}^{beam} \approx \frac{s_{NN}}{2m_N^2}\right]\left[\frac{1}{R_N+R_N}\right]$
- $x_\gamma^{max.} = \frac{s_{\gamma N}^{max.}}{s_{NN}}$

- $\left[\frac{1}{R_p+R_p} \approx 140\ MeV\right]$ $x_\gamma^{max.} \approx 0.12$
- $\left[\frac{1}{R_p+R_{Pb}} \approx 30\ MeV\right]$ $x_\gamma^{max.} \approx 0.02$ Larger Charge Radius !

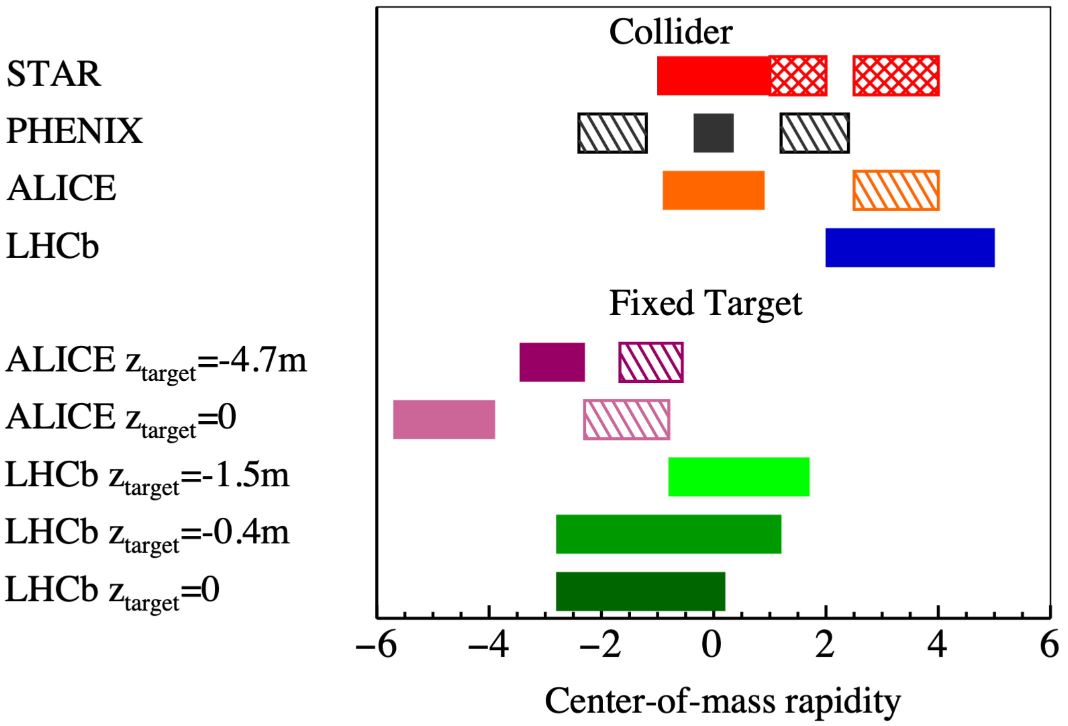
System	target thickness (cm)	$\sqrt{s_{NN}}$ (GeV)	$\mathcal{L}_{AB}$ [2] ($pb^{-1}yr^{-1}$)	E_A^{lab} (GeV)	E_B^{lab} (GeV)	γ^{cms} $\left(\frac{\sqrt{s_{NN}}}{2m_N}\right)$	$\gamma^{A\leftrightarrow B}$ $\left(\frac{s_{NN}}{2m_N^2}\right)$	$\frac{\hbar c}{R_A+R_B}$ (MeV)	$E_{\gamma\ max}^{A/B\ rest}$ (GeV)	$\sqrt{s_{\gamma N}^{max}}$ (GeV)	$E_{\gamma\ max}^{cms}$ (GeV)	$\sqrt{s_{\gamma\gamma}^{max}}$ (GeV)
AFTER@LHC												
pp	100	115	2.0×10^4	7000	m_N	61.0	7450	141	1050	44	8.6	17
pPb	1	115	160	7000	m_N	61.0	7450	25.3	188	19	1.5	3.1
pd	100	115	2.4×10^4	7000	m_N	61.0	7450	69.5	517	31	4.2	8.5
PbPb	1	72	$7. \times 10^{-3}$	2760	m_N	38.3	2940	13.9	40.7	8.8	0.53	1.1
Pbp	100	72	1.1	2760	m_N	38.3	2940	25.3	74.2	12	0.97	1.9
Arp	100	77	1.1	3150	m_N	40.9	3350	41.1	138	16	1.7	3.4
Op	100	81	1.1	3500	m_N	43.1	3720	53.0	197	19	2.3	4.6
RHIC												
pp	n/ap	200	12	100	100	106	22600	141	3190	77	15	30
AuAu	n/ap	200	2.8×10^{-3}	100	100	106	22600	14.2	320	25	1.5	3.0
SPS												
InIn	n/av	17	n/av	160	m_N	9.23	170	16.9	2.87	2.4	0.16	0.31
PbPb	n/av	17	n/av	160	m_N	9.23	170	13.9	2.36	2.1	0.13	0.26

