Inclusive quarkonium photoproduction in ultra-peripheral collisions

Kate Lynch

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Quarkonia as Tools, Aussois 2024

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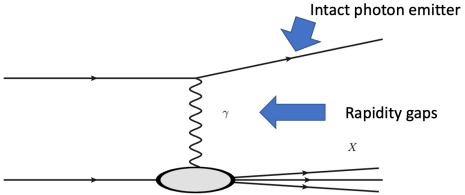
Photoproduction

- Accelerated charged particles emit photons resulting in photon-induced interactions



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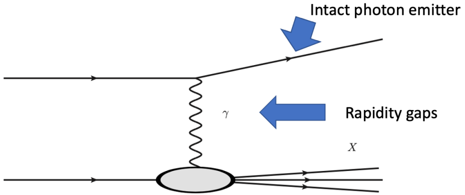

- Photoproduction on a proton is usually studied in $e-p$ colliders
- However, the LHC is an excellent source of photons
- While $e-p$ collisions offer a clean photoproduction environment (not the case at the LHC) the LHC offers some important advantages for photoproduction studies...
  - increased statistical precision
  - increased centre-of-mass energy range
  - extension to photon-ion studies

Photoproduction @ the LHC

The LHC is a rich hadronic environment, and so, **Ultra Peripheral Collisions** are used as a photoproduction selecting criteria

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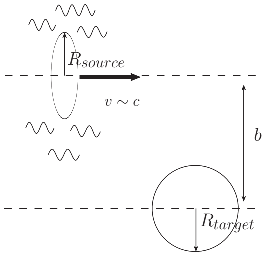

UPC: interaction mediated over distances larger than charge radius ($b > R_{source} + R_{target}$), where electromagnetic exchange is dominant

- Fewer particles than in hadronic interactions (rapidity gaps)
- Coherent emission: wavelength of emitted photon is larger than charge radius of emitting object, therefore γ-emitter remains **intact**.

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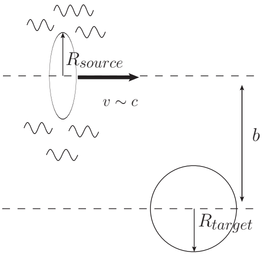

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- The photon energy observed by the target particle,

$$E_{\gamma}^{\prime max.} = \frac{\hbar c}{(\lambda^{min.} = b_{min})} \times \left(\gamma_L \simeq \frac{s_{NN}}{2m_N^2}\right),$$

  is highly boosted resulting in extremely large $W_{\gamma N}$ at the LHC:

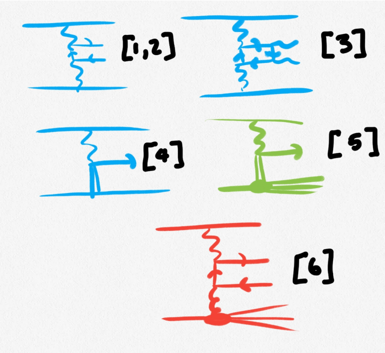
pp @ $\sqrt{s} = 13$ TeV $\rightarrow$ $W_{\gamma p}^{max} \approx 5$ TeV; pPb @ $\sqrt{s_{NN}} = 8.16$ TeV $\rightarrow$ $W_{\gamma p}^{max} \approx 1.5$ TeV

- Compared to energies available at $e - p$ colliders:

  $\sqrt{s_{ep}^{HERA}} = 320$ GeV; $\sqrt{s_{ep}^{EIC}} = 45 - 140$ GeV

Photoproduction via UPC @ the LHC

- Focus of UPCs @ LHC has been on exclusive processes (fully determined final state) **[1–4]**
- However, recently there have been studies of more inclusive processes (**not** fully determined final state) … diffractive quarkonium photoproduction with nuclear break up **[5]**, inclusive photoproduced dijets **[6]**
- Note that quarkonium photoproduction has newly been studied in peripheral collisions in AA at low p_T ALICE, PLB 846 (2023) 137467; LHCb, PRC 105 (2022) L032201 [see talk of Adam]



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[2] **Exclusive dilepton**: ATLAS, PRC 104 (2021) 024906, PLB 777 (2018) 303-323, PLB 749 (2015) 242-261; CMS, JHEP 01 (2012) 052

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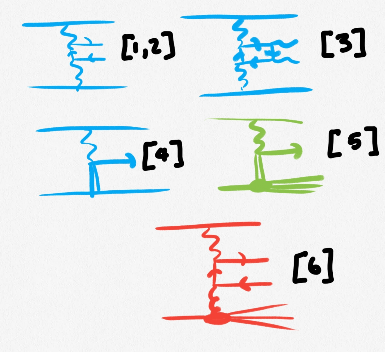

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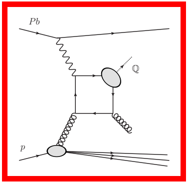
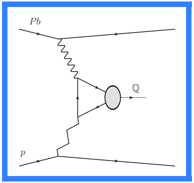
No LHC measurement of inclsuive quarkonium photoproduction!

Inclusive and exclusive photoproduction of quarkonium

- Measuring exclusive quarkonium photoproduction does not say anything about the conventional COM
- Measuring inclusive quarkonium photoproduction presents the opportunity to understand the production mechanism





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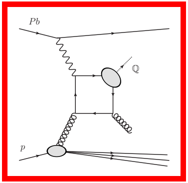
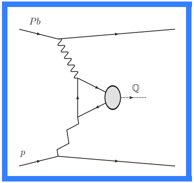
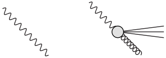




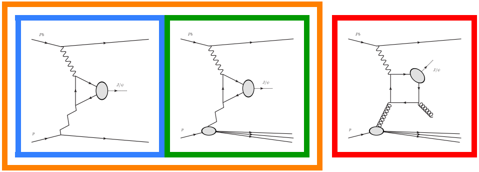
- Photoproduction processes are in general simpler than hadroproduction, however, resolved-photon interactions introduce the photon PDF

direct and resolved photons



- It is possible to select a kinematic region (in terms of $W_{\gamma p}$ and $z = P_p \cdot P_\psi / P_p \cdot P_\gamma$) where the resolved-photon contribution is minimised **[later]**

Existing J/ψ photoproduction measurements from HERA



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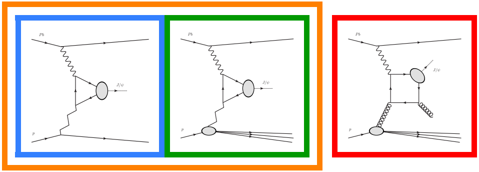

- Data exists for **diffractive** (exclusive and proton-disassociative) & **inclusive** photoproduction @ HERA $\sqrt{s} = 320$ GeV
- Different contributions separated using experimental cuts ...
  - Diffractive region: $p_T < 1$ GeV $\quad z > 0.9$
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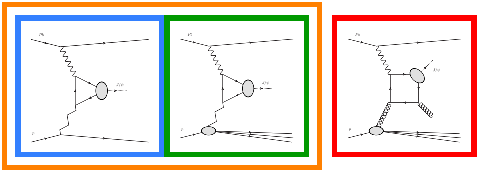

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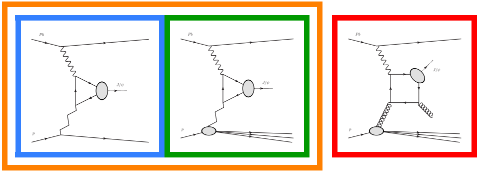

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We propose inclusive **photoproduction** is measured at the LHC; opportunity to extend p_T- & $W_{\gamma p}$-reach, capture a variety of quarkonium species & improve statistical accuracy of existing data

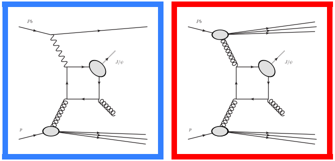
Inclusive photoproduction in *p*-Pb collisions at the LHC

p-Pb is the ideal system since at the LHC since:

- **no ambiguity** as to which beam particle emits the photon [*p-p* or *Pb-Pb*]
- **less hadronic activity** than in *Pb-Pb*

Photoproduction is suppressed by a factor of α/α_s with respect to hadroproduction;

$\sigma_{had.} \gg \sigma_{photo.}$



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- In order to make a measurement we must be able to significantly reduce the hadroproduction contribution background

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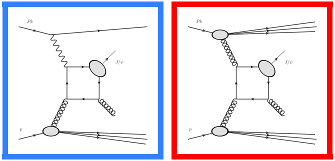


- In *p*-Pb the relative size of these contributions is strongly rapidity-dependent
- In order to make a measurement we must be able to significantly reduce the hadroproduction contribution background
- In this work we asses the feasibility of measuring inclusive photoproduction at the LHC in proton-lead collisions

Table of Contents

Set-up: generating samples

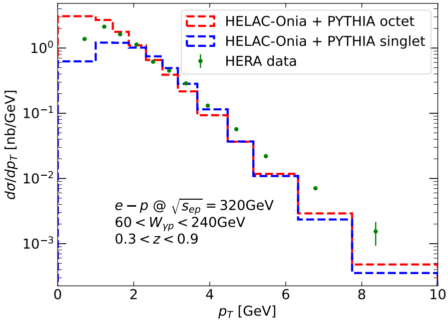
Comput.Phys.Commun. 184 (2013) 2562-2570

- Use MC samples generated by HELAC-Onia in the NRQCD framework to model the photoproduction and hadroproduction
  - Signal $[\gamma g \to J/\psi(^3S_1^1)g]$ and $[\gamma g \to J/\psi(^1S_0^8)g]$
  - Background $[gg \to J/\psi(^3S_1^1)g]$ and $[gg \to J/\psi(^3S_1^8)g]$
- Use PYTHIA to shower partonic events
- The p_T distribution is not well described by leading order NRQCD or leading order NRQCD + Parton shower
- Perfrom a tune of leading order NRQCD + Parton shower MC to experimental data to correctly describe the p_T shape
  - photoproduction signal H1 *ep* 320 GeV data **10.1140/epjc/s10052-010-1376-5**; **10.1007/s10052-002-1009-8**
  - hadroproduction background LHCb 5 TeV *pp* data **10.1007/JHEP11(2021)181**

Tuning: photoproduction signal

Tune MC to HERA data @ $\sqrt{s} = 320$ GeV;

- $60 < W_{\gamma p} < 240$ GeV
- $0.3 < z < 0.9$



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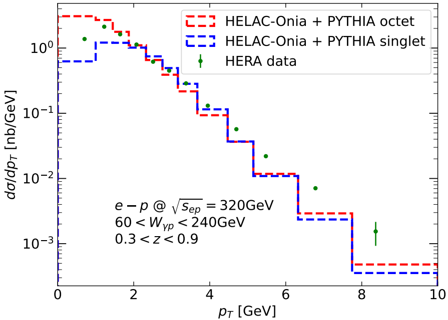

Note: The octet cross-section is divergent for $p_T \to 0$; a p_T cut is placed on the octet at the level of the matrix element; the bin $p_T < 1$ GeV is filled by the Parton Shower.

Tune factors for octet and singlet HELAC-Onia + PYTHIA to HERA data:

p_T bin [GeV]	$\left({}^1S_0^{(8)}\right)$	$\left({}^3S_1^{(1)}\right)$
$0.0 < p_T < 1.0$	0.45	2.20
$1.0 < p_T < 1.45$	0.79	1.75
$1.45 < p_T < 1.87$	0.92	1.35
$1.87 < p_T < 2.32$	1.03	1.11
$2.32 < p_T < 2.76$	0.94	0.83
$2.76 < p_T < 3.16$	1.16	0.91
$3.16 < p_T < 3.67$	1.33	1.01
$3.67 < p_T < 4.47$	1.40	1.14
$4.47 < p_T < 5.15$	1.56	1.54
$5.15 < p_T < 6.32$	1.87	2.01
$6.32 < p_T < 7.75$	2.43	3.02
$7.75 < p_T < 10.0$	3.21	4.34
$p_T > 10.0$	$\frac{0.37}{[GeV]} \cdot p_T$	$\frac{0.06}{[GeV]^2} \cdot p_T^2$

Tune and validation: hadroproduction background

Assumptions:

1. Tuning is y independent
2. Tuning is $\sqrt{s}$ independant

Singlet and octet HELAC-Onia + PYTHIA tune factors to rapidity integrated data (LHCb data @ 5 TeV):

p_T bin [GeV]	$\left({}^3S_1^{(1)}\right)$	$\left({}^3S_1^{(8)}\right)$
$0.0 < p_T < 1.0$	1.71	0.27
$1.0 < p_T < 2.0$	1.45	0.64
$2.0 < p_T < 3.0$	1.37	0.95
$3.0 < p_T < 4.0$	1.58	1.11
$4.0 < p_T < 5.0$	2.42	1.17
$5.0 < p_T < 6.0$	4.47	1.15
$6.0 < p_T < 7.0$	8.49	1.16
$7.0 < p_T < 8.0$	14.61	1.12
$8.0 < p_T < 10.0$	26.93	1.04
$10.0 < p_T < 14.0$	53.44	0.96
$14.0 < p_T < 20.0$	116.4	0.88

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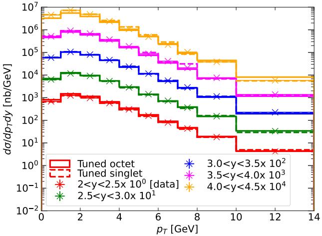

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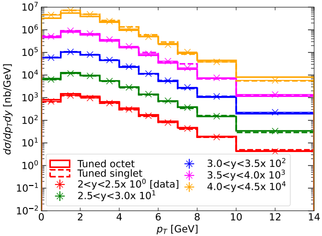
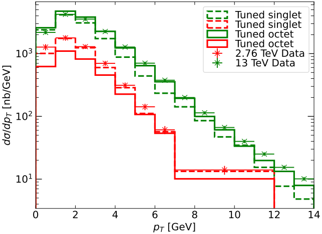


Validation 2: tune vs. 13- and 2.76 TeV data.



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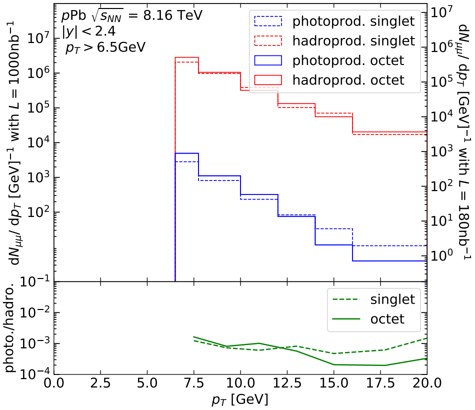
Results: p_T distributions and yields

CMS-like detector



Yield: Run 2 $\mathcal{O}(10^3)$; Run 3+4 $\mathcal{O}(10^4)$

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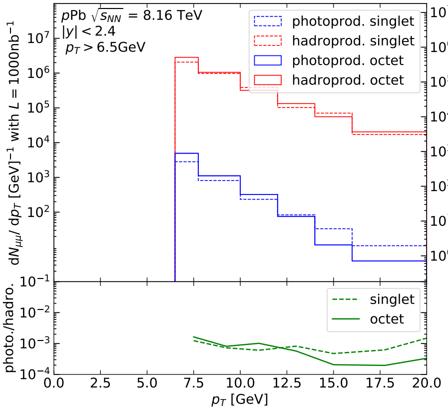
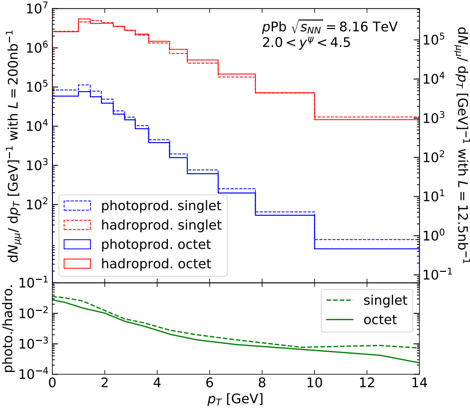


LHCb-like detector



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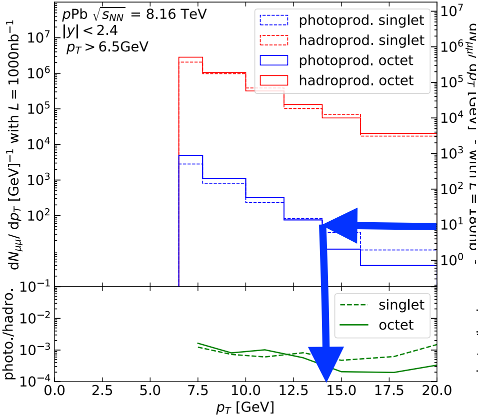

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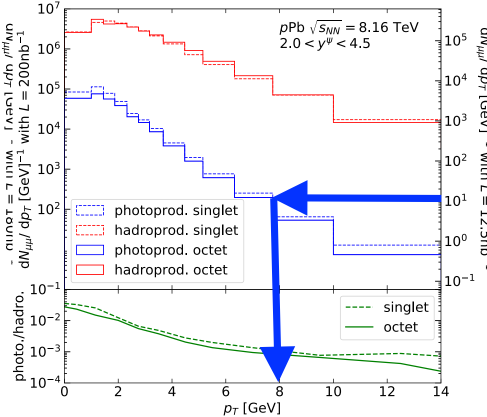

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p_T reach with Run 2 luminosity: 14 GeV

Run 2 $\mathcal{O}(10^3 - 10^4)$; Run 3+4 $\mathcal{O}(10^4 - 10^5)$

8 GeV

Results: p_T distributions and yields

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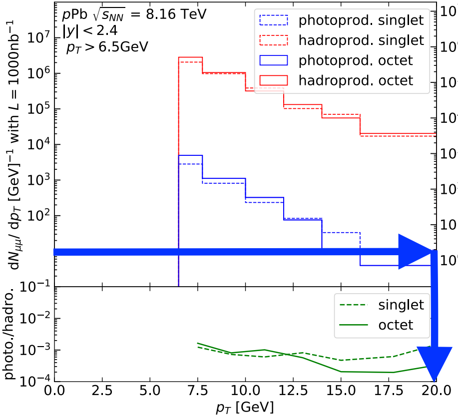

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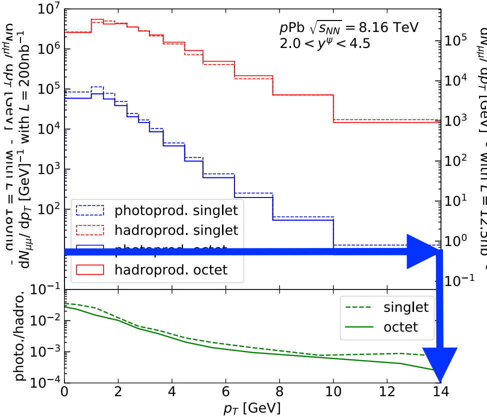

Yield: Run 2 $\mathcal{O}(10^3)$; Run 3+4 $\mathcal{O}(10^4)$

p_T reach with Run 3+4 luminosity: 20 GeV

Run 2 $\mathcal{O}(10^3 - 10^4)$; Run 3+4 $\mathcal{O}(10^4 - 10^5)$

14 GeV

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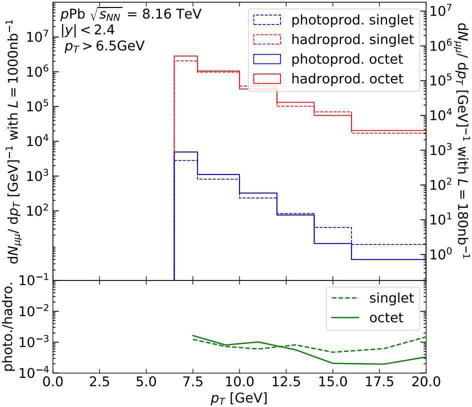
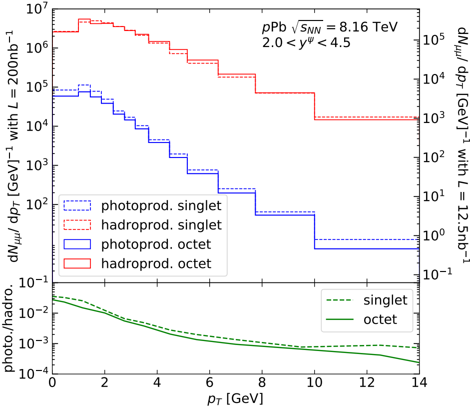


LHCb-like detector



Yield: Run 2 $\mathcal{O}(10^3)$; Run 3+4 $\mathcal{O}(10^4)$ Run 2 $\mathcal{O}(10^3 - 10^4)$; Run 3+4 $\mathcal{O}(10^4 - 10^5)$

- Hadroproduced J/ψ have a flatter p_T distribution than photoproduced J/ψ; background reduction becomes more critical at larger p_T

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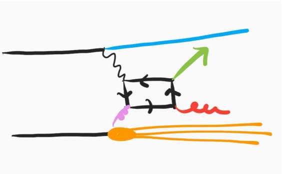
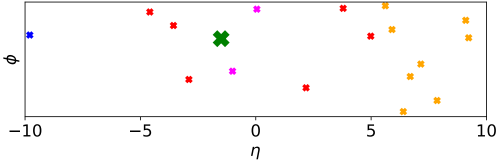
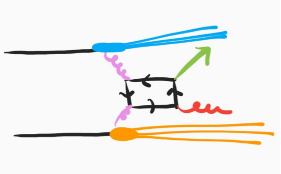
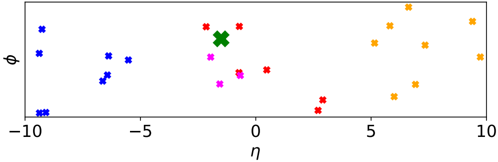
Background reducing techniques









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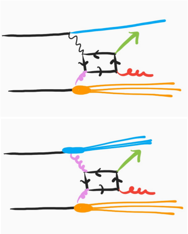

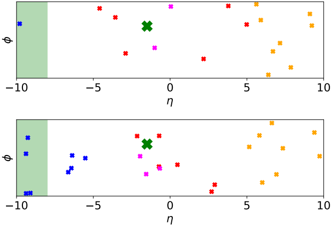

Method I: far-forward activity with zero-degree calorimeter

- detector close to the beam pipe ($|\eta| \gtrsim 8$) sensitive to neutral particles installed at ALICE, ATLAS, and CMS
- Photoproduction events identified with **no signal** in ZDC

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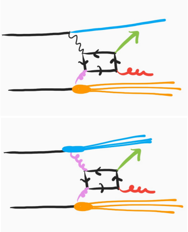

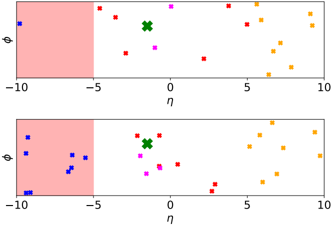

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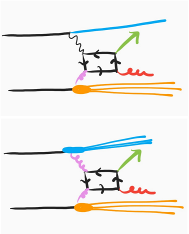

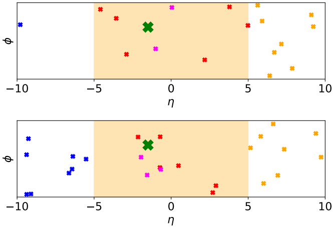

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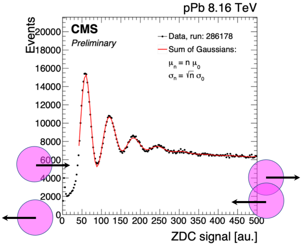
Method III: central activity in the main detectors

- distribute events according to distance in rapidity between main detector on photon-going side and closet particle activity ($-5 \lesssim \eta \lesssim 5$)
- Photoproduction events identified with **large rapidity gaps**

Method I: far-forward activity with zero degree calorimeter

ZDCs at ALICE, ATLAS, and CMS can of resolve single to few neutron emissions.



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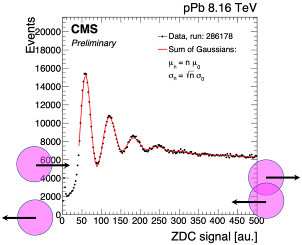
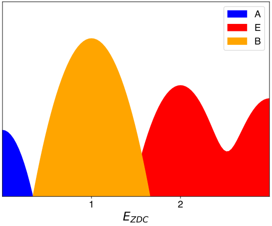
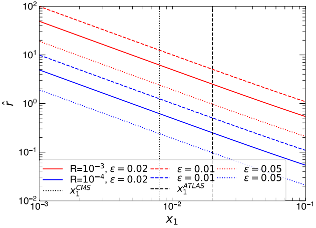






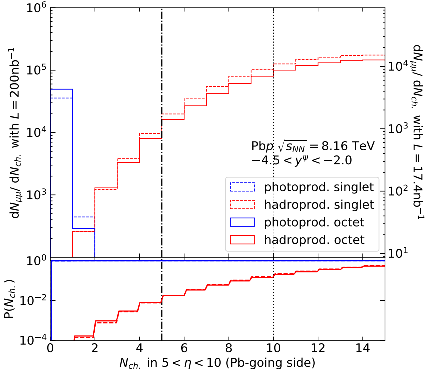
We estimate the background reducing potential of the ZDC in a data driven way. Assumptions:

1. Photoproduction events have no neutron emissions
2. Hadroproduction events have at least 1 neutron emission
3. Only 1-neutron events contaminate 0-neutron events with a probability ϵ
4. We assume something of the shape of the background ($x_1 = B/A$)

The resulting signal-over-background after a ZDC selection requirement ($\hat{r}$) is estimated to be of the order of 10 at low p_T and of order unity at large p_T.

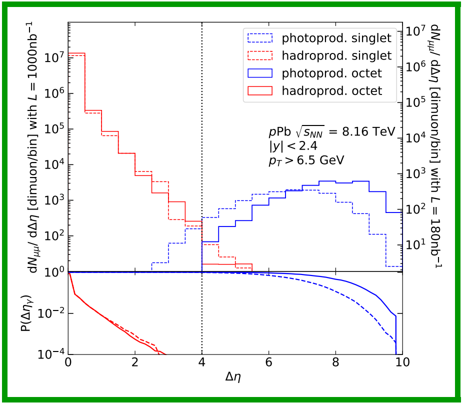
Method II: forward activity with High Rapidity Shower Counter @ LHCb

- HeRSCheL detectors at forward and backward rapidity in the region $5 < |\eta| < 10$
- Use MC samples to count the number of charged tracks in HeRSCheL region



We expect a visible signal for events with $\gtrsim 5$ tracks in the HeRSCheL accpetance and expect to retain $\mathcal{O}(100\%)$ of the signal and remove $\mathcal{O}(99\%)$ the background.

Method III: Rapidity gaps in CMS- and LHCb-like detectors



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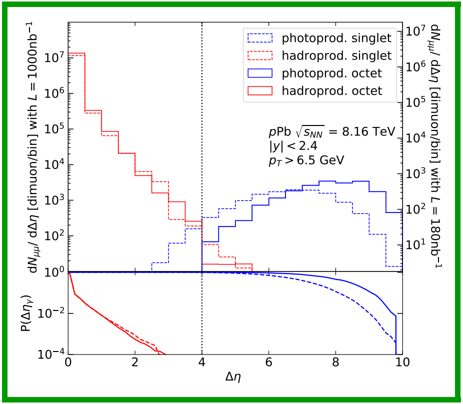

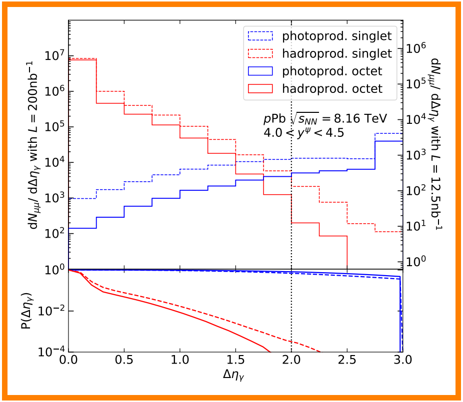

- A wide rapidity coverage (CMS-like detector) allows for a clean separation between photoproduction and hadroproduction events
- A narrow rapidity coverage (LHCb-like detector) allows for a less pronounced separation between photoproduction and hadroproduction events

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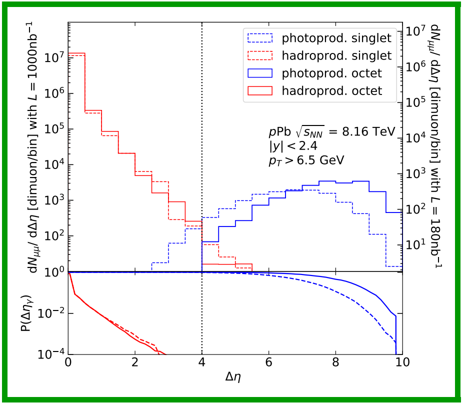

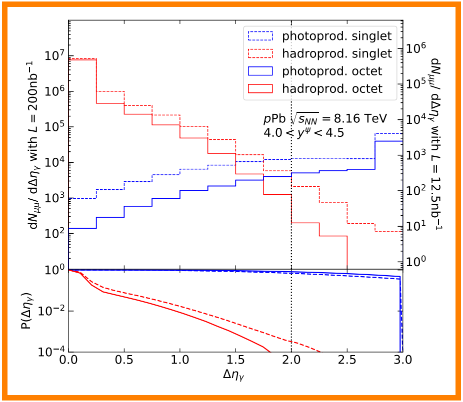

- A wide rapidity coverage (CMS-like detector) allows for a clean separation between photoproduction and hadroproduction events
- A narrow rapidity coverage (LHCb-like detector) allows for a less pronounced separation between photoproduction and hadroproduction events
- Selecting events with $\Delta\eta$ larger than 4 (2) removes $\mathcal{O}(99.9\%)$ of background events

Purity after selection requirements

The retained % of photoproduction and hadroproduction events after selection requirements and the resulting signal purity:

	% retained after selection requirements		signal purity
	photoproduction	hadroproduction	$\frac{\text{photo.}}{\text{photo.} + \text{hadro.}}$ [%]
CMS $p_T > 6.5$ GeV			
ZDC ($\epsilon = 0.02^{+0.03}_{-0.01}$)	100	$0.07^{+0.01}_{-0.06}$	62^{+30}_{-1}
Rapidity gap ($\Delta\eta_\gamma > 4 \pm 0.25$)	$99.0^{+1.0}_{-2.1}$	$0.0007^{+0.0006}_{-0.0004}$	$99.0^{+0.4}_{-0.6}$
LHCb Pbp			
HeRSCheL ($N_{ch.} < 5^{+5}_{-4}$)	$100.0^{+0.0}_{-1.3}$	$0.1^{+2.3}_{-0.1}$	75^{+25}_{-65}
Rapidity gap ($\Delta\eta_\gamma > 2 \pm 0.25$)	$87.0^{+4.7}_{-5.2}$	$0.01^{+0.02}_{-0.01}$	$97.0^{+2.4}_{-5.5}$
HeRSCheL & rapidity gap	$87.0^{+4.7}_{-5.6}$	$0.001^{+0.009}_{-0.001}$	$99.6^{+0.4}_{-3.4}$

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Motivation: kinematic reconstruction

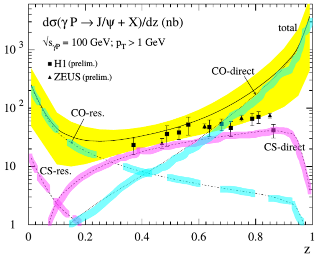
We are interested in reconstructing...

$W_{\gamma p}$ **:** to know the **collision energy**

z **:** discriminant variable for **quarkonium production mechanism** (singlet vs. octet)

Both variables allow for **control of the resolved-photon** contribution and are dependent on the photon energy!

KRAMER, hep-ph/016120



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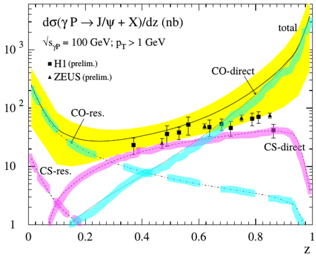

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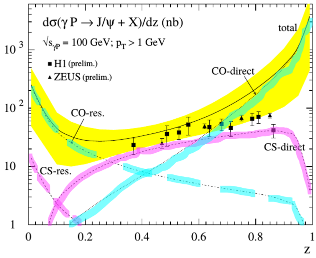

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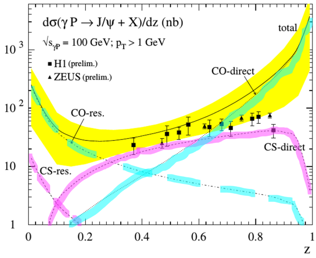

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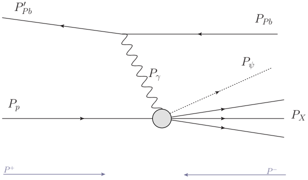
- At the LHC the scattered photon-emitter is in the beam-pipe and **cannot** be measured. Therefore, the photon energy must be reconstructed from the final-state system.
  - In the exclusive case this is simple; detected particle gives the photon energy
  - This is **not** true for the inclusive case... how well can we reconstruct the final state?

Kinematics: z and $W_{\gamma p}$ reconstruction



- Lead-ion moving backward with negative rapidity $(P_{Pb} \simeq \frac{1}{2} P^-_{Pb} \eta_+)$
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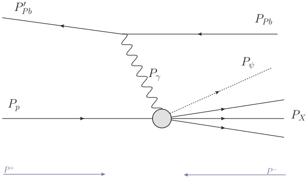

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$$z = \frac{P_p \cdot P_\psi}{P_p \cdot \underbrace{(P_\psi + P_X - P_p)}_{P_\gamma}} \simeq \frac{P^-_\psi}{P^-_X + P^-_\psi}$$

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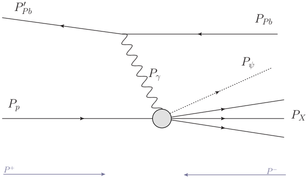

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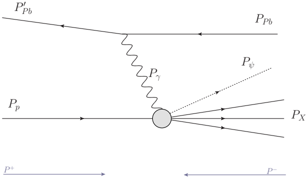

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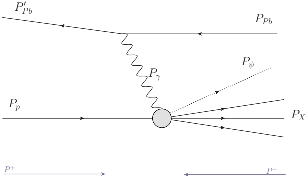

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- A particle i **collinear to the proton** has $P^-_i = 0$ and does not contribute to z
    - Exclusive case: $P^-_X = 0 \rightarrow z = 1$
- A particle i **collinear to the photon emitter** has a large P^-_i
    - As we expect a rapidity gap between the **photon emitter** and the produced particles, much of the produced particles can be captured by the main LHC detectors

Kinematic reconstruction: results

- We remind that $P_X^- = \sum_i^N P_i^-$ and due to limited detector coverage $N_{meas.} < N_{true}$.
- This results in the following biases; $z_{meas.} > z_{true}$ and $W_{\gamma p}^{meas.} < W_{\gamma p}^{true}$.

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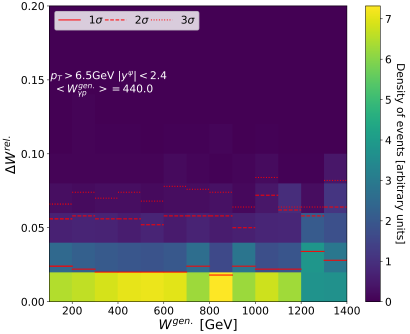

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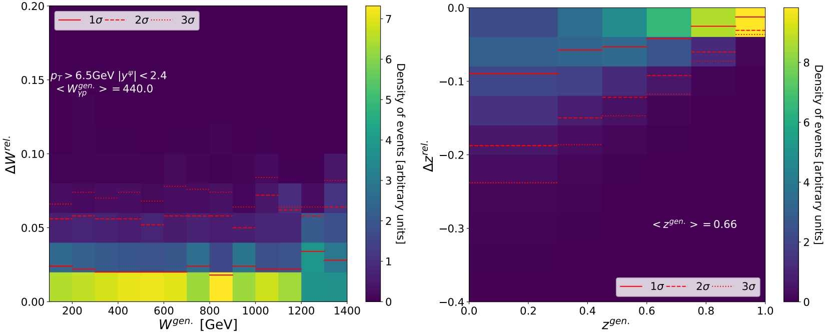


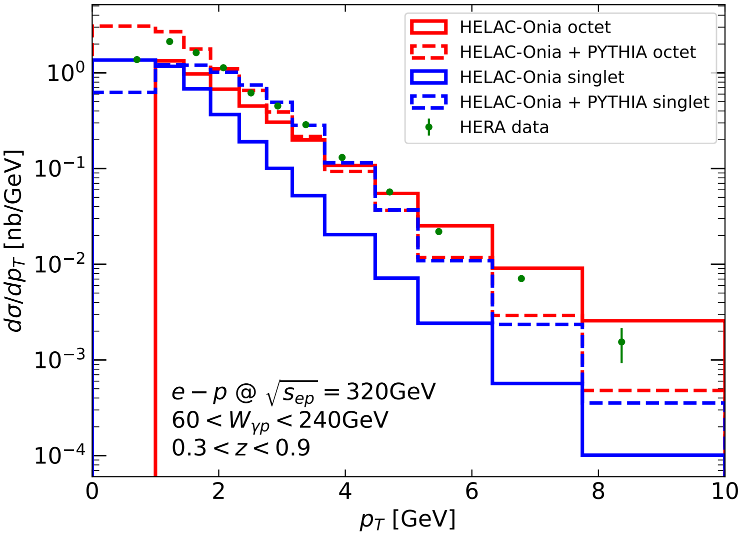
- $W_{\gamma p}$ is reconstructed within 5% in a CMS-like detector
- z reconstruction is best at large values of z where the kinematics are dominated by the J/ψ varying from 10% to 2%

Summary and outlook

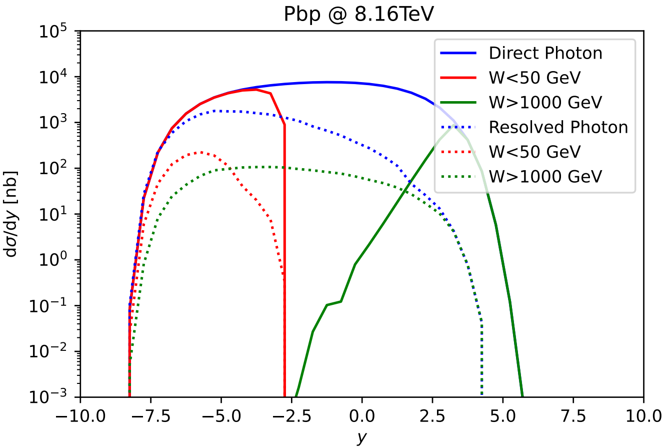
- The LHC can be used as a photon-nucleon collider
  - measuring inclusive J/ψ photoproduction at the LHC appears feasible which is complimentary to existing HERA measurements
- In J/ψ photoproduction events in **proton-lead** collisions
  - a puirity of $> 95\%$ can be achieved in each of the LHC detectors by using a combination of selection requirements
  - in CMS, ATLAS and ALICE the rapidity gap and ZDC based slection requirements are likely sufficient to suppress background
  - in LHCb a combination of gap and HeRSCheL requirements are likely sufficient to suppress background
- The $\Delta\eta$ value at which the cut is placed allows for control over statistics and purity
- Both z and $W_{\gamma p}$ reconstruction appear possible with varying resolution which will allow control of the resolved contribution and offer the possibility to constrain the quarkonium production mechanism.

Backup

HELAC-Onia vs. HELAC-Onia + PYTHIA: photoproduction p_T distribution

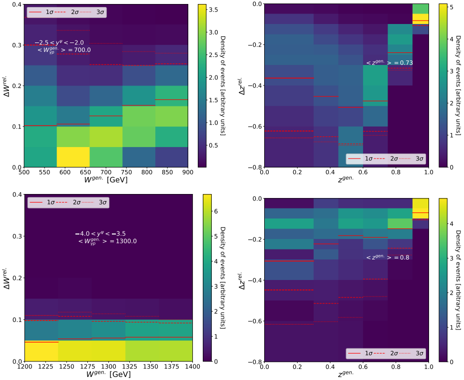


Direct and resolved photon rapidity comparison



Resolved photon contribution increases with increasing photon energy ($W_{\gamma p}$); however, at most forward rapidities is suppressed.

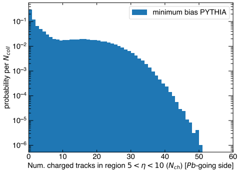
Kinematic reconstruction: results in LHCb large photon energy config.



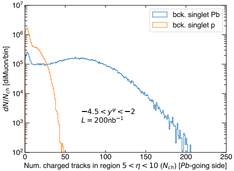
At largest absolute rapidities J/ψ activity trails behind the J/ψ and is captured by the detector (bottom); whereas, when the J/ψ is on the proton-going side of the detector much of the activity is missed (top). This results in an improved reconstruction with increasing absolute rapidity.

From p to Pb in the HeRSCheL region

- The background is modelled by generating pA events with HELAC-Onia and passing them through PYTHIA; PYTHIA reads these as pp events.
- In a pp collision $N_{coll.} = 1$; whereas in a pA collision there are many more nucleons and therefore it is possible to have $N_{coll.} > 1$ [typically modelled using Glauber-type models].
- Using minimum bias events generated by PYTHIA, one can obtain a probability distribution for the number of charged tracks in the HeRSCheL region. **[bottom left]**
- To model the HeRSCheL signal using the PYTHIA events (i.e., converting pp to pA) events are randomly assigned a centrality class and then assigned $N_{coll.}$ based on ALICE results. **[bottom centre arXiv:1605.05680]**
- For a given event, the total number of charged tracks in the HeRSCheL region is given by throwing $i = 1, .., N_{coll.} - 1$ points into the probability distribution, and summing over $N_{coll.}$.
- The transformation from pp to pA HeRSCheL distribution. **[bottom right]**

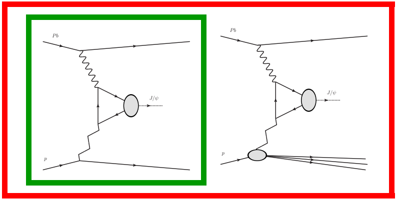


Centrality class	$\langle N_{\rm coll}\rangle_{\rm opt.}$	$\langle N_{\rm coll}\rangle_{\rm ALICE}$	b [fm]
2–10%	14.7	$11.7 \pm 1.2 \pm 0.9$	4.14
10–20%	13.6	$11.0 \pm 0.4 \pm 0.9$	4.44
20–40%	11.4	$9.6 \pm 0.2 \pm 0.8$	4.94
40–60%	7.7	$7.1 \pm 0.3 \pm 0.6$	5.64
60–80%	3.7	$4.3 \pm 0.3 \pm 0.3$	6.29
80–100%	1.5	$2.1 \pm 0.1 \pm 0.2$	6.91



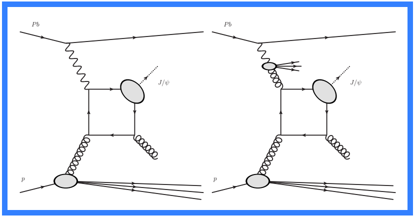
Diffractive vs. inclusive photoproduction

Diffractive production



- Colourless exchange
- Only CSM contributes
- **exclusive**: **only** J/ψ decay products

Inclusive production



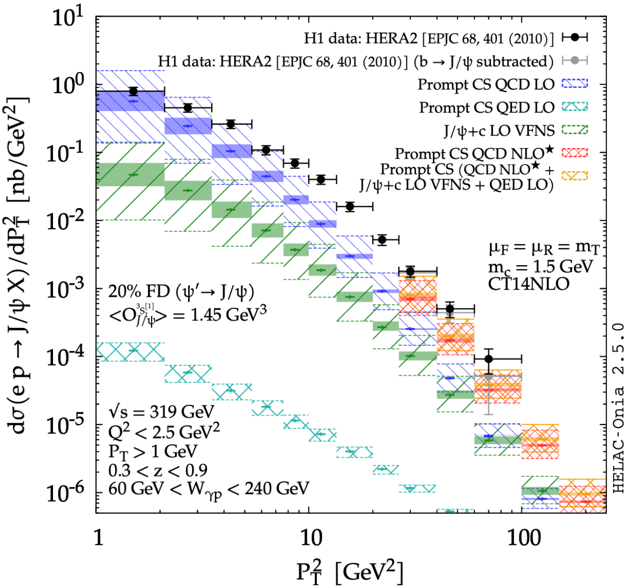
- Hard final state gluon
- Resolved vs. direct contribution
- Test production mechanism
- Probe gluon PDF

Lightcone four-vector representation

1. Choose two vectors along an axis such that,
$$\eta^{\pm} \cdot \eta^{\pm} = 0 \quad \& \quad \eta^{\mp} \cdot \eta^{\pm} = 2. \tag{1}$$
2. A particle's four-momentum can be written as,
$$p = (E, p_x, p_y, p_z) = [P^+, P^-, \mathbf{p}]. \tag{2}$$
3. The scalar product of two four-momenta is given as,
$$p \cdot q = \frac{1}{2}\left(P^+Q^- + P^-Q^+\right) - \mathbf{p} \cdot \mathbf{q}. \tag{3}$$
4. If p lies along the vector η^-, then the scalar product reduces to,
$$p \cdot q = \frac{1}{2}\left(P^-Q^+\right). \tag{4}$$
5. Consider some massless particle q,
   - If q lies on the vector η^+: $p \cdot q$ is maximised $\rightarrow p \cdot q = A$.
   - If q is perpendicular to the vectors $\eta^{\pm}$: $p \cdot q = A/2$.
   - If q lies on the vector η^-: $p \cdot q$ is minimised $\rightarrow p \cdot q = 0$.

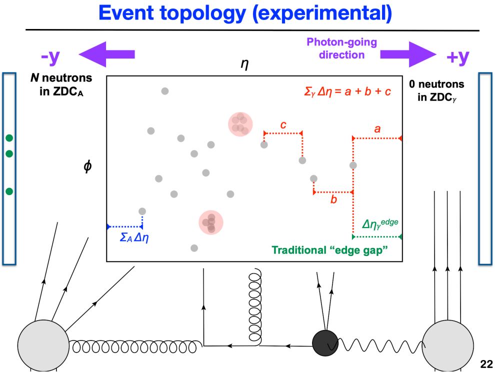
NLO inclusive J/ψ photoproduction at HERA

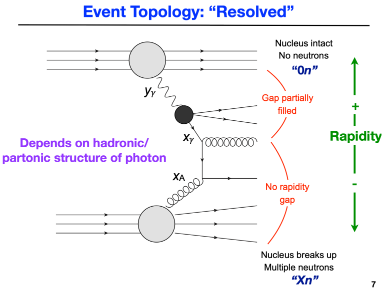
"NLO inclusive J/ψ photoproduction at large p_T at HERA and the EIC", Flore et. al. 2021



ATLAS-CONF-2022-021

- Pb-Pb @ $\sqrt{s_{NN}} = 5.02$ TeV
  - 0nXn requirement [$E_{ZDC} < 1$ TeV]
  - $\sum_{\gamma} \Delta\eta$ requirement [instead of $\Delta\eta_{\gamma}^{edge}$]
    - Include resolved photon in analysis
    - What is the effect of higher order corrections on choice of gap definition?





Slides from A. Angerami

Luminosity targets taken from LHC programme coordination meeting; *p*Pb and PbPb targets are for Run 3 and 4 and *pp* targets are for Run 3 only.

	ATLAS	CMS	ALICE	LHCb
pp	160 fb^{-1}		200 pb^{-1}	25 fb^{-1}
PbPb	13 nb^{-1}			2 nb^{-1}
*p*Pb	1 pb^{-1}		0.5 pb^{-1}	0.2 pb^{-1}

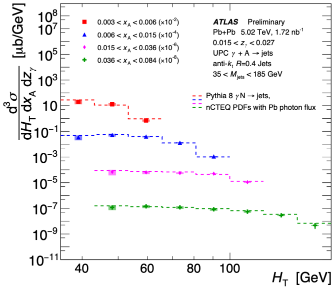
Pb-Pb inclusive dijets

ATLAS-CONF-2017-011, ATLAS-CONF-2022-021

- Triply differential cross section in,

$$z_\gamma = \frac{m_{jets}}{\sqrt{s_{NN}}} e^{+y_{jets}}, \quad x_A = \frac{m_{jets}}{\sqrt{s_{NN}}} e^{-y_{jets}}, \quad H_T = p_T^{jet1} + p_T^{jet2} \tag{5}$$

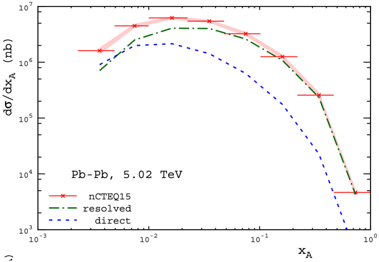
- Jets defined using anti-k_T with $R = 0.4$; $p_T^{jet1(2)} > 15(20)$ GeV and $|\eta^{jet}| < 4.4$.
- selection of events:
  - $\Delta\eta_A < 3$ [hadro.] and $\sum_\gamma \Delta\eta > 2.5$ [photo.]
  - sum-of-gaps retains high efficiency for the resolved-photon contribution
  - 0nXn biases towards lower impact parameter collisions



Pb-Pb inclusive dijets

Guzey, Klasen, PHYSICAL REVIEW C 99, 065202 (2019)

- Resolved contribution dominant in region $x_A > 0.01$ [equivalently, resolved-photon contribution dominant for J/ψ in most forward region]
- Resolved and direct contributions comparable in region $x_A < 0.01$
- LO results (PYTHIA 8 + EPPS16 nPDF) quantatively similar
- However, resolved contribution is larger @ NLO [this statement is scheme and scale dependant]



Method III: central activity; rapidity gaps

Characterise the central activity and exploit the difference between signal and background event topologies to cut background events

- **Signal**: more events with larger gaps
- **Background**: more events with smaller gaps

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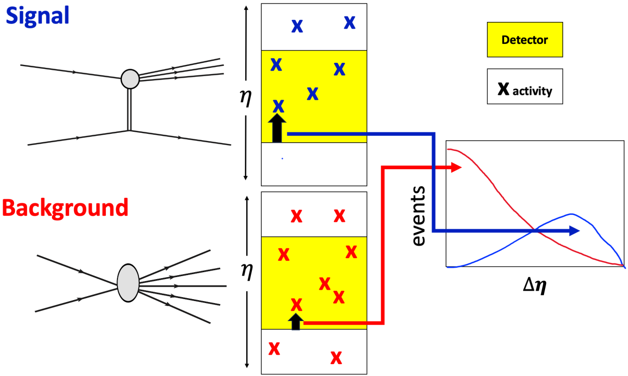
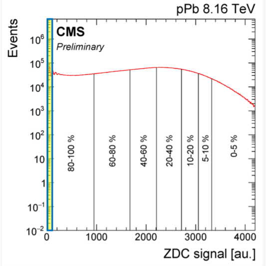
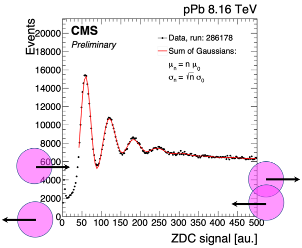


Method I: far-forward activity with zero degree calorimeter

- Far-forward detectors close to beam-pipe; used to classify centrality





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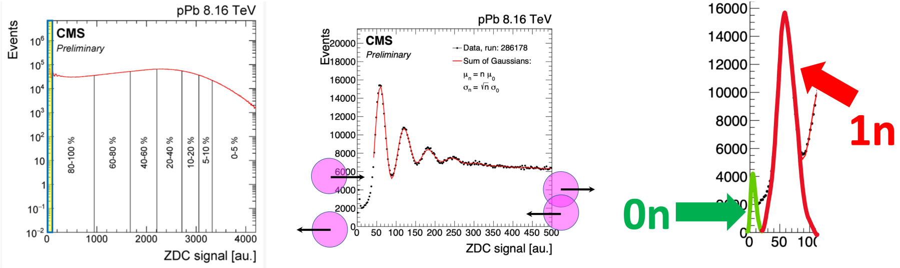

Minimum bias data ($\geq$7 GeV in forward calorimeter) **CMS 10.1088/1748-0221/16/05/P05008**

- Can resolve single to few neutron emissions
- All of the signal is in the 0-neutron bump [signal with neutron emission is negligible]
- $\geq$ 1-neutron region is all background
- Efficiency (ϵ) for detecting 1n is $> 98\%$ **CMS, 2102.06640**; **ALICE, 1203.2436**

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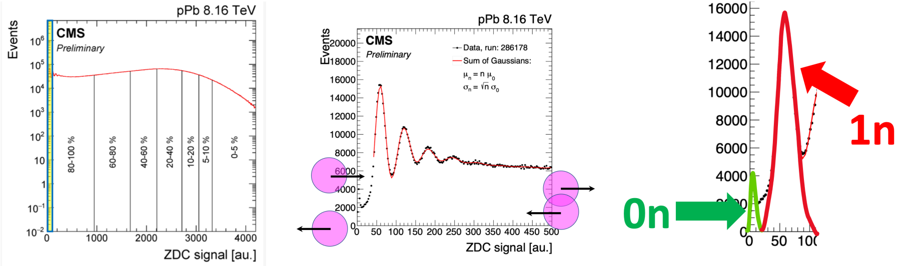

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    - Therefore maximally 2% of 1n events look like 0n events

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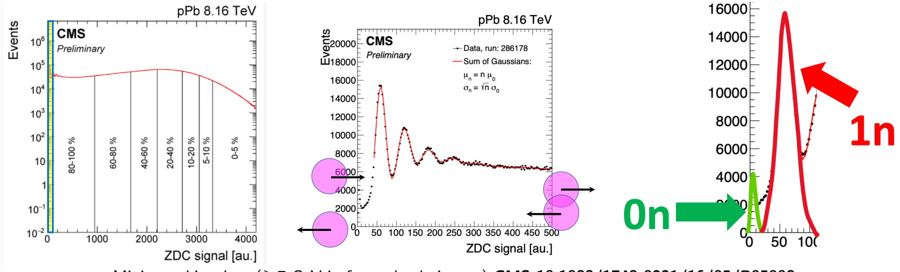

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Assume that the minimum bias and inclusive J/ψ ZDC spectra are similar.

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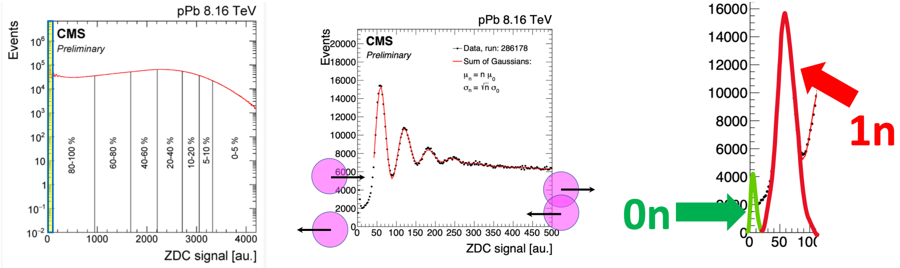

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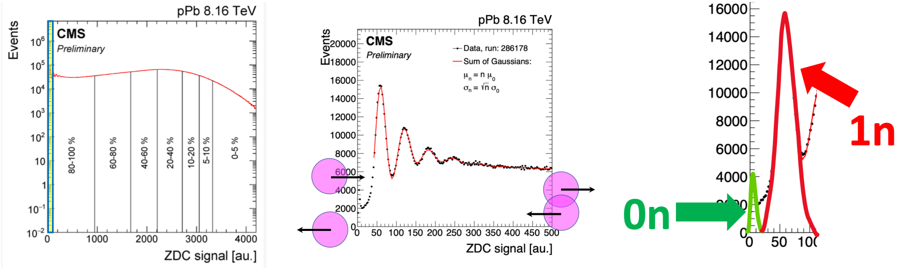

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- From the figure above; $N_{0n} = 45000$; $N_{1n} = 560000$.
- The true 1n peak has $\frac{N_{1n}}{1-\epsilon}$ events.

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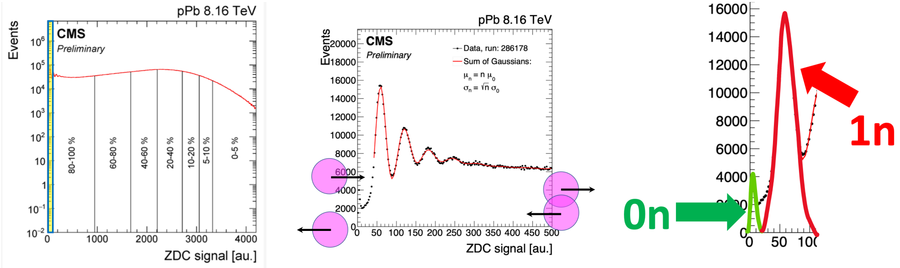

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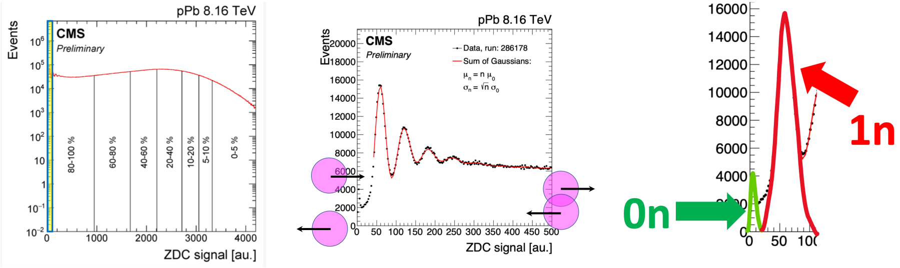

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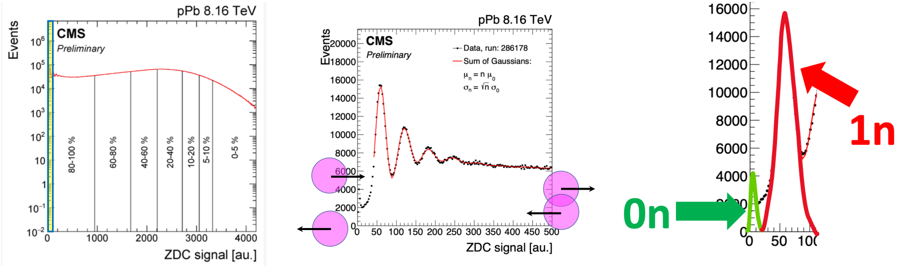

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  - 3 with $\epsilon = 0.02$ and 7 with $\epsilon = 0.01$

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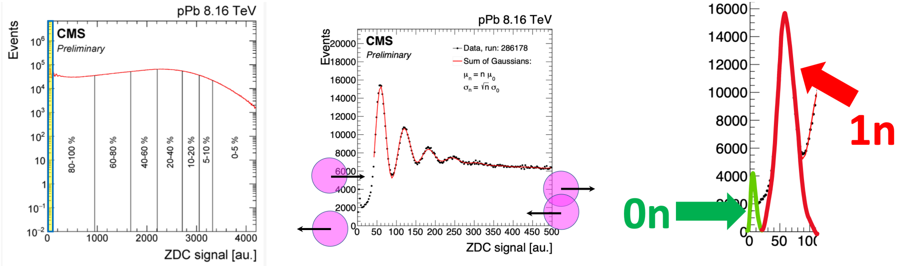

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  - 3 with $\epsilon = 0.02$ and 7 with $\epsilon = 0.01$
- This background reduction technique can be used in CMS, ALICE & ATLAS.