Results from peripheral and ultra-peripheral collisions at the LHC

Giulia Manca,
Universita` degli studi di Cagliari (IT) & I.N.F.N.
on behalf of the ALICE, ATLAS, CMS and LHCb collaboration

MPI@LHC 2021, Online & Lisbon (Portugal) 11th-15th Oct 2021

Outline

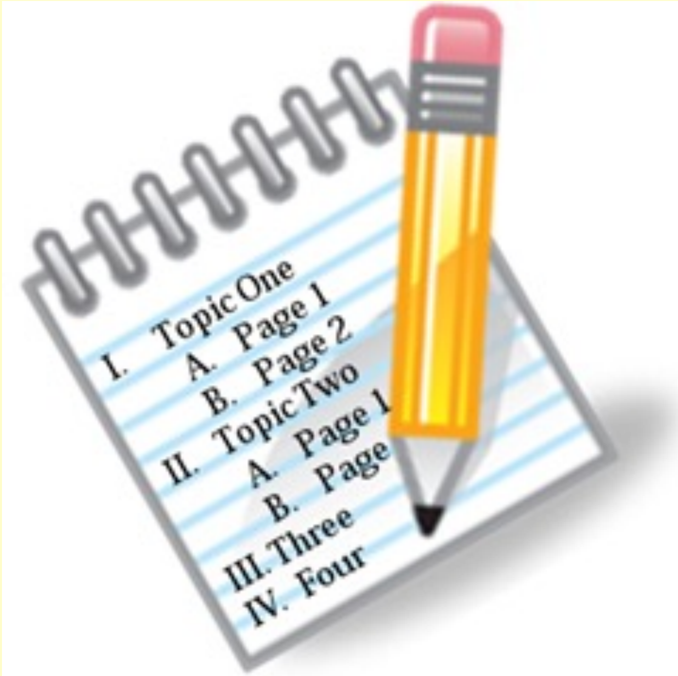
→ Motivation

→ Cern and the LHC

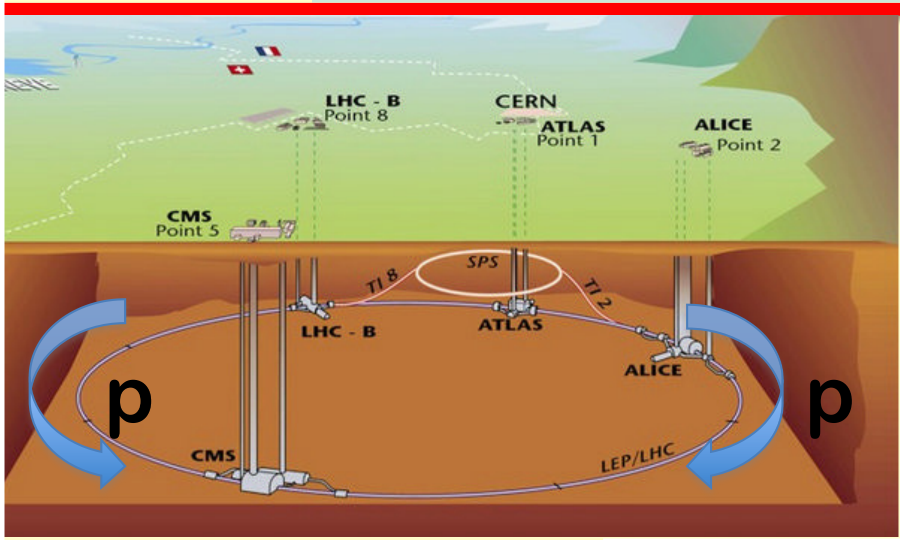
→ The experiments

→ Some selected results

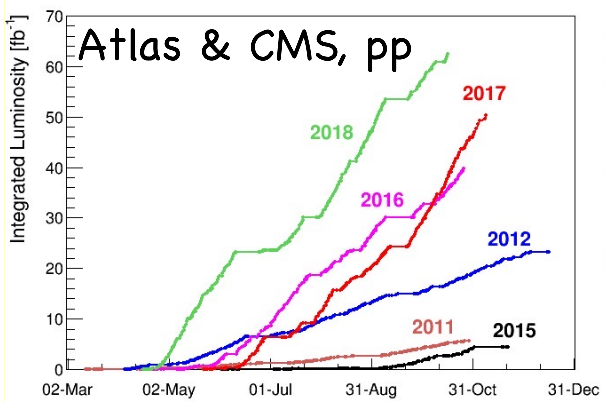
→ Conclusions and outlook

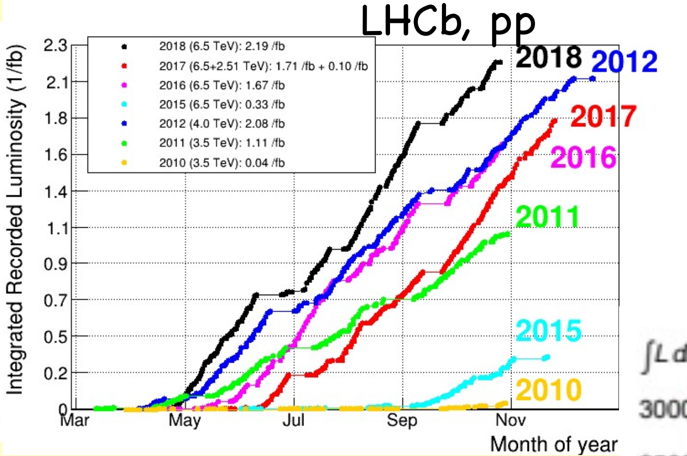


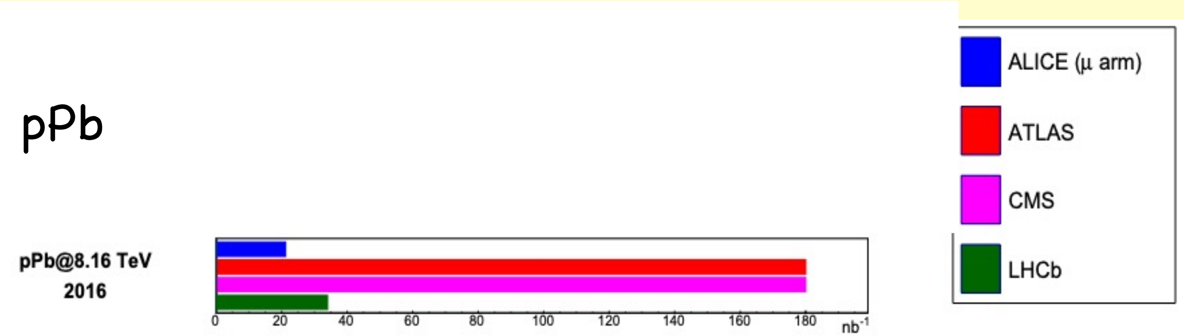
CERN and the LHC

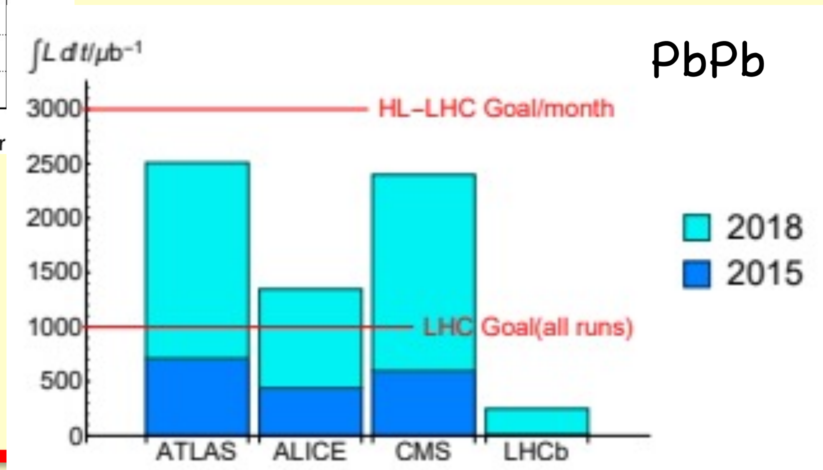


- → pp collider 2010-18@$\sqrt{s}$ = 2.76, 5, 7, 8, 13 TeV
- → In 2013 & 2016 collected pPb/Pbp data @ $\sqrt{s_{NN}}$=5 and 8.16 TeV
- → PbPb collisions @ $\sqrt{s}$=5TeV, in 2015 & in 2018
  - → First time all 4 experiments participated
- → XeXe collisions @$\sqrt{s}$=5.4 TeV, L≈0.4 μb^{-1}
- → LHCb also able to collect data in "fixed target" mode (SMOG)



