Inclusive quarkonium photoproduction in ultra-peripheral collisions

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Quarkonia as Tools

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- Accelerated charged particles emit electromagnetic radiation
- Photon-induced interactions

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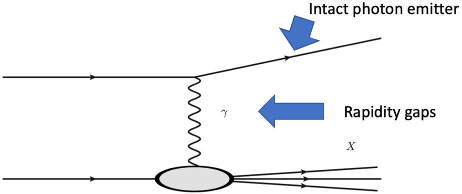

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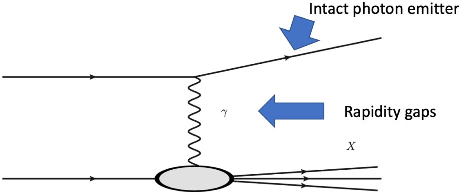

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  - By detecting the scattered lepton the photon energy is known
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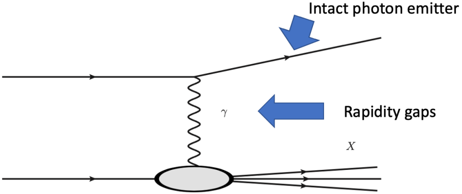

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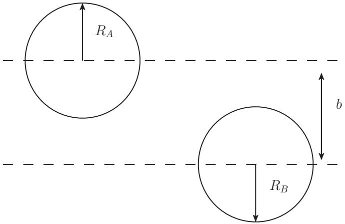
  - By detecting the scattered lepton the photon energy is known
  - Can **not** be done for small photon virtuality
    - ★ Photon energy is determined by reconstructing hadronic final states
- In **pp** and **AA** collisions...
  - Emitter is intact → **coherent photoproduction** → Photon emitted outside charge radius → ultra peripheral collisions (UPC)
  - Can we reconstruct the photon energy at the LHC? (Later...)

Ultra peripheral collisions...



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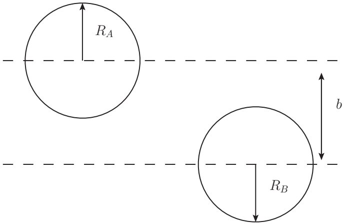

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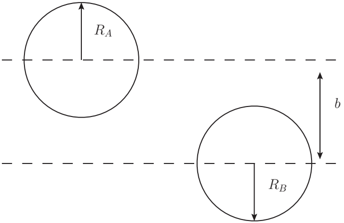

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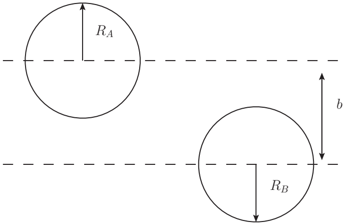

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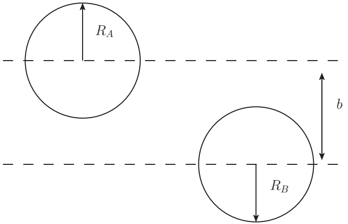

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  - proton-lead: $\sqrt{s_{NN}} = 8.16$ TeV $\rightarrow W_{\gamma N}^{max} \approx 1.4$ TeV
  - electron-proton:
    - HERA: $\sqrt{s_{ep}} = 320$ GeV
    - EIC: $\sqrt{s_{ep}} = 45 - 140$ GeV

Quarkonia and photoproduction

- Bound states of heavy quarks $c\bar{c}$ or $b\bar{b}$
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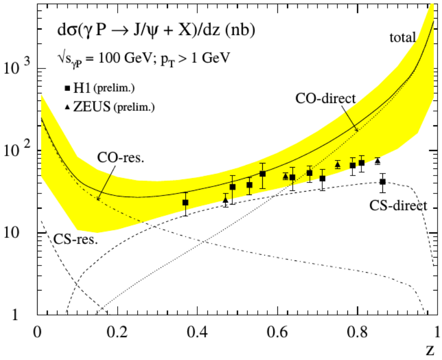

KRAMER, hep-ph/016120

- Elasticity $z = \frac{P_\psi \cdot P_p}{P_\gamma \cdot P_p}$

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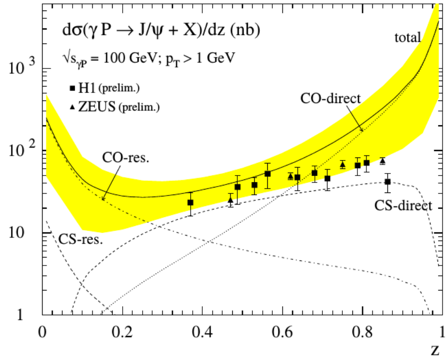

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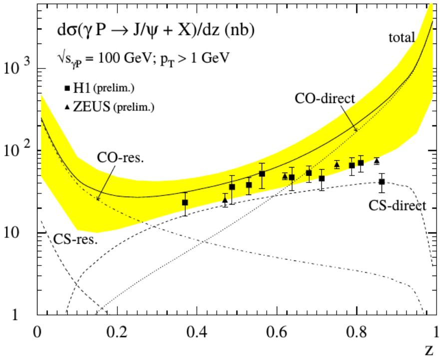

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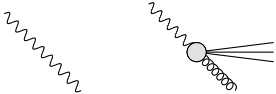

direct and resolved photons

Quarkonium Production

1. Colour Singlet Model
   - $Q\bar{Q}$ pair produced with the same quantum numbers as $\mathcal{Q}$
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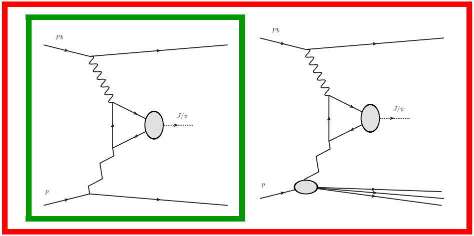
3. Colour Evaporation Model
   - Quantum numbers of $Q\bar{Q}$ decorrelated from $\mathcal{Q}$
   - Semi-soft gluon emissions during hadronisation
   - $\mathrm{d}\sigma(\mathcal{Q}+X) \propto \int_{2m_Q}^{2m_H} \frac{d\sigma(Q\bar{Q}+X)}{dm_{Q\bar{Q}}} dm_{Q\bar{Q}}$

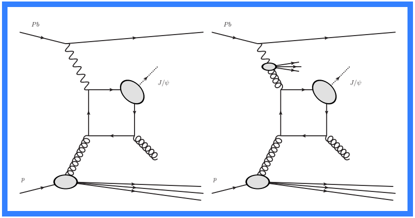
Inclusive photoproduction vs. exclusive photoproduction

Diffractive production



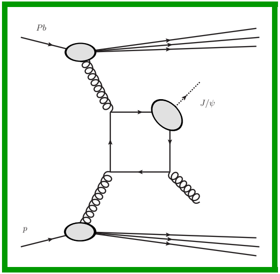
- Colourless exchange
- Extract gluon GPDs
- Only CSM contributes
- **exclusive**: **only** J/ψ decay products

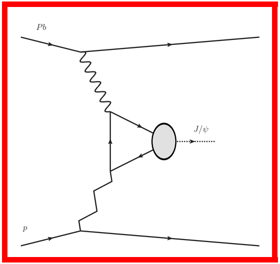
Inclusive production

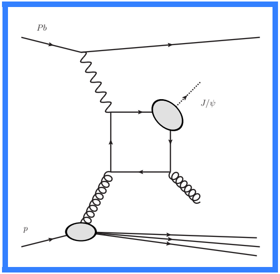


- Hard final state gluon
- Resolved vs. direct contribution
- Test production mechanism
- Probe gluon PDF

What has been measured...