JHEP 09 (2015) 087

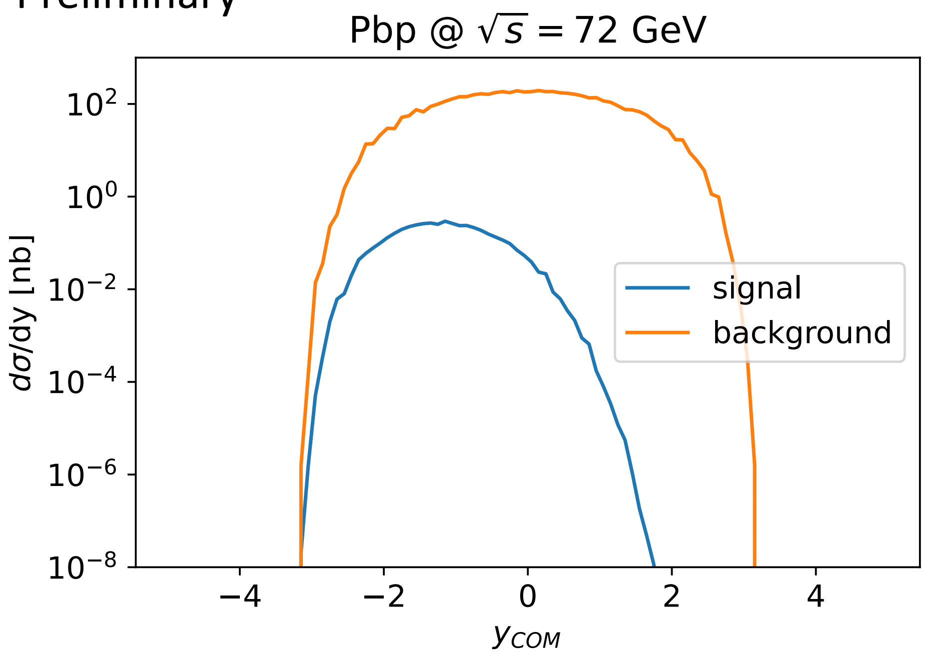
Fixed Target -inclusive quarkonium production

Nucl.Phys.A 982 (2019) 971-974

beam	$\sqrt{s}$	y_{cms}
Pb	72 GeV	-4.3
p	115 GeV	-4.8



Preliminary



Pbp @ $\sqrt{s}$ = 72 GeV	σ
Signal ($\gamma + g \rightarrow J/\psi + g$)	4.2 nb
Background ($g + g \rightarrow J/\psi + g$)	4900 nb
Ratio	0.001

calculated at LO in CSM using HELAC-Onia;
in full acceptance with decay to dimuons

Questions:
1. What is the target position ?
2. What is the kinematic acceptance ?

BACK-UP MATERIAL

UPC in the fixed target mode

- $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
- $E_\gamma^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/(R_{\rm Pb}+R_p) \simeq 30$ MeV)
- $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
- No pile-up