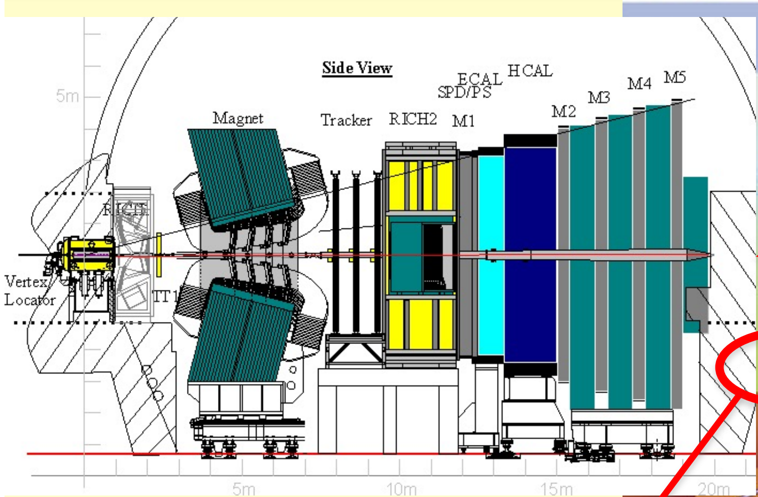


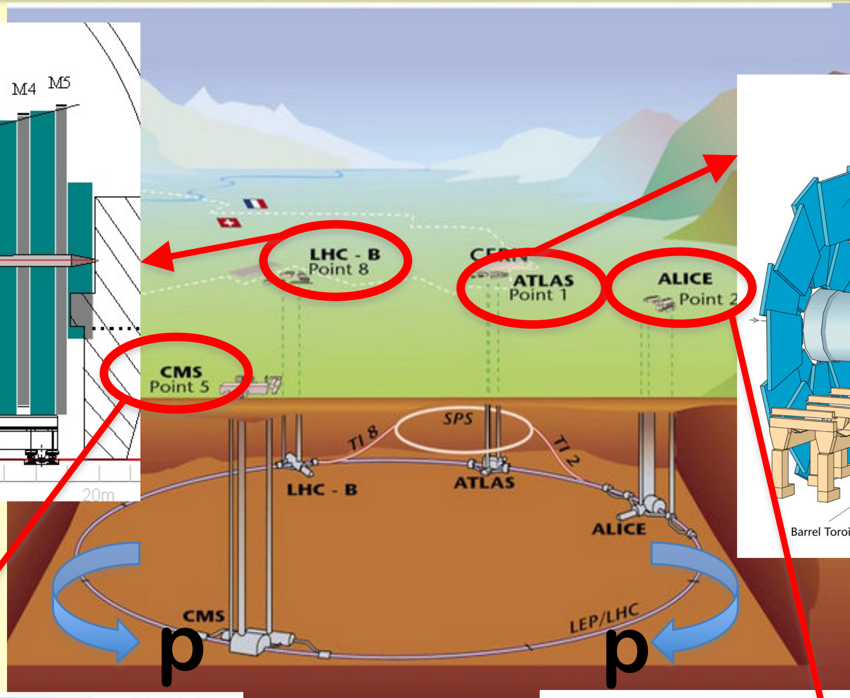


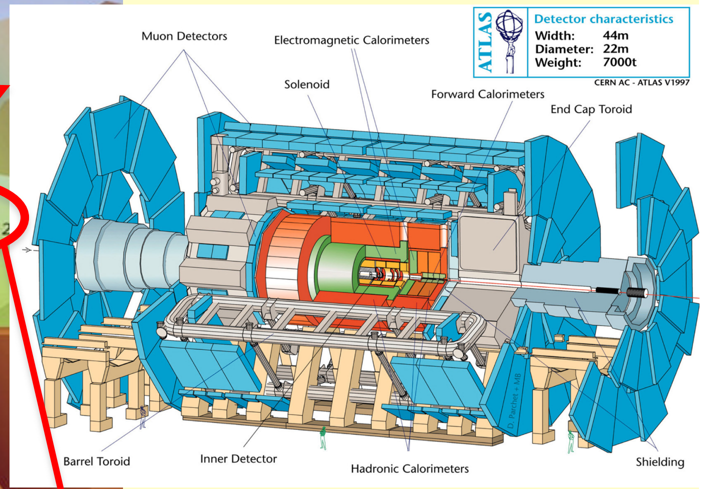


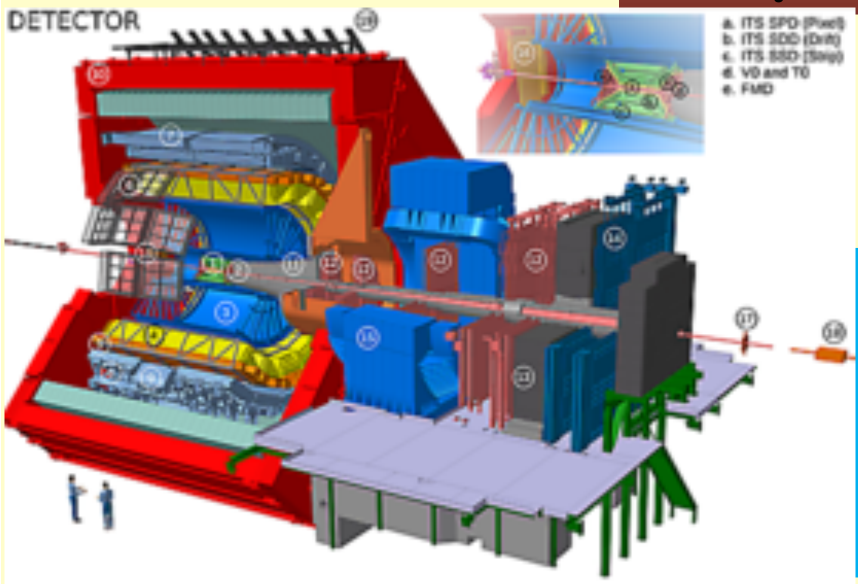
doi:10.18429/JACoW-IPAC2019-WEYYPLM2

The four LHC Detectors

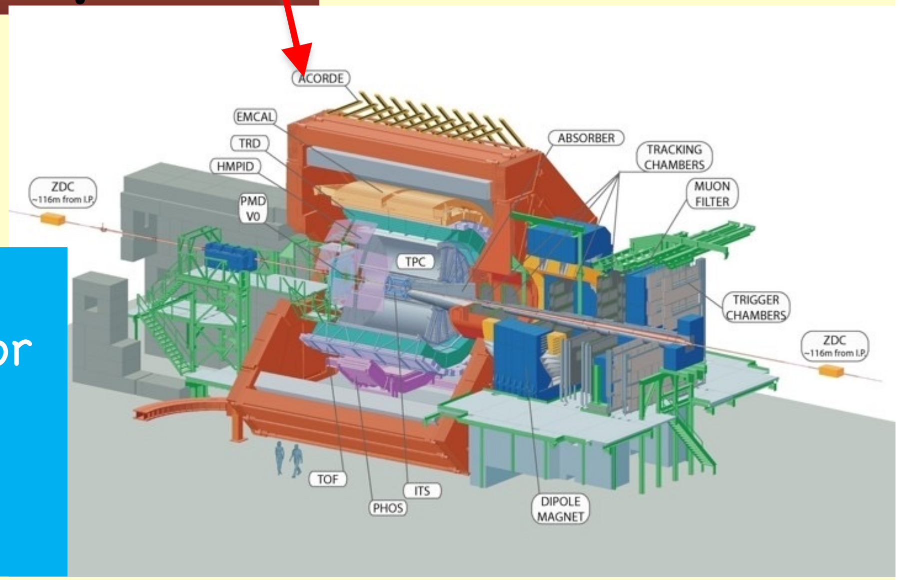




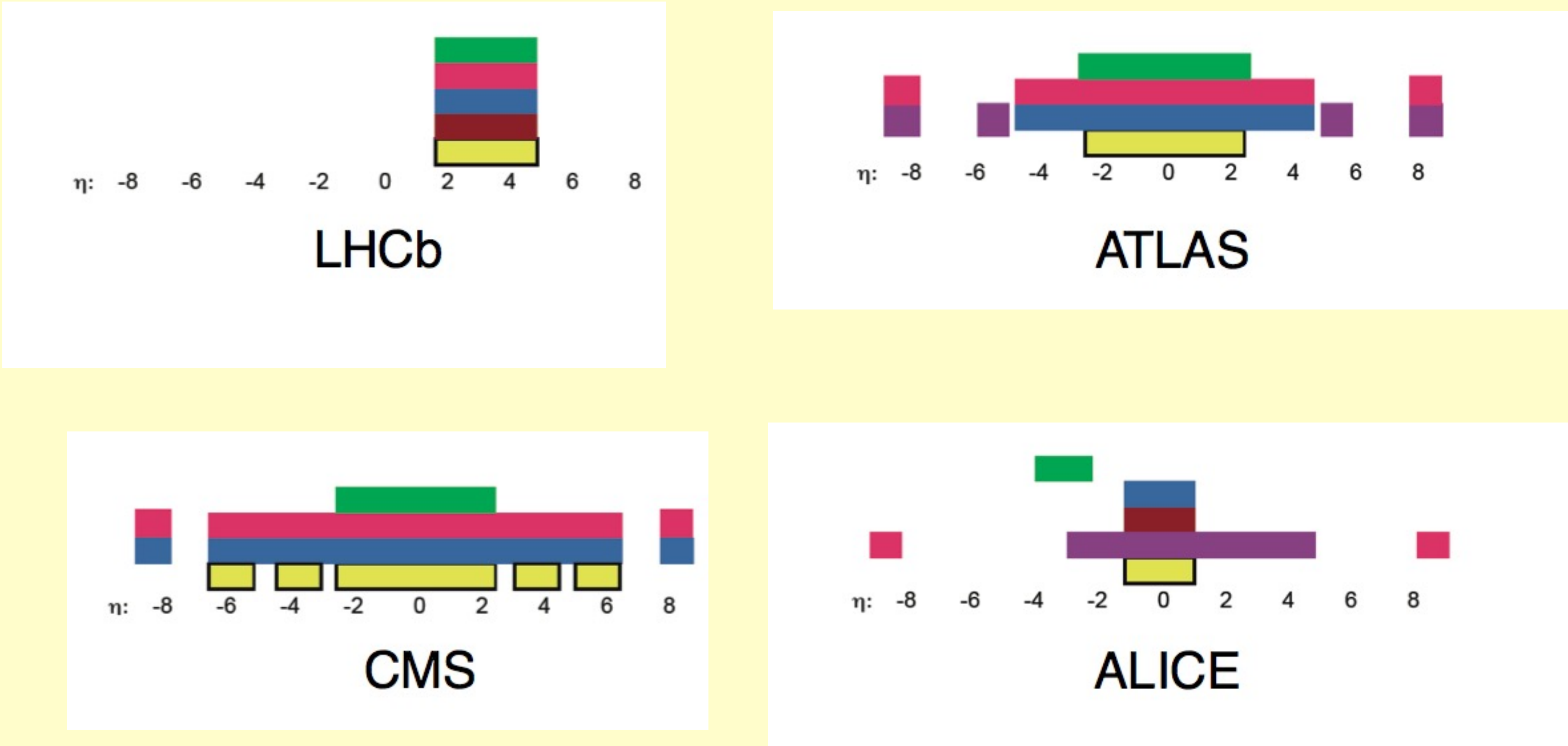