- Inclusive hadroproduction in $PbPb$, pPb, $\bar{p}p$, pp, dAu, $AuAu$...
- **Exclusive photoproduction** in pp, pPb, $\bar{p}p$, $PbPb$, dAu, ep
- **Inclusive photoproduction** in ep

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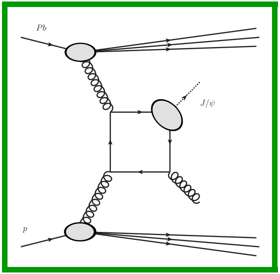

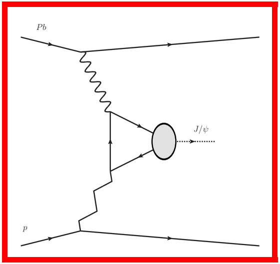

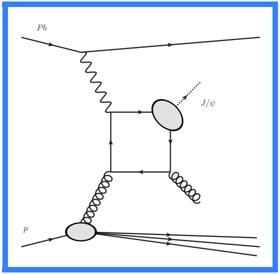

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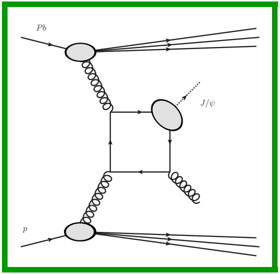

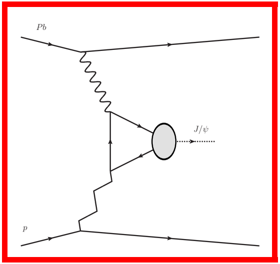

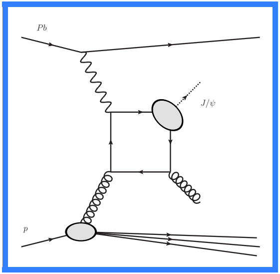

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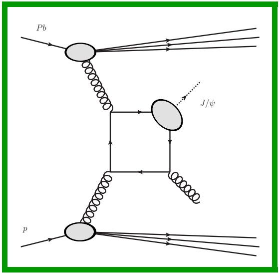

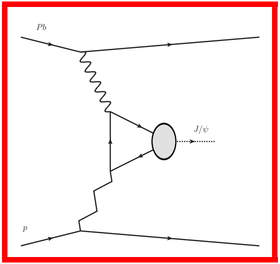

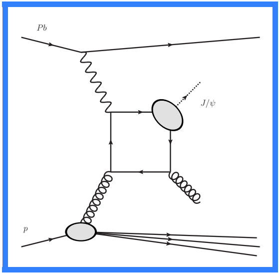

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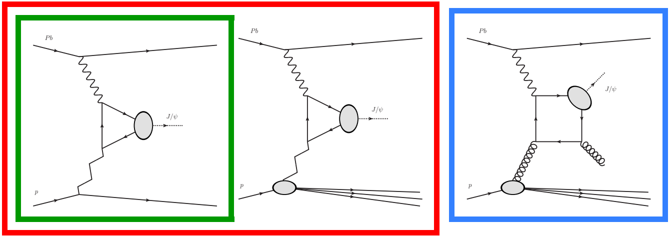
  - Limited data
  - Propose it should be studied at the LHC

What has been measured...at HERA in ep



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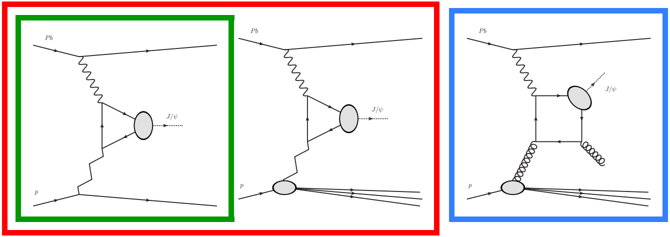
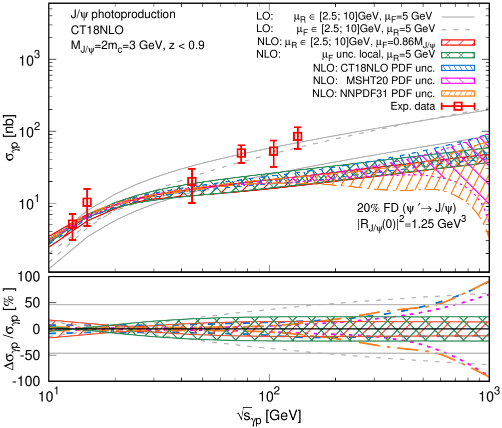


- **Diffractive**, **exclusive** & **inclusive** photoproduction @ HERA $\sqrt{s} = 320$ GeV [Computed at NLO [see Carlo's talk on Monday]]
  - separated using experimental cuts ...
    - ★ Diffractive: $p_T < 1$ GeV & $z = \frac{P_{J/\psi} \cdot P_p}{P_\gamma \cdot P_p} > 0.9$
    - ★ Inclusive: $p_T > 1$ GeV & $z < 0.9$
- Each contribution is found to be comparable
- z is reconstructed experimentally

NLO computation for inclusive photoproduction

Colpani Serri, Feng, Flore, Lansberg, Ozcelik,Shao,Yedelkina, PLB835 (2022) 137556

See Carlo's talk Monday



NLO computation for $\gamma p \to J/\psi X$.

At the LHC can extend the measurement to $\sim 10^3$ GeV.

Generating Events

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

- HELAC-Onia $\rightarrow$ cross sections & partonic events for signal $[\gamma g \rightarrow J/\psi(^3S_1^1)g\ ]$ and background $[gg \rightarrow J/\psi(^3S_1^1)g\ ]$ LO CSM
- Pass partonic events through PYTHIA
- Place detector cuts

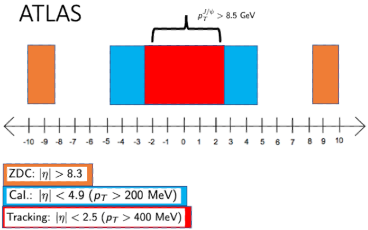
Feasibility: Detector Acceptance

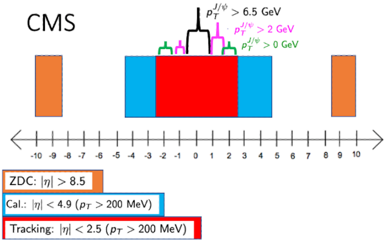
Basic kinematic cuts

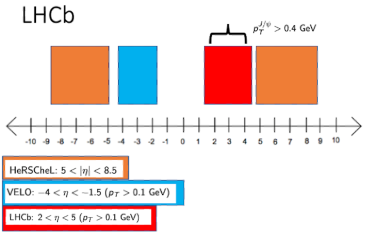
LHCb	**CMS** typical	**CMS** low p_T
$2 < y^{\psi} < 4.5$	$\|y^{\psi}\| < 2.1$	$1.2 > \|y^{\psi}\|,\ p_T^{\psi} > 6.5$
$p_T^{\mu} > 0.4$	$p_T^{\psi} > 6.5$	$1.2 < \|y^{\psi}\| < 1.6,\ p_T^{\psi} > 2$
		$1.6 < \|y^{\psi}\| < 2.4,\ p_T^{\psi} > 0$

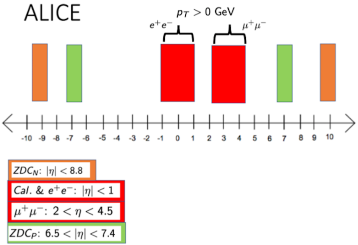
ALICE e^-e^+	**ALICE** $\mu^-\mu^+$	**ATLAS**
$\|y^{\psi}\| < 0.9$	$2.5 < y^{\psi} < 4$	$\|y^{\psi}\| < 2.1$
		$p_T^{\psi} > 8.5$

Detectors @ LHC

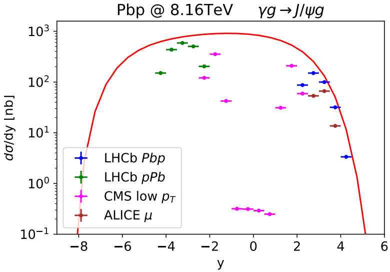


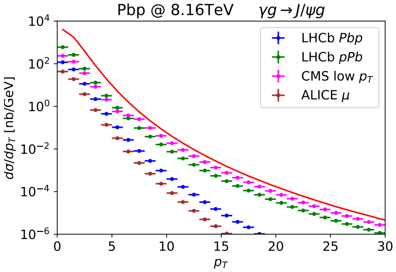






Detector acceptance: signal $\gamma g \to J/\psi(^3S_1^1)g$





Differential cross section with respect to y and p_T and effect of kinematic cuts.

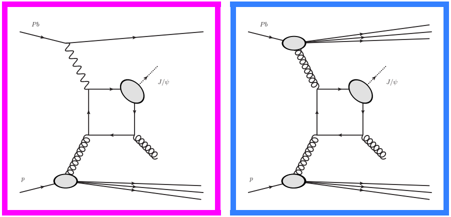
Detector acceptance:

LHCb	**CMS** typical	**CMS** low p_T	**ATLAS**	**ALICE** e^-e^+	**ALICE** $\mu^-\mu^+$
3% (*Pbp*) 15% (*pPb*)	0.01%	6%	0.003%	10%	1% (*Pbp*) 6% (*pPb*)

- Asymmetry due to beam energies and different flux
- Can extend to {**p-p**} and {**Pb-Pb**}

Feasibility... can we distinguish signal from background?

Can we distinguish these in practice ?



photoproduction signal vs. hadroproduction background...

- γ emitter remains intact
- rapidity gaps

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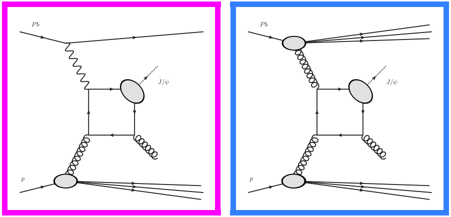


photoproduction signal vs. hadroproduction background...

- γ emitter remains intact
- rapidity gaps
- At HERA (320 GeV) these contributions are comparable
  Nucl.Phys.B 472 (1996) 3-31
- At 8.16 TeV in p-Pb estimate from HELAC-Onia gives...

$$R_{\text{sigback}} = \frac{\sigma_{sig}}{\sigma_{back}} \approx 1/12$$

$\rightarrow$ Need to use detectors to reduce background contribution

Background/Signal ratio ...

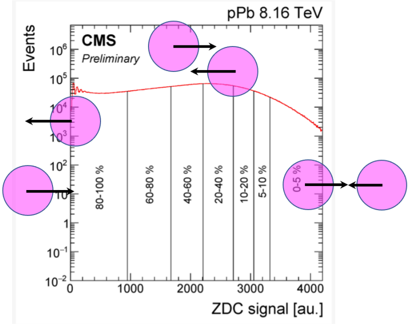
Background $(gg \to J/\psi(^3S_1^1)g \to \mu^+\mu^-)$: 38330 nb
Signal$(\gamma g \to J/\psi(^3S_1^1)g \to \mu^+\mu^-)$: 3154 nb

background/signal	12
LHCb *Pbp*	30
LHCb *pPb*	8
CMS typical	200
CMS low p_T	12
ALICE *Pbp* $\mu^+\mu^-$	30
ALICE *pPb* $\mu^+\mu^-$	8
ATLAS	180

$\to$ need to remove experimental background
Focus on LHCb and CMS (ALICE and ATLAS cover similar regions)

Cutting background: zero degree calorimeter

CMS 10.1088/1748-0221/16/05/P05008



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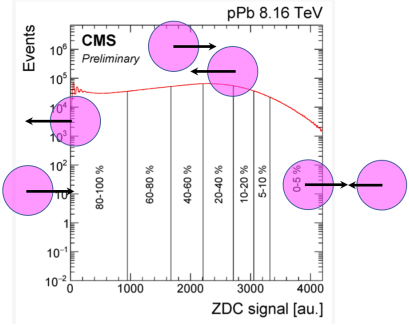
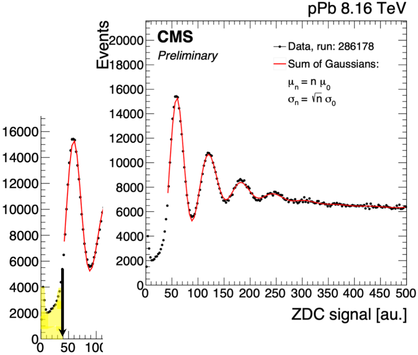
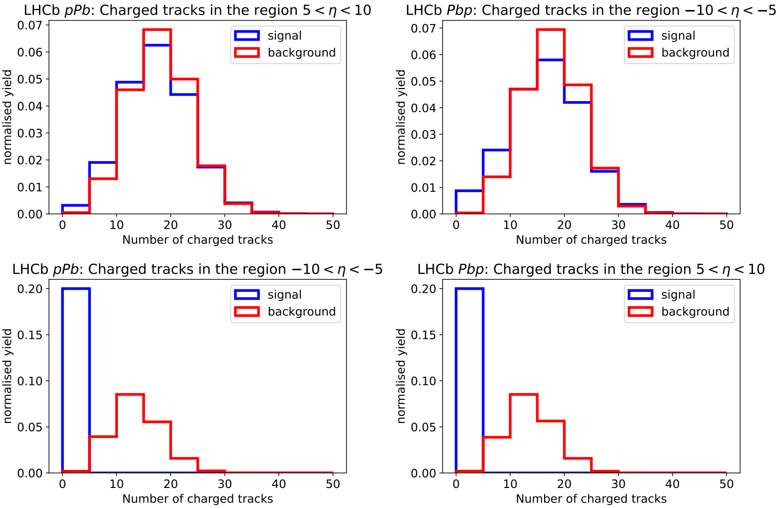




99.7 % of events are 1σ to the right of the 1n peak!

Cutting background: HeRSCheL



Expect signal for 5 or more tracks.

Cuts from forward activity

Using this information to estimate the ability to cut background using far-forward and far-backward detectors...

background/signal	12
LHCb *Pbp*	30
HeRSCheL	$0.29^{+1.2}_{-0.3}$
LHCb *pPb*	8
HeRSCheL	$0.07^{+0.30}_{-0.06}$
CMS low p_T	12
ZDC	0.03

Additional cuts can improve purity of the sample!

ATLAS UPC dijet Study

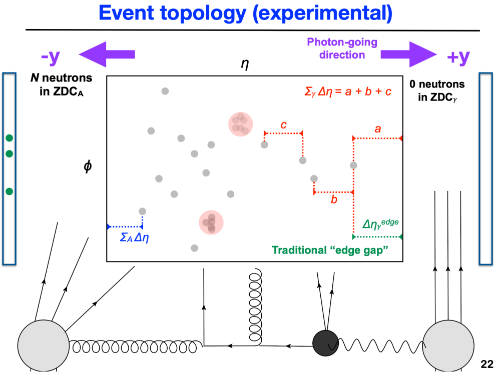
ATLAS-CONF-2022-021

- Pb-Pb @ $\sqrt{s_{NN}} = 5.02$ TeV
  - 0nXn requirement [$E_{ZDC} < 1$ TeV]

ATLAS UPC dijet Study

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 $\Delta\eta_\gamma^{edge}$]



Slides from A. Angerami

ATLAS UPC dijet Study

ATLAS-CONF-2022-021

- Pb-Pb @ $\sqrt{s_{NN}} = 5.02$ TeV
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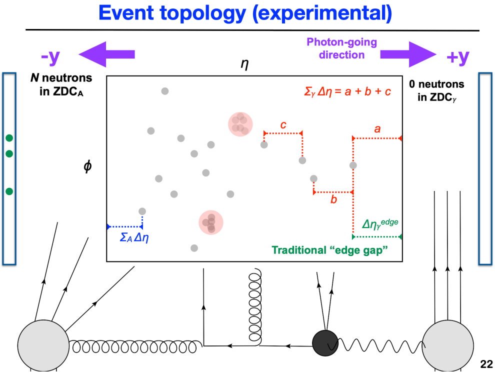

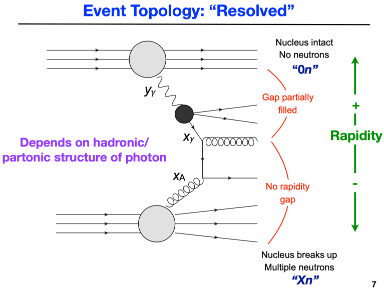

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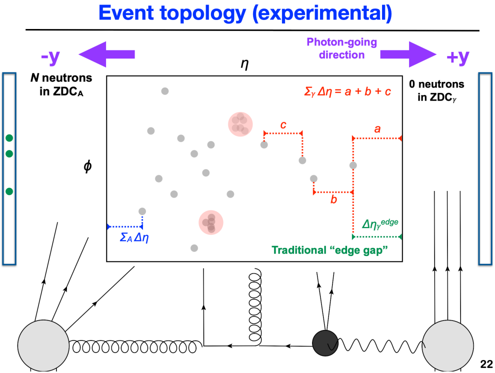
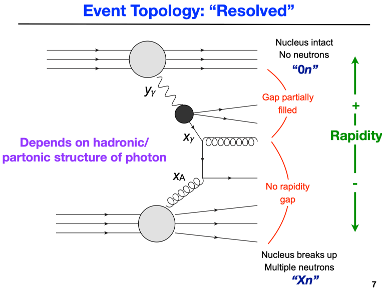
    - What is the effect of higher order corrections on choice of gap definition?





Slides from A. Angerami

Rapidity gaps: CMS

Requirement on Monte Carlo sample for track/cluster to be reconstructed:

charged	$p_T > 0.4$ GeV	$\|\eta\| < 2.5$
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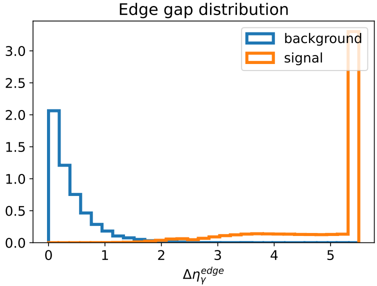

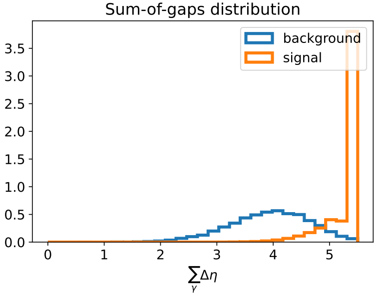

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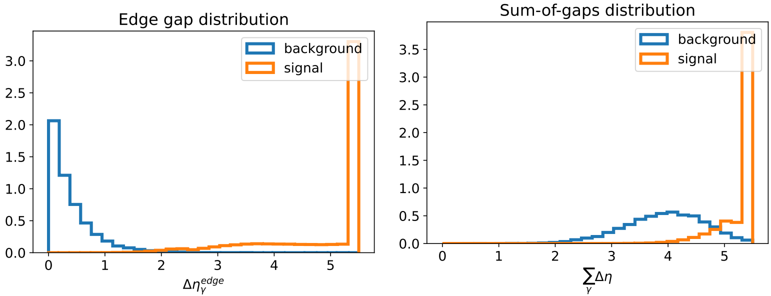


- $\sum_\gamma \Delta\eta$ is less discriminant than $\Delta\eta_\gamma^{edge}$
- A larger gap cut will increase the purity of the sample

Cuts from forward activity and gaps

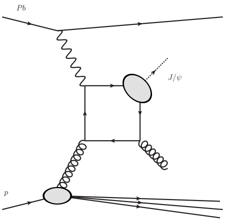
background/signal	12
LHCb *Pbp*	30
HeRSCheL	$0.29^{+1.2}_{-0.3}$
$\sum \Delta\eta_\gamma < 2.5$	$0.6^{+0.8}_{-0.4}$
HeRSCheL $+\sum \Delta\eta_\gamma < 2.5$	$0.005^{+0.004}_{-0.004}$
LHCb *pPb*	8
HeRSCheL	$0.07^{+0.30}_{-0.06}$
$\sum \Delta\eta_\gamma < 1.5$	$3.2^{+1.1}_{-0.8}$
HeRSCheL $+\sum \Delta\eta_\gamma < 1.5$	$0.03^{+0.08}_{-0.02}$
CMS low p_T	12
ZDC	0.03
$\sum \Delta\eta_\gamma < 4.5$	$2.7^{+1.5}_{-1.2}$
ZDC $+\sum \Delta\eta_\gamma < 4.5$	$0.007^{+0.004}_{-0.003}$

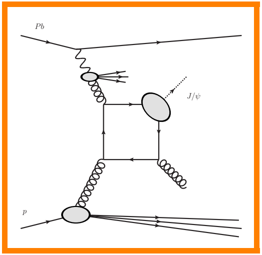
Can suppress background using cuts !!

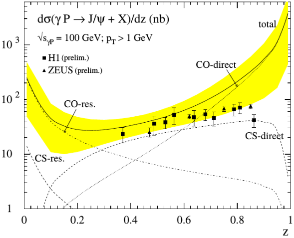
Purity of sample can be further increased by placing harsher gap cuts.

Still need to consider the resolved contribution...

KRAMER, hep-ph/016120







Photoproduction easier to extract PDFs than hadroproduction **however**, the resolved contribution introduces the photon PDF...

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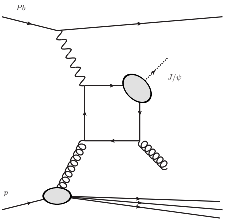

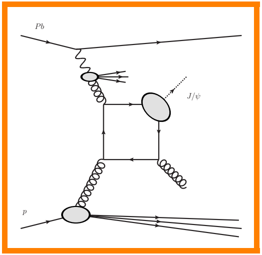

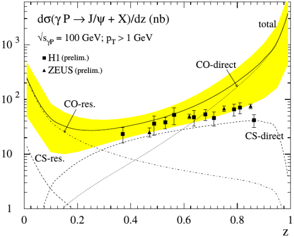

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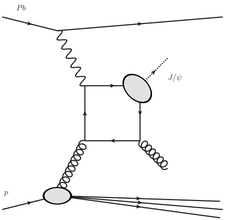
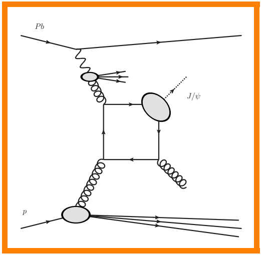
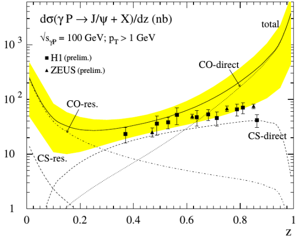




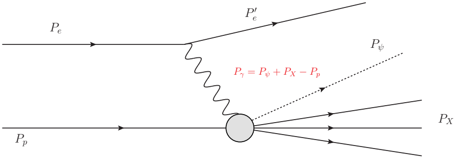


Photoproduction easier to extract PDFs than hadroproduction **however**, the resolved contribution introduces the photon PDF...

- Can we isolate regions where the resolved photon contribution is minimal?
- Can we reconstruct kinematic variable **z** at the LHC?

z Reconstruction at HERA

Nucl.Phys.B 472 (1996) 3-31



Electron moving with forward rapidity
Proton moving with negative rapidity

$$z = \frac{P_p \cdot P_\psi}{P_p \cdot (P_\psi + P_X - P_p)}$$

$$= \frac{(E + p_z)_\psi}{(E + p_z)_\psi + \sum (E + p_z)_X}$$

$$= \frac{1}{1 + \frac{\sum (E+p_z)_X}{(E+p_z)_\psi}} = \frac{1}{1 + \frac{P_X^+}{P_\psi^+}}$$

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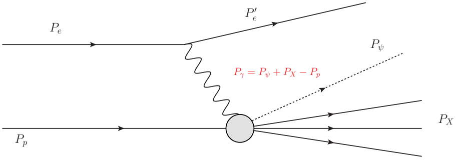

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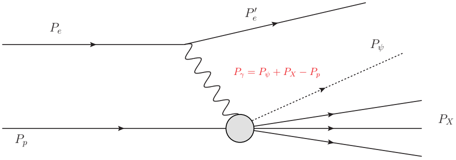

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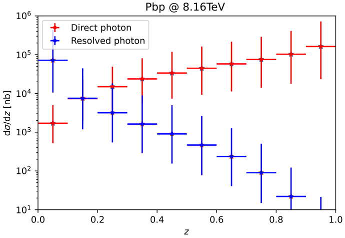
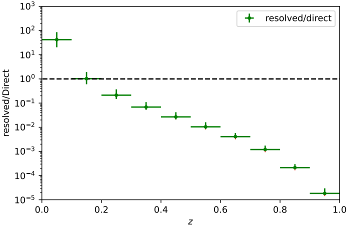
- Anything collinear to the proton $(E + p_z = 0)$ does not contribute!
  - In the exclusive case z=1
  - In the diffractive proton break-up case $z \to 1$
- The most forward tracks contribute most strongly $(E + p_z = m_T e^y)$
  - In the resolved photon case $z \to 0$

z distribution

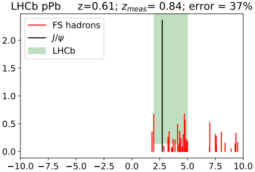




- A cut of $z > 0.5 \sim 1\%$ contamination
- HERA study estimates 2.5% resolved contribution with a cut $z > 0.45$
  Eur. Phys. J. C, 68:401–420, 2010

z Reconstruction at the LHC

← **proton direction**



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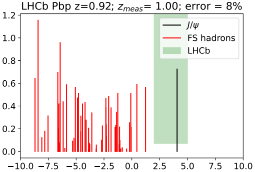

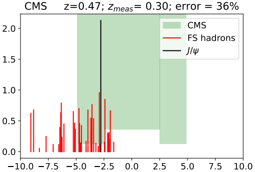

	CMS		**LHCb**
Charged	no	yes	no
p_T	$p_T > 200$ MeV	$p_T > 400$ MeV	$p_T > 100$ MeV
η	$2.5 < \lvert\eta\rvert < 5$	$\lvert\eta\rvert < 2.5$	$2 < \eta < 5$

- $z = \dfrac{1}{1+\frac{P_X^+}{P_\psi^+}}$

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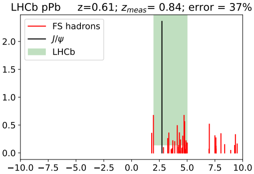

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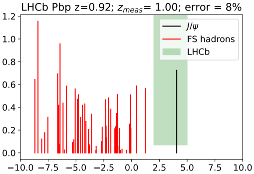

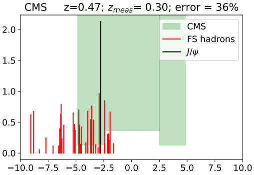

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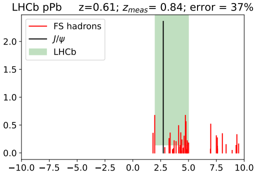

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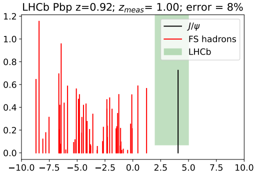

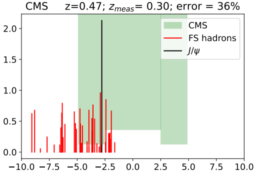

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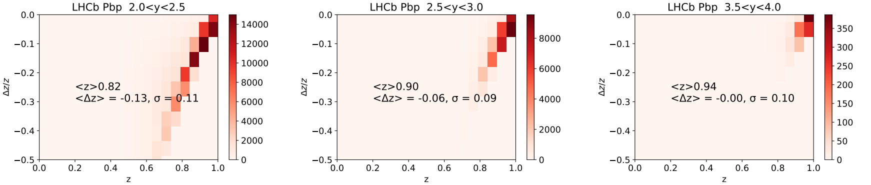
- Particles **in** the **detector acceptance**
  - $z_{meas.} > z$
- $< z >$ increases with rapidity
- z resolution $(\sigma_{\Delta z})$ improves with increasing z

Reconstructing z LHCb *Pbp*...



Relative error [$\Delta z = z - z_{meas.}$] for *"measured"* z as a function of z in bins of rapidity in LHCb *Pbp* collisions.

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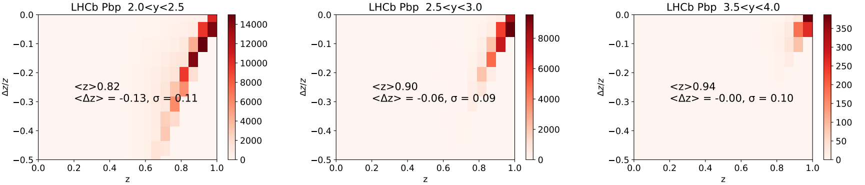

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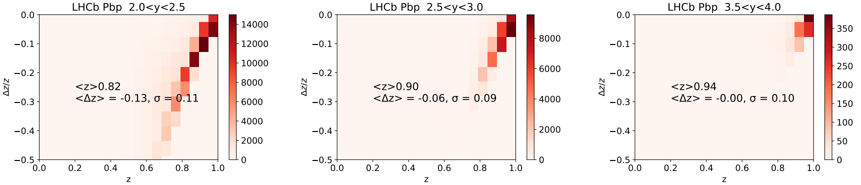

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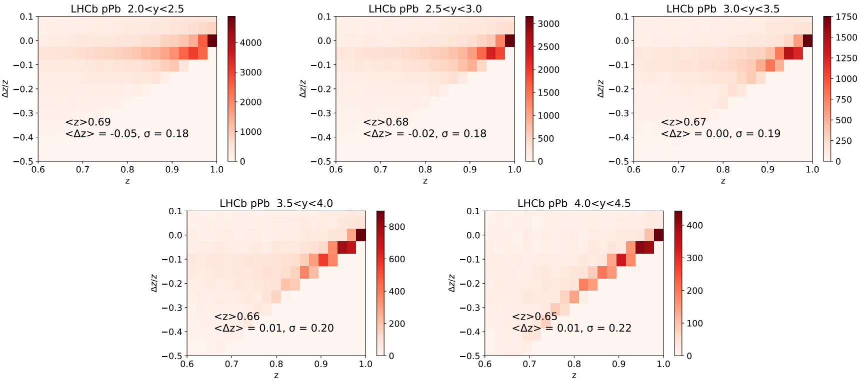
- resolution $\sigma_{\Delta z} \approx 0.1$
  - **LHCb** pPb : $< \Delta z > \mathcal{O}(0.01)$; $\sigma_{\Delta z} \approx 0.2$
  - **CMS** : $< \Delta z > \mathcal{O}(0.1)$; $\sigma_{\Delta z} \approx 0.15$

Summary

- Measuring inclusive photoproduction at the LHC appears feasible which is complimentary to the HERA measurement
- At CMS the ZDC can suppress background to $\mathcal{O}(\%)$
- At LHCb a combination of gap and HeRSCheL cuts can suppress background...
  - In *Pbp* to $\mathcal{O}(0.1\%)$
  - In *pPb* to $\mathcal{O}(1\%)$
- Increasing the size of the rapidity gap cut will enhance the purity of the sample
- z reconstruction appears possible in some regions which will allow control of the resolved contribution
  - LHCb *Pbp*: bias ~ 0.1 (~ 0.001 in most forward bin); resolution ~ 0.1
  - CMS: bias ~ 0.1; resolution ~ 0.15
  - LHCb *pPb*: bias ~ 0.01; resolution ~ 0.2

Reconstructing z @ LHCb pPb...



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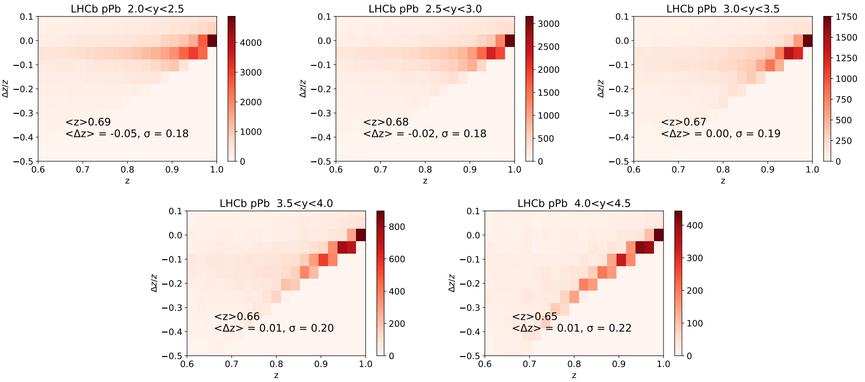
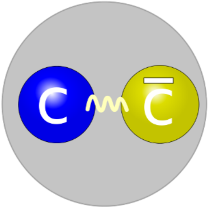


Relative error [$\Delta z = z - z_{meas.}$] for *"measured"* z as a function of z in bins of rapidity in LHCb pPb collisions.

- Resolution ($\sigma_{\Delta z}$) best when J/ψ is furthest from proton

What are Quarkonia

- Bound states of heavy quarks $c\bar{c}$ or $b\bar{b}$



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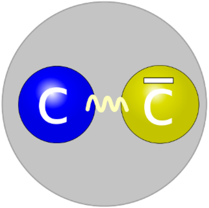

- Quarkonium production is separated into two energy regimes
  - Heavy quark pair production $m_Q >> \Lambda_{QCD}$
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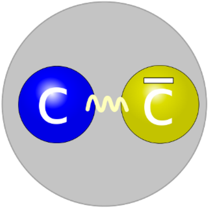

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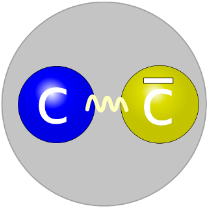

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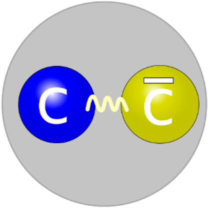

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- **Factorisation** between short and long distance physics
- Production mechanism remains an open question!

Status today ...?

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   - problems in p_T spectrum at large p_T
   - improved by NLO corrections
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3. Colour Evaporation Model
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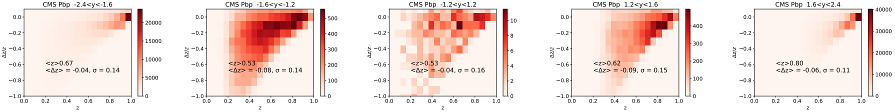
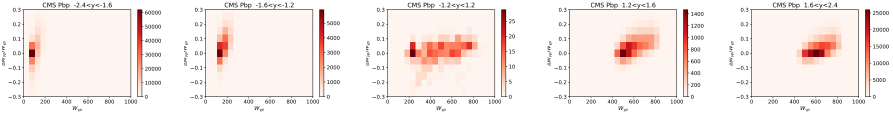
   - fails for $J/\psi J/\psi$ data

Reconstructing z and $W_{\gamma p}$ @ CMS...



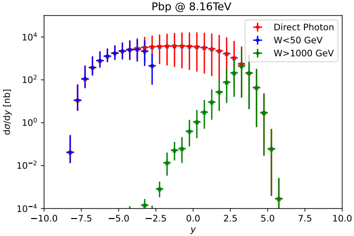
Relative error for real and reconstructed values of z (above) and $W_{\gamma p}$ (below) as a function of z and $W_{\gamma p}$ in bins of rapidity in CMS Pbp collisions. The reduced statistics in the central rapidity bin reflects the large p_T cut.

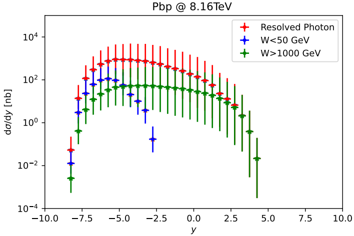


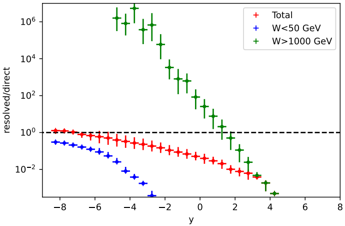
		CMS			
		Mean	Std.	IQR	median
$-2.4 < y^{\psi} < -1.6$	$0 < z < 0.2$	-0.771	0.709	0.841	-0.670
	$0.2 < z < 0.4$	-0.444	0.438	0.537	-0.416
	$0.4 < z < 0.6$	-0.201	0.273	0.321	-0.214
	$0.6 < z < 0.8$	-0.050	0.200	0.203	-0.089
	$0.8 < z < 1$	0.028	0.148	0.116	-0.017
$-1.6 < y^{\psi} < -1.2$	$0 < z < 0.2$	-0.739	0.744	0.941	-0.617
	$0.2 < z < 0.4$	-0.433	0.451	0.580	-0.392
	$0.4 < z < 0.6$	-0.220	0.288	0.367	-0.220
	$0.6 < z < 0.8$	-0.056	0.200	0.239	-0.080
	$0.8 < z < 1$	0.030	0.142	0.154	-0.016
$-1.2 < y^{\psi} < 1.2$	$0 < z < 0.2$	-0.315	0.634	0.745	-0.208
	$0.2 < z < 0.4$	-0.278	0.478	0.629	-0.204
	$0.4 < z < 0.6$	-0.103	0.379	0.526	-0.085
	$0.6 < z < 0.8$	-0.023	0.238	0.295	-0.048
	$0.8 < z < 1$	0.011	0.122	0.098	-0.016
$1.2 < y^{\psi} < 1.6$	$0 < z < 0.2$	-0.517	0.664	0.974	-0.390
	$0.2 < z < 0.4$	-0.394	0.424	0.576	-0.372
	$0.4 < z < 0.6$	-0.268	0.315	0.429	-0.280
	$0.6 < z < 0.8$	-0.102	0.205	0.257	-0.131
	$0.8 < z < 1$	-0.006	0.122	0.130	-0.031
$1.6 < y^{\psi} < 2.4$	$0 < z < 0.2$	-0.418	0.514	0.596	-0.373
	$0.2 < z < 0.4$	-0.361	0.382	0.462	-0.369
	$0.4 < z < 0.6$	-0.283	0.259	0.319	-0.293
	$0.6 < z < 0.8$	-0.145	0.170	0.182	-0.170
	$0.8 < z < 1$	-0.027	0.099	0.080	-0.028

Measures of error in reconstructing z, quantities are in reference to $\frac{\Delta z}{z}$.

Rapidity distribution with slices in $W_{\gamma p}$

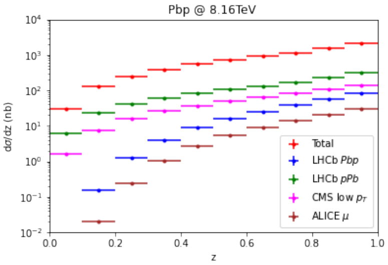


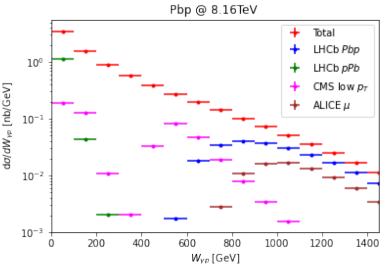




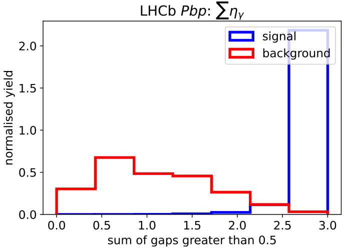
		LHCb							
		Pbp				*pPb*			
		Mean	Std.	IQR	median	Mean	Std.	IQR	Median
$2 < y^{\psi} < 2.5$	$0 < z < 0.2$	-0.278	0.390	0.390	-0.200	-3.201	1.859	1.898	-2.856
	$0.2 < z < 0.4$	-0.280	0.356	0.525	-0.217	-0.919	0.587	0.762	-0.840
	$0.4 < z < 0.6$	-0.414	0.266	0.377	-0.413	-0.213	0.256	0.331	-0.200
	$0.6 < z < 0.8$	-0.296	0.152	0.155	-0.299	-0.018	0.183	0.210	-0.041
	$0.8 < z < 1$	-0.093	0.087	0.110	-0.088	0.047	0.151	0.150	-0.012
$2.5 < y^{\psi} < 3$	$0 < z < 0.2$	-	-	-	-	-2.878	2.424	2.163	-2.300
	$0.2 < z < 0.4$	-0.232	0.286	0.406	-0.174	-0.559	0.511	0.649	-0.483
	$0.4 < z < 0.6$	-0.218	0.290	0.392	-0.189	-0.102	0.257	0.295	-0.090
	$0.6 < z < 0.8$	-0.184	0.191	0.179	-0.23	0.009	0.218	0.256	-0.042
	$0.8 < z < 1$	-0.064	0.084	0.083	-0.059	0.059	0.182	0.185	-0.014
$3 < y^{\psi} < 3.5$	$0 < z < 0.2$	-	-	-	-	-2.282	2.608	1.989	-1.530
	$0.2 < z < 0.4$	-0.351	0.270	0.480	-0.280	-0.296	0.422	0.494	-0.232
	$0.4 < z < 0.6$	-0.152	0.212	0.273	-0.127	-0.050	0.285	0.327	-0.068
	$0.6 < z < 0.8$	-0.116	0.185	0.233	-0.123	0.022	0.259	0.332	-0.053
	$0.8 < z < 1$	-0.030	0.123	0.098	-0.051	0.067	0.212	0.223	-0.018
$3.5 < y^{\psi} < 4$	$0 < z < 0.2$	-	-	-	-	-1.613	2.389	1.661	-0.880
	$0.2 < z < 0.4$	-	-	-	-	-0.165	0.380	0.428	-0.125
	$0.4 < z < 0.6$	-	-	-	-	-0.031	0.319	0.402	-0.077
	$0.6 < z < 0.8$	-0.082	0.161	0.152	-0.094	0.021	0.306	0.429	-0.075
	$0.8 < z < 1$	-0.005	0.101	0.073	-0.039	0.072	0.240	0.264	-0.023
$4 < y^{\psi} < 4.5$	$0 < z < 0.2$	-	-	-	-	-1.060	2.190	1.045	-0.485
	$0.2 < z < 0.4$	-	-	-	-	-0.109	0.390	0.429	-0.105
	$0.4 < z < 0.6$	-	-	-	-	-0.048	0.378	0.487	-0.106
	$0.6 < z < 0.8$	-	-	-	-	-0.006	0.354	0.528	-0.113
	$0.8 < z < 1$	-	-	-	-	0.070	0.266	0.282	-0.032

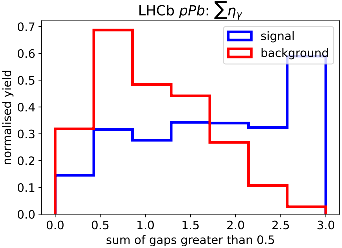
Measures of error in reconstructing z, quantities are in reference to $\frac{\Delta z}{z}$.


Pbp @ 8.16TeV
$d\sigma/dz$ (nb)
z
Total
LHCb *Pbp*
LHCb *pPb*
CMS low p_T
ALICE μ


Pbp @ 8.16TeV
$d\sigma/dW_{\gamma p}$ [nb/GeV]
$W_{\gamma p}$ [GeV]
Total
LHCb *Pbp*
LHCb *pPb*
CMS low p_T
ALICE μ

Rapidity gaps: LHCb

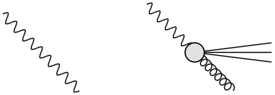




Quarkonium Production @ EIC

(Quasi)on-shell or off-shell photon...

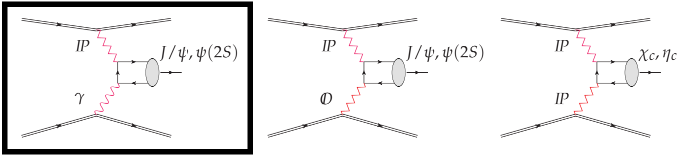
- **Photoproduction** quasi-real photon $Q^2 << m^2_{J/\psi}$
  - Bulk of the cross-section
  - easy to compute (hard scale)
  - resolved component!
- **Leptoproduction** virtual photon γ^* $Q^2 > m^2_{J/\psi}$
  - Smaller cross-section
  - difficult to compute (introduce new scale)
  - **NO** resolved component



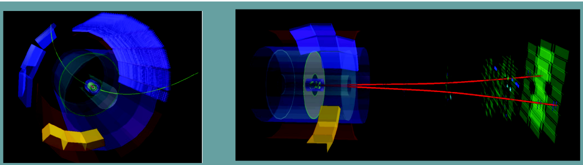
direct and resolved photons

Exclusive J/ψ production

Colourless exchanges via $\mathbb{P}$,$\mathbb{O}$ or γ emission.

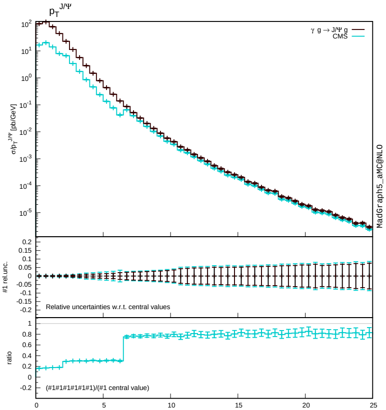


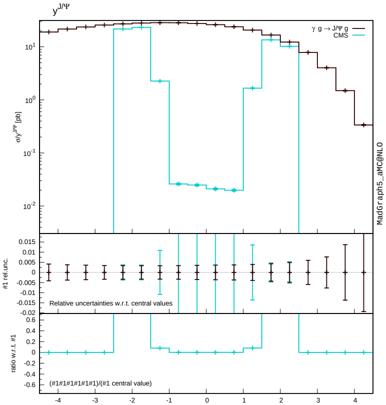
- only **colour singlet** contributions
- Clean signal
  - **only** quarkonia and its decay products are produced.
  - **both** colliding particles stay intact



UPC candidate in the central barrel and muon spectrometer

Photoproduction cross section



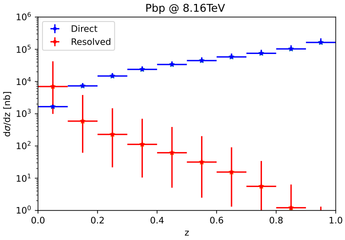


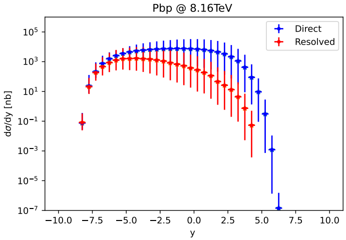
8.16 TeV photoproduction in Pbp

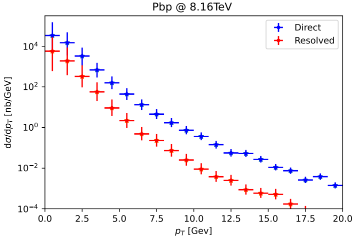
CMS cuts

- Cross-section steeply falling in p_T

Photoproduction cross section: resolved vs. direct



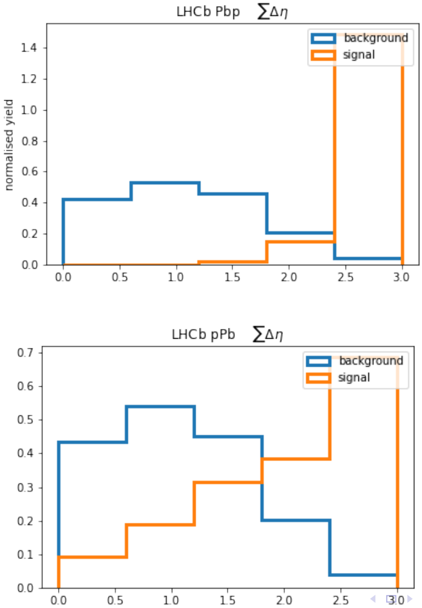




J/Ψ with decay to dimuon cross section in given rapidity regions and mean values of p_T, $|\mathbf{p}|$,z and $W_{\gamma p}$.

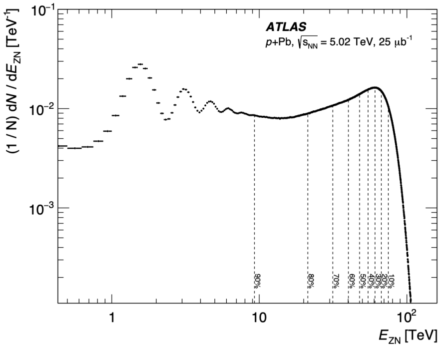
region	σ	$< p_T >$	$< \lvert\mathbf{p}\rvert >$	$< z >$	$< W_{\gamma p} >$
$-5 < y^{\psi} < -3$	665 nb	0.86 GeV	93 GeV	0.73	37 GeV
$-3 < y^{\psi} < -1$	876 nb	0.94 GeV	13 GeV	0.74	98 GeV
$-1 < y^{\psi} < 1$	841 nb	0.99 GeV	2 GeV	0.75	255 GeV
$1 < y^{\psi} < 3$	462 nb	0.97 GeV	11 GeV	0.78	609 GeV
$3 < y^{\psi} < 5$	50 nb	0.86 GeV	50 GeV	0.84	1246 GeV
Total	3148 nb	0.92 GeV	74 GeV	0.74	212 GeV

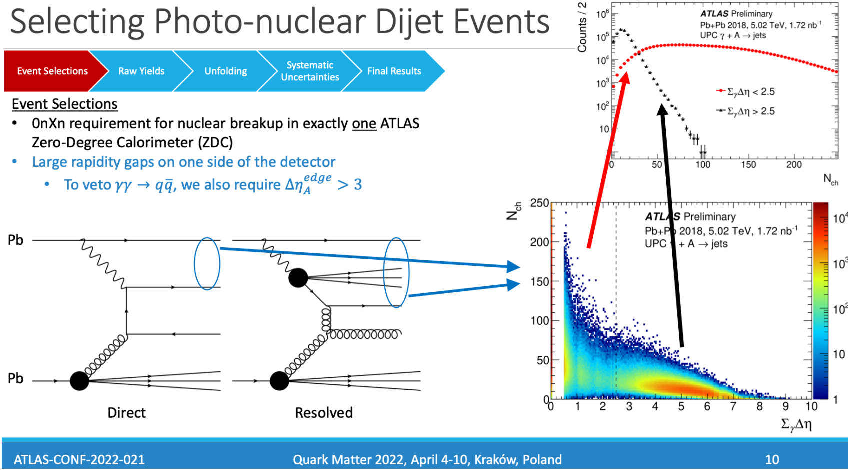
Rapidity gaps: LHCb



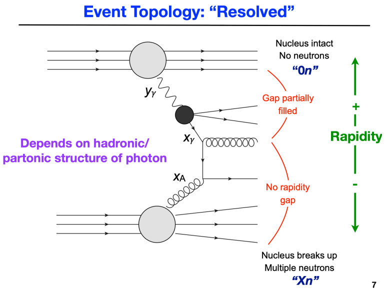
Cutting background: zero degree calorimeter

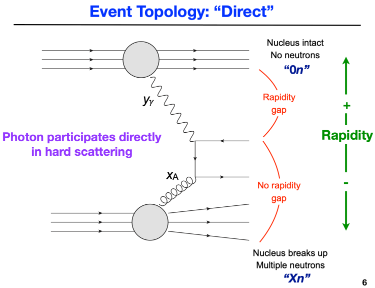
ATLAS CERN-EP-2022-086

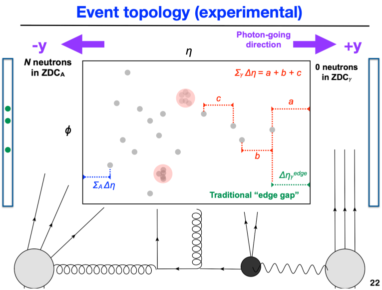




Slide from Ben Gilbert







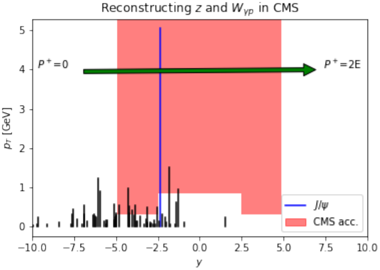
Slides from A. Angerami

z and $W_{\gamma p}$ exclusive vs. inclusive...

$$z = \frac{P_p \cdot P_\psi}{P_p \cdot (P_\gamma = P_\psi + P_X - P_p)} \qquad W_{\gamma p} = \sqrt{(P_\gamma + P_p)^2} = \sqrt{(P_p^- P_\psi^+)\frac{2}{z}}$$

EXCLUSIVE: $P_p \cdot P_\psi \quad \rightarrow z = 1 \qquad \rightarrow W_{\gamma p} = \sqrt{4E_p(m_T e^y)_\psi}$

INCLUSIVE: $P_p \cdot (P_\psi + P_X) \quad \rightarrow z = \frac{1}{1+\frac{P_X^+}{P_\psi^+}}$

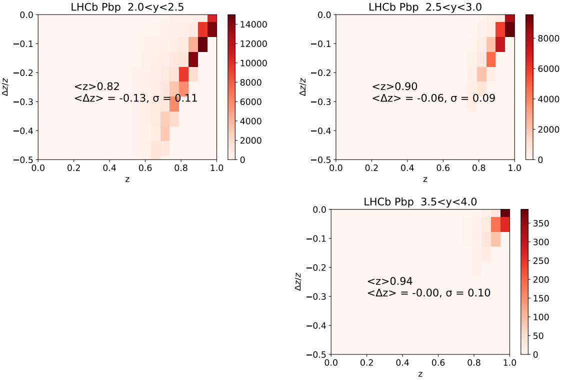


Assuming:

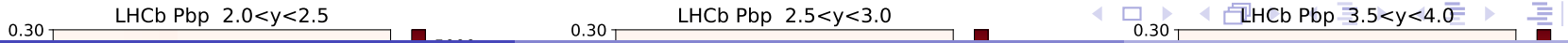
- LHCb Ap: $\mathcal{L}$= 17.4 nb^{-}1
- LHCb pA: $\mathcal{L}$= 12.5 nb^{-}1
- CMS: $\mathcal{L}$= 180 nb^{-}1

	Background	Signal	$\frac{background}{signal}$
Cross section	38330 ± 12 nb	3154 ± 27 nb	~ 12
LHCb *Pbp*	1,600	49,200	~ 30
LHCb *pPb*	5,800	48,000	~ 8
CMS typical	90	18,000	~ 200
CMS low p_T	36,700	436,000	~ 12

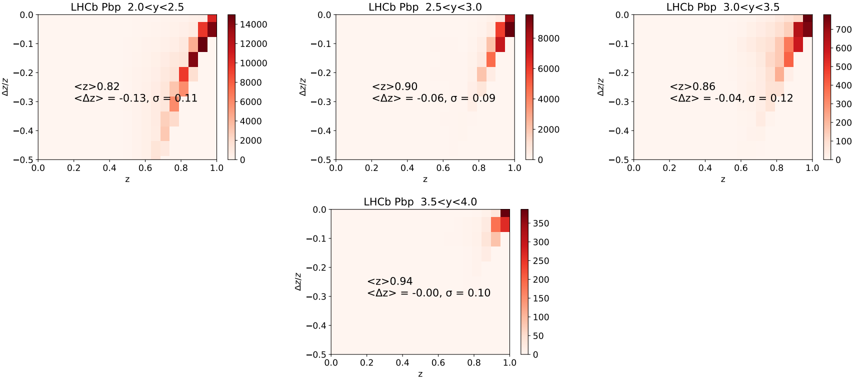
Reconstructing z and $W_{\gamma p}$ @ LHCb *Pbp*...



Relative error for real and measured values of z (above) and $W_{\gamma p}$ (below) as a function of z and $W_{\gamma p}$ in bins of rapidity in LHCb *Pbp* collisions.

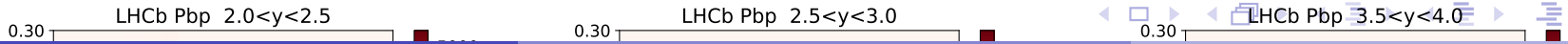


Reconstructing z and $W_{\gamma p}$ @ LHCb Pbp...

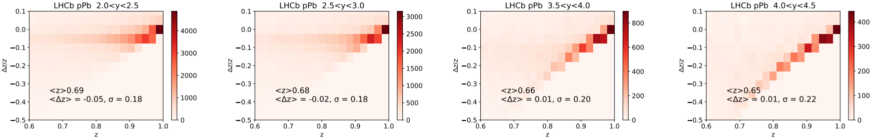


Relative error for real and measured values of z (above) and $W_{\gamma p}$ (below) as a function of z and $W_{\gamma p}$ in bins of rapidity in LHCb Pbp collisions.

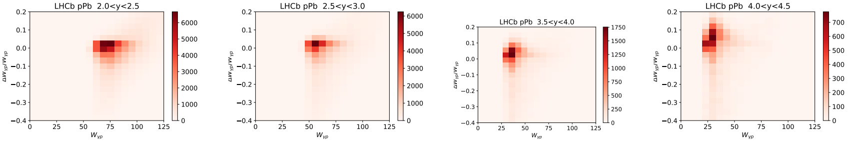
- $z_{meas} > z$
- $W_{\gamma p}^{meas} < W_{\gamma p}$
- Relative error least in largest z bin



Reconstructing z and $W_{\gamma p}$ @ LHCb pPb...



Relative error for real and reconstructed values of z (above) and $W_{\gamma p}$ (below) as a function of z and $W_{\gamma p}$ in bins of rapidity in LHCb pPb collisions.



through direct photon processes are

$$\gamma + g \;\rightarrow\; c\bar{c}\left[1,{}^3S_1;\, 8,{}^3S_1;\, 8,{}^1S_0;\, 8,{}^3P_J\right] + g, \quad (17)$$

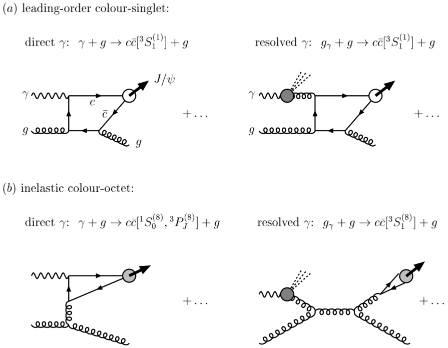
$$\gamma + q/\bar{q} \;\rightarrow\; c\bar{c}\left[8,{}^3S_1;\, 8,{}^1S_0;\, 8,{}^3P_J\right] + q/\bar{q}, \quad (18)$$

where the initial-state parton originates from the target proton. For resolved photon processes, the subchannels are

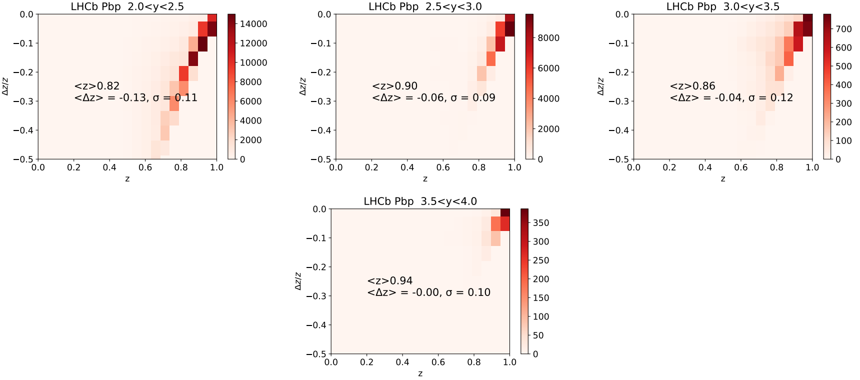
$$g + g \;\rightarrow\; c\bar{c}\left[1,{}^3S_1;\, 8,{}^3S_1;\, 8,{}^1S_0;\, 8,{}^3P_J\right] + g, \quad (19)$$

$$g + q/\bar{q} \;\rightarrow\; c\bar{c}\left[8,{}^3S_1;\, 8,{}^1S_0;\, 8,{}^3P_J\right] + q/\bar{q}, \quad (20)$$

$$q + \bar{q} \;\rightarrow\; c\bar{c}\left[8,{}^3S_1;\, 8,{}^1S_0;\, 8,{}^3P_J\right] + g, \quad (21)$$



Reconstructing z LHCb *Pbp*...



Relative error [$\Delta z = z - z_{meas.}$] for *"measured"* z as a function of z in bins of rapidity in LHCb *Pbp* collisions.

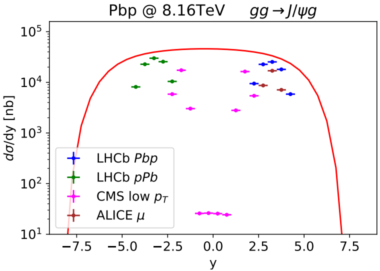
- $z_{meas} > z$

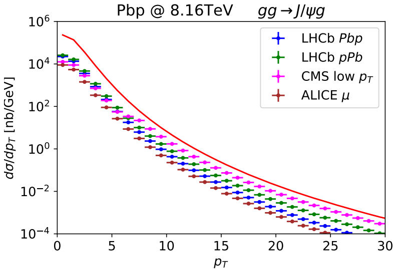
	diffractive		γg-fusion		background
	exclusive (p break-up)	resolved-Pomeron	direct-photon	resolved-photon	gg fusion
J/ψ	67 μb (134 μb)	2 μb (4 μb)	52 μb	8 μb	642 μb
Υ	104 nb (208 nb)	5 nb (10 nb)	108 nb	54 nb	95 μb

Total cross section at $\sqrt{s} = 8.16$ TeV for exclusive and resolved-Pomeron contributions from the theoretical study described in the text [Phys. Rev. D, 96(7):074029, 2017]. The diffractive quantities in parenthesis account proton break-up contributions. All other contributions calculated using HELAC-Onia. Also included is the $\Upsilon(1S)$ cross sections.

Detector acceptance: background $gg \to J/\psi(^3S_1^1)g$

- Photoproduction cross section has steeper p_T distribution





Detector acceptance for **background**:

LHCb	**CMS** typical	**CMS** low p_T	**ATLAS**	**ALICE** e^-e^+	**ALICE** $\mu^-\mu^+$
7% (*Pbp*) 10% (*pPb*)	0.26%	6%	0.04%	7%	3% (*Pbp*) 4% (*pPb*)

Detector acceptance for **signal** :

3% (*Pbp*) 15% (*pPb*)	0.01%	6%	0.003%	10%	1% (*Pbp*) 6% (*pPb*)