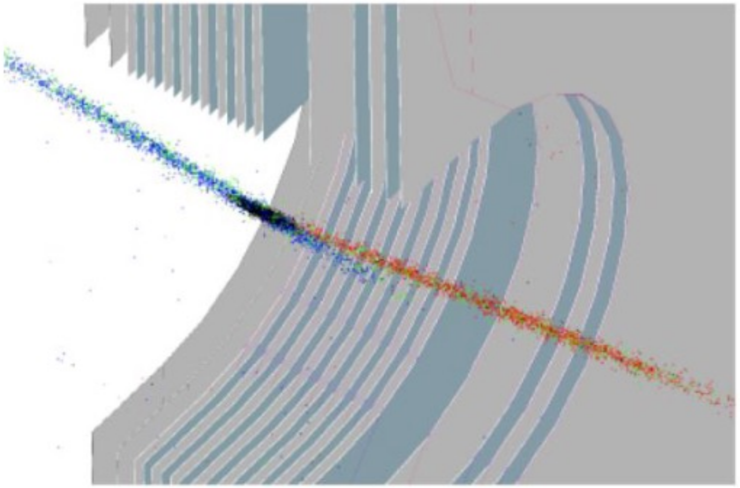
System	target thickness (cm)	$\sqrt{s_{NN}}$ (GeV)	$\mathcal{L}_{AB}$ [a] ($\rm pb^{-1}yr^{-1}$)	$E_A^{\rm lab}$ (GeV)	$E_B^{\rm lab}$ (GeV)	$\gamma^{\rm c.m.s.}$ $(\frac{\sqrt{s_{NN}}}{2m_N})$	$\gamma^{A\leftrightarrow B}$ $(\frac{s_{NN}}{2m_N^2})$	$\frac{\hbar c}{R_A+R_B}$ (MeV)	$E_{\gamma\ \max}^{A/B\ \rm rest}$ (GeV)	$\sqrt{s_{\gamma N}^{\max}}$ (GeV)	$E_{\gamma\ \max}^{\rm c.m.s.}$ (GeV)	$\sqrt{s_{\gamma\gamma}^{\max}}$ (GeV)
AFTER												
pp	100	115	2.0×10^4	7000	m_N	61.2	7450	140	1050	44	8.5	17
pPb	1	115	1.6×10^2	7000	m_N	61.2	7450	26	190	19	1.6	3.2
pd	100	115	2.4×10^4	7000	m_N	61.2	7450	70	520	31	4.3	8.5
PbPb	1	72	$7.\times10^{-3}$	2760	m_N	38.3	2940	14	40	9	0.5	1.0
Pbp	100	72	1.1	2760	m_N	38.3	2940	26	76	12	1.6	3.2
Arp	100	77	1.1	3150	m_N	40.9	3350	41	140	16	2.5	5.0
Op	100	81	1.1	3500	m_N	43.1	3720	52	190	19	3.2	6.3
RHIC												
pp	N/A	200	1.2×10^1	100	100	106.4	22600	140	3150	77	15	30
AuAu	N/A	200	2.8×10^{-3}	100	100	106.4	22600	14	320	24	1.5	3.0
SPS												
InIn	.	17	.	160	m_N	9.22	170	17	2.9	2.5	0.15	0.31
PbPb	.	17	.	160	m_N	9.22	170	14	2.4	2.1	0.13	0.26

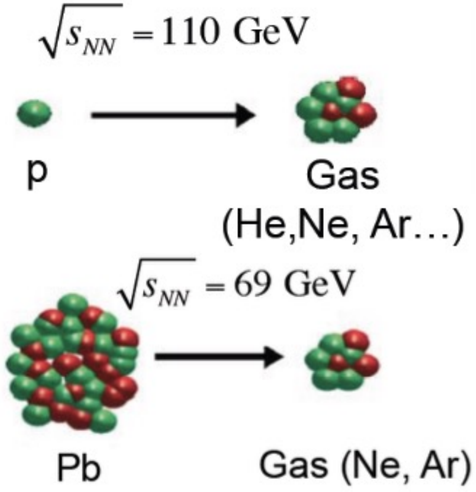
[a] For Arp and Op luminosity with AFTER, we conservatively assumed the same extracted flux of Ar and O as for Pb, *i.e.* 2×10^5 Pb/s.

Attempt at CERN-SPS: “In-In Ultra Peripheral Collisions in NA60” by P. Ramalhete (PhD), 2009

http://after.in2p3.fr/after/images/5/5b/UPC-CERN_2014_JPL.pdf

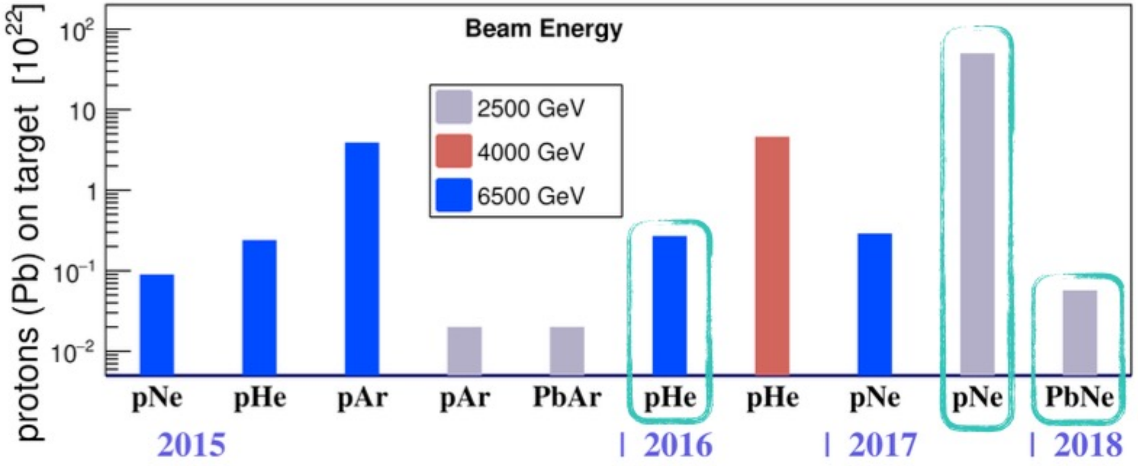
Fixed-target programme at LHCb: SMOG





- Fixed-target measurements at LHCb are possible thanks to the **SMOG device** (System for Measuring the Overlap with Gas)
- **Injection of noble gases** at a pressure of $O(10^{-7})$ mbar in the VELO
- Conceived for precise **luminosity measurements** based on the beam-imaging technique

- Rich and unique **fixed-target research programme** became possible during the LHC Run 2
- **Dedicated SMOG runs** at LHCb, exploiting only the LHC non-colliding bunches
- Previous SMOG results: first measurements of charm production in pNe and measurements of antiproton production in pHe



Slide from Shinichi Okamura.

Screening effects in electron–positron pair production with capture in ultrarelativistic collisions

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Abstract

We study the influence of the shielding of the atomic nucleus by atomic electrons on positron–electron pair production with capture in ultrarelativistic nucleus-atom collisions. The importance of the shielding is shown to increase with the collision energy and with the atomic number of the target atom. We report calculations of cross sections for the pair production with capture in collisions of 160 GeV/nucleon Pb^{82+} projectiles with different atomic targets ranging from Be to Au. Depending on the atomic number of the target the shielding is shown to reduce the cross sections by 2.5–14 percent at this collision energy.

	Mass	Resolution
e^+e^-	1 MeV	200 fm
J/ψ	3 GeV	0.1 fm
Higgs	125 GeV	0.001 fm
Top	171 GeV	0.001 fm

proton	1 fm
atom	100000 fm

- In nucleus-atom collisions screening is found to reduce the cross section for electron-positron pair production by 2.5-14%
- For higher energy (~GeV) processes this effect will be minimised

- https://link.springer.com/content/pdf/10.1140/epjc/s10052-018-6185-2.pdf?pdf=button

Eur. Phys. J. C (2018) 78:693

Table 1 Total cross sections for the exclusive ρ, ω and J/Ψ photoproduction in fixed-target collisions at the LHC considering pA (PbA) collisions at $\sqrt{s} = 110\ (69)$ GeV

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

The predictions obtained assuming the LHCb requirements are presented in parenthesis

Ultra-peripheral-collision studies in the fixed-target mode with the proton and lead LHC beams

Table 1: The key figures of the UPC in the FT mode at the LHC [6]. E_{beam} is the beam energy per nucleon.

System	E_{beam} [GeV]	$\sqrt{s_{\gamma p}^{\max}}$ [GeV]	$\sqrt{s_{\gamma\gamma}^{\max}}$ [GeV]
pH	7000	44	17
pPb	7000	19	3.2
PbPb	2760	9	1.0
PbH	2760	12	3.2

https://arxiv.org/pdf/1902.10534.pdf

Target Technique	Target Type	p beam $\int \mathscr{L}_{\text{ALICE}}$	Pb beam $\int \mathscr{L}_{\text{ALICE}}$	p beam $\int \mathscr{L}_{\text{LHCb}}$	Pb beam $\int \mathscr{L}_{\text{LHCb}}$
Gas jet	$H^{\uparrow}$	43 pb^{-1}	0.56 nb^{-1}	43 pb^{-1}	0.56 nb^{-1}
	H_2	0.26 fb^{-1}	28 nb^{-1}	10 fb^{-1}	118 nb^{-1}
	Xe	7.7 pb^{-1}	8.1 nb^{-1}	0.31 fb^{-1}	23 nb^{-1}
Storage cell	$H^{\uparrow}$	0.26 fb^{-1}	28 nb^{-1}	9.2 fb^{-1}	118 nb^{-1}
	H_2	0.26 fb^{-1}	28 nb^{-1}	10 fb^{-1}	118 nb^{-1}
	Xe	7.7 pb^{-1}	8.1 nb^{-1}	0.31 fb^{-1}	30 nb^{-1}
Bent crystal and solid target	C (658 μm)	37 pb^{-1}	–	–	–
	C (5 mm)	–	5.6 nb^{-1}	280 pb^{-1}	5.6 nb^{-1}
	W (184 μm)	5.9 pb^{-1}	–	–	–
	W (5 mm)	–	3.1 nb^{-1}	160 pb^{-1}	3.1 nb^{-1}

Table 1: Summary of the achievable integrated yearly luminosities for some technical implementations and targets with the ALICE and LHCb detectors in the fixed target mode, accounting for the data-taking-rate capabilities (see text). The integrated luminosity corresponds to a LHC year with time duration of $t_p = 10^7$ s and $t_{Pb} = 10^6$ s for the proton and lead beams, respectively.