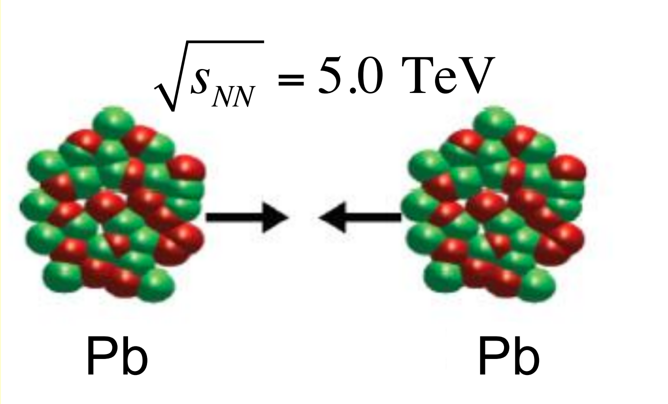
LHCb & ALICE major upgrades, ready in 2022



Rapidity Range



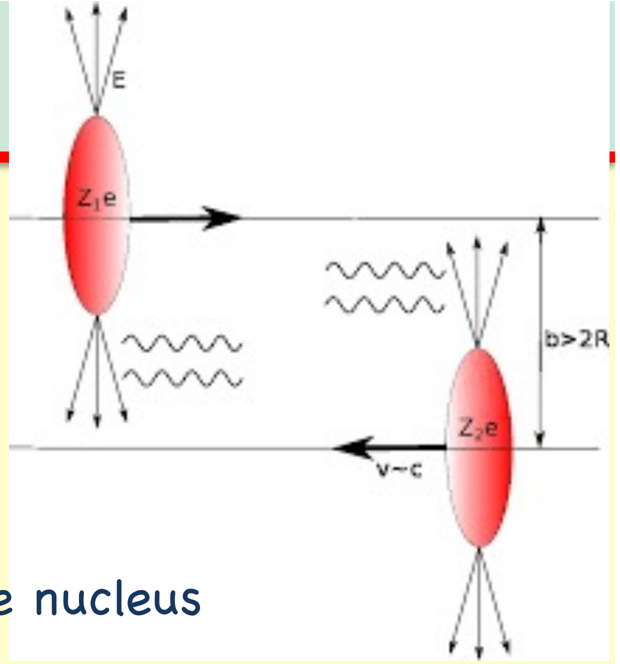
tracking, ECAL, HCAL, counters lumi, muon, hadron PID



PbPb collisions

LHCb: arXiv:2107.03223, arXiv:2108.02681
ALICE: Eur.Phys.J.C 81 (2021), PLB 817 (2021) 136280 (http://alice-figure.web.cern.ch/node/18568, http://alice-figure.web.cern.ch/node/19575)
ATLAS: Phys.Rev. C 104 (2021) 024906, ATLAS-CONF-2019-051,Phys. Rev. C. 104 014903 JHEP 03 (2021) 243)
CMS: CMS-PAS-HIN-18-011, Phys. Rev. Lett. 127, 122001, Phys.Lett.B 797 (2019) 134826

Ultra-Peripheral PbPb Collisions



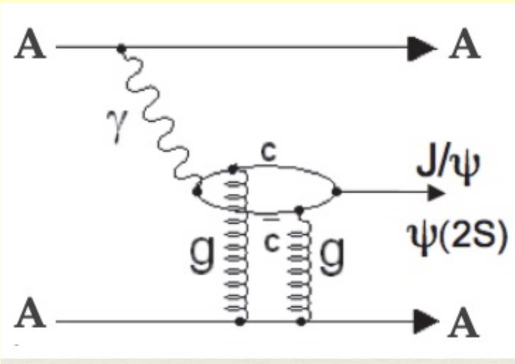
→ UPC: Two nuclei collide with each-other with impact parameter larger than the sum of their radii

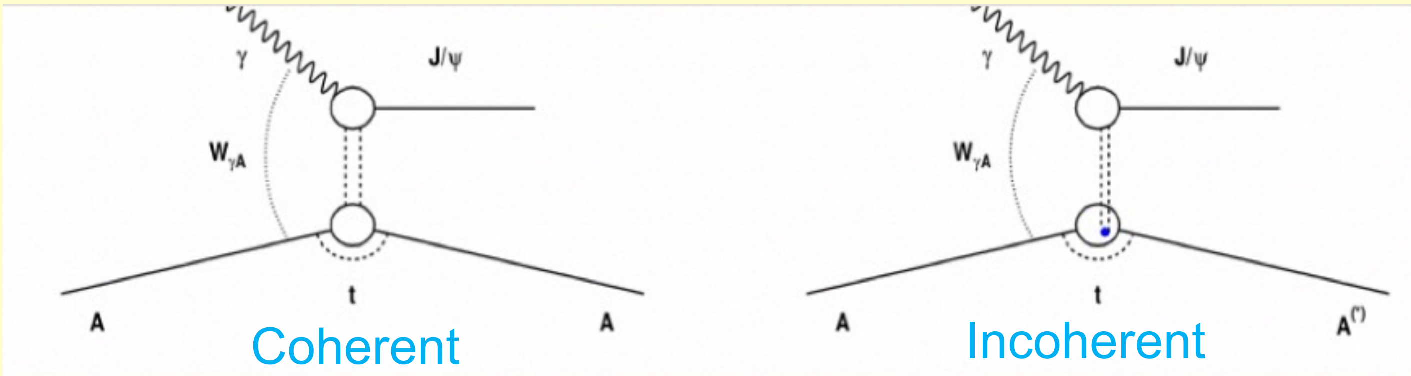
→ Can exchange a photon ! => Photon induced interactions enhanced by strong EM field of nucleus.

- Coherent: photon interacts with nucleus as a whole
- Incoherent: photon interacts with the nucleons in the nucleus

→ Coherent charmonia production (J/ψ and ψ(2S))

- Constraints on gluon PDFs
- Ratio of the two indicates the correct vector meson wave function in dipole scattering models [PLB 772 (2017) 832, PRC (2011) 011902]





Charmonium production in UPC

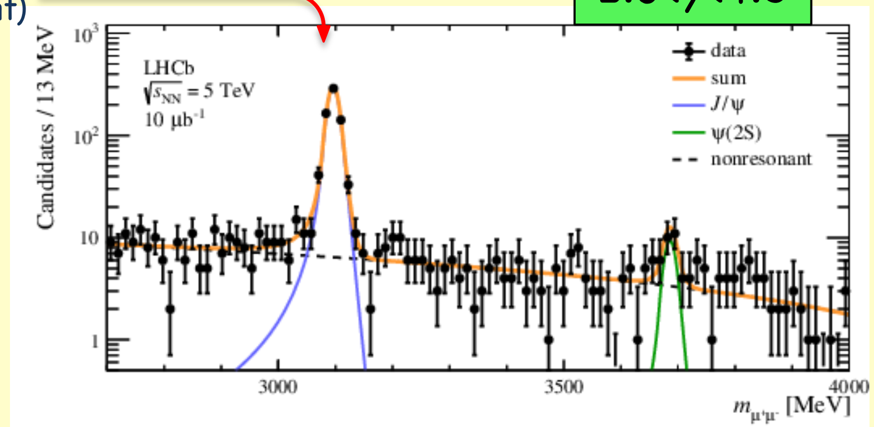
→ Measurement of coherent cross-section: *[Arxiv:2107.03223, Phys.Lett. B798 (2019) 134926]*

$$\frac{d\sigma^{\psi}_{coherent}}{dy} = \frac{N^{\psi}_{coherent}}{\varepsilon_{total} \cdot B(\psi \to \mu^+\mu^-) \cdot \mathcal{L} \cdot \Delta y}, \qquad \psi = J/\psi, \psi(2S)$$

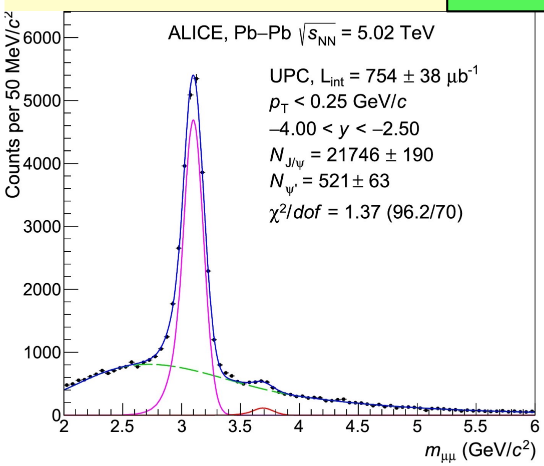
→ Signal: essentially two tracks and nothing else in the detector!

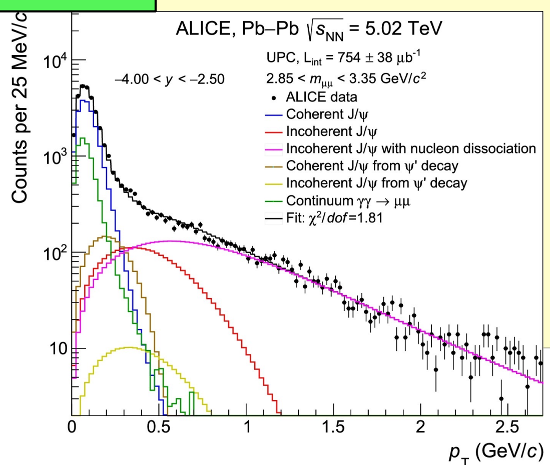
→ N signal events extracted from fit on $M_{\mu\mu}$ (coherent+incoherent)

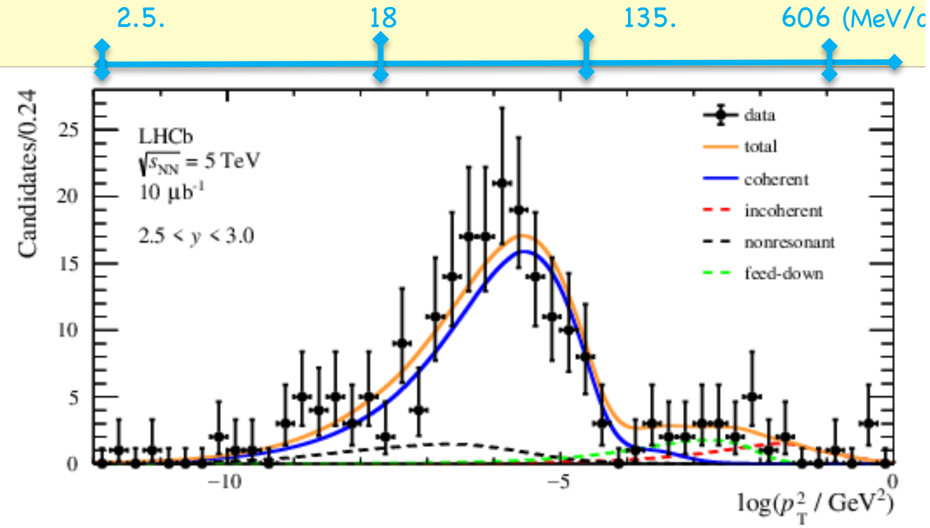
2.0<y<4.5



-4.0<y<-2.5







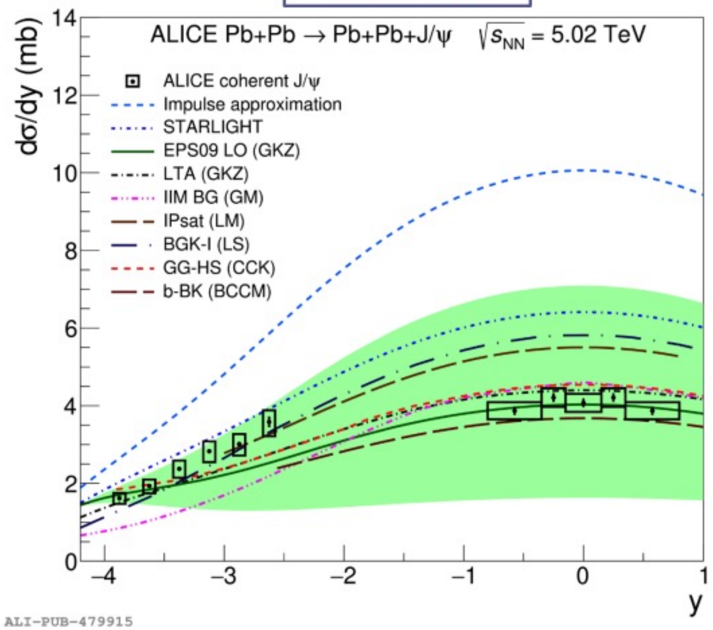
→ ALICE explored also the mid-rapidity range |y| < 0.8 in ee,μμ and pp decays

→ Coherent component extracted using template fits from STARlight

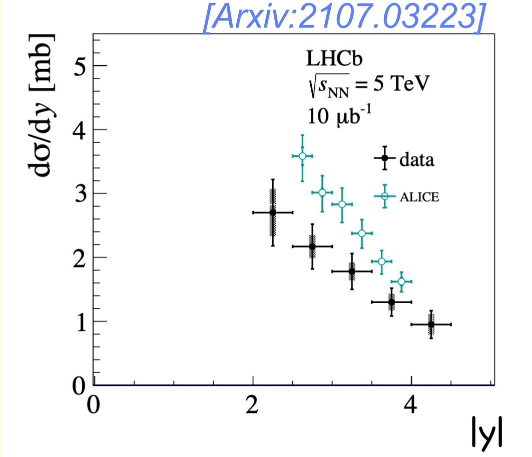
Results

- Impulse approximation: Exclusive photoproduction data off protons, neglecting all nuclear effects except coherence.
- STARlight: Vector Meson Dominance model with Glauber-like formalism to calculate cross section in Pb-Pb
- GKZ: EPS09 LO parametrization of the nuclear shadowing data
- GKZ: Leading twist approximation (LTA) of nuclear shadowing
- CCK: Color dipole model with the structure of the nucleon described by the hot spots
- BCCM: Color dipole approach coupled to the solutions of the Balitsky-Kovchegov equation
- GM, LM, LS: Color dipole approach coupled to the Color Glass Condensate formalism with different assumptions on the dipole-proton scattering amplitude

arXiv:2101.04577



[Arxiv:2107.03223]



→ *Results are within 1.3σ*

→ ALICE Extracted R_g=0.65±0.03 at Bjorken-x $(0.3,1.4)\times10^{-3}$

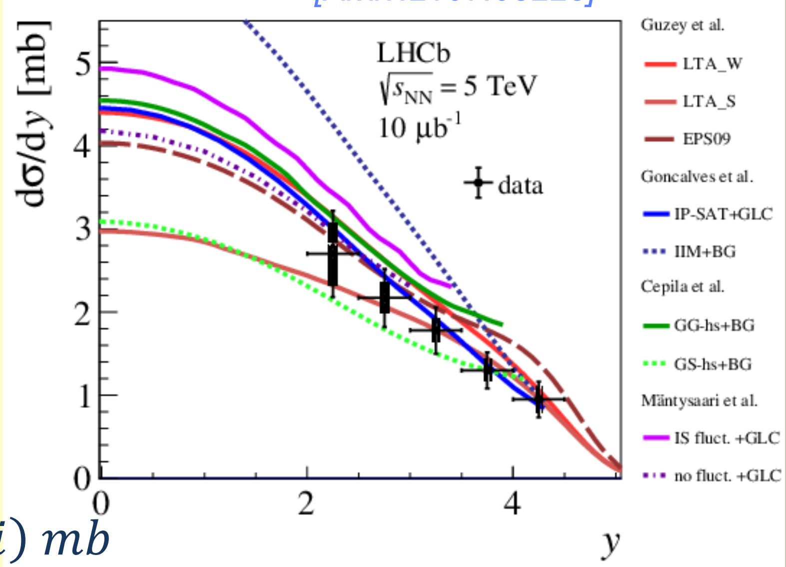
→ pQCD calculation [PRC 93 (2016) 055206]

→ Color dipole models [PRD 96 (2017) 094027] [PRC 97 (2018) 024901] [PLB 772 (2017) 832]

→ LHCb Integrated over y [2.0-4.5]:

$$\sigma^{\psi}_{coherent} = 4.45 \pm 0.24(stat) \pm 0.18(syst) \pm 0.58(lumi)\ mb$$

[Arxiv:2107.03223]

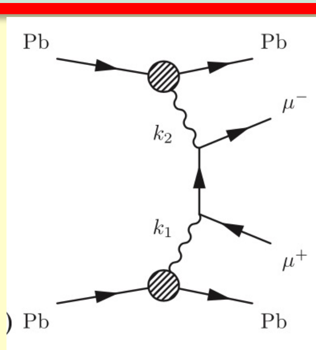


More UPC measurements !

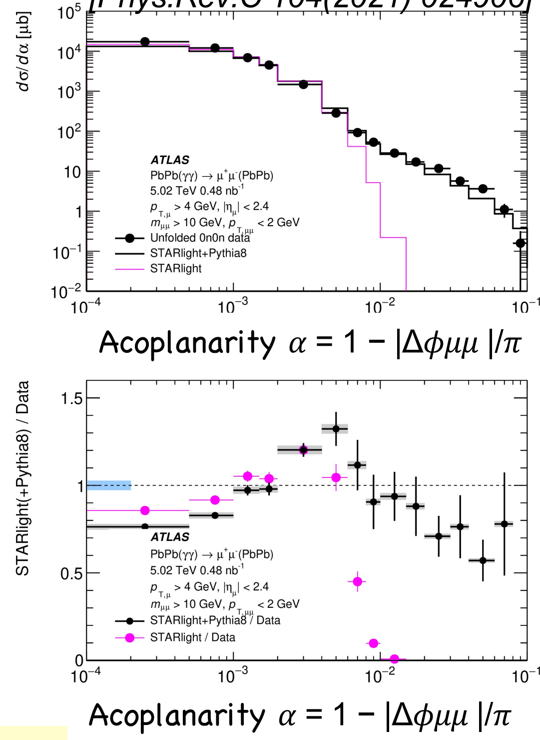
ATLAS Exclusive dimuon production

- $\mathcal{L} = 0.48\, nb^{-1}$
- $p_T^{\mu} > 4$ GeV/c,
- $|\eta^{\mu}| < 2.4$,
- $M^{\mu\mu} > 10$ GeV/c^2, $p_T^{\mu\mu} < 2$ GeV/c
- Cross-section $\gamma+\gamma \rightarrow \mu^+\mu^-$: $\sigma^{\mu\mu}_{fid} = 34.1 \pm 0.3(stat.) \pm 0.7(syst.)$ μb

→ *Two-particle azimuthal correlations [Talk H.Hamdaoui onThu@5pm]*



[Phys.Rev.C 104(2021) 024906]



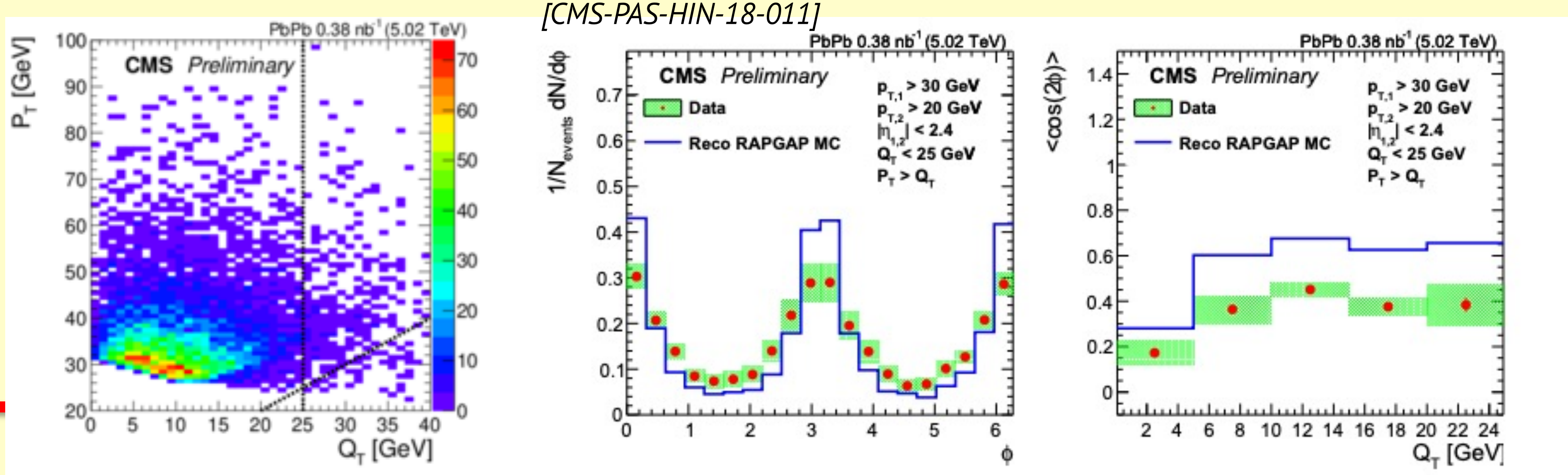
CMS Angular correlations in exclusive dijet photoproduction

- $\mathcal{L} = 0.38\, nb^{-1}$
- p_T^{j} ($p_T^{j'}$) > 30(20) GeV/c, $\eta^{j,j'} < 2.4$, φ = angle

between $\mathbf{Q_T = p_T^{j} + p_T^{j'}}$ and $\mathbf{P_T} = 1/2(\mathbf{p_T^{j} - p_T^{j'}})$

[CMS-PAS-HIN-18-011]

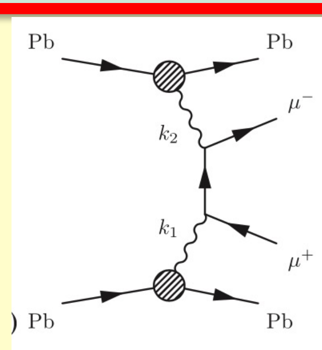
First step towards extraction of Wigner or Husimi gluon PDFs



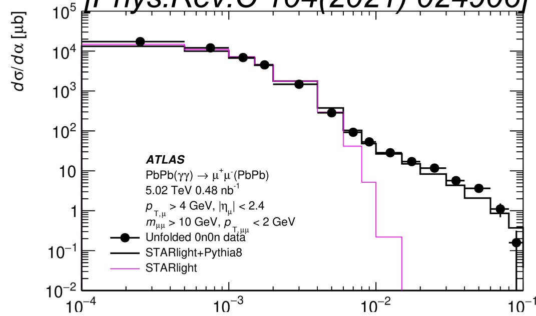
More UPC measurements !

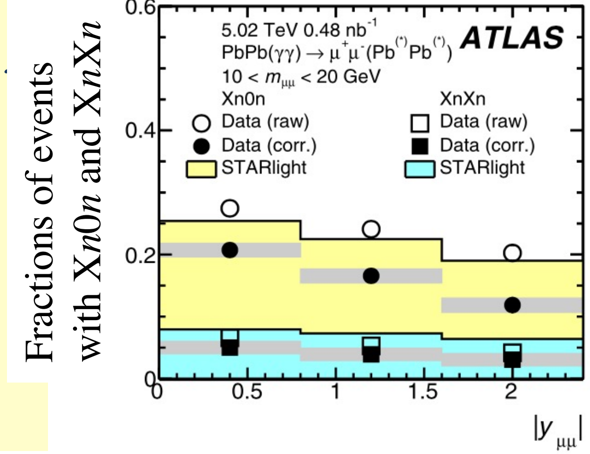
Exclusive dimuon production

- $\mathcal{L} = 0.48\, nb^{-1}$
- $p_T^{\mu} > 4$ GeV/c,
- $|\eta^{\mu}| < 2.4$,
- $M^{\mu\mu} > 10$ GeV/c^2, $p_T^{\mu\mu} < 2$ GeV/c
- Cross-section $\gamma+\gamma \rightarrow \mu^+\mu^-$: $\sigma^{\mu\mu}_{fid} = 34.1 \pm 0.3(stat.) \pm 0.7(syst.)\ \mu b$



[Phys.Rev.C 104(2021) 024906]





→ *Two-particle azimuthal correlations [Talk H.Hamdaoui onThu@5pm]*

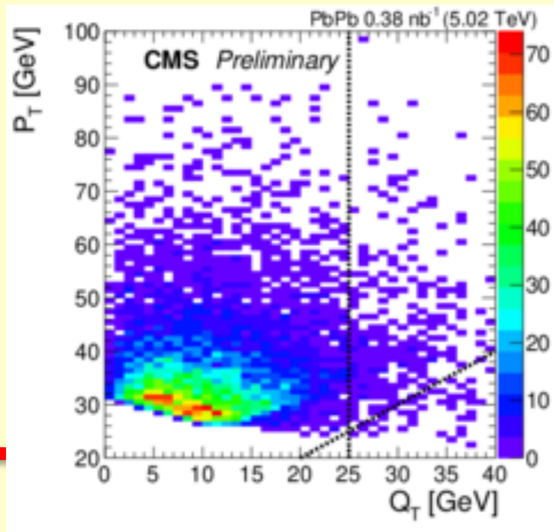
Angular correlations in exclusive j-j photoproduction

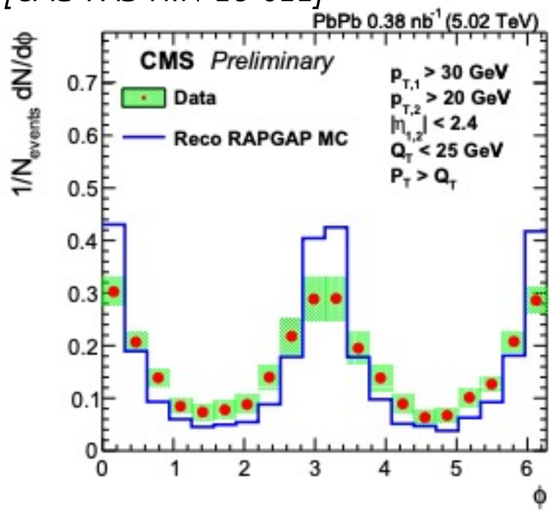
- $\mathcal{L} = 0.38\, nb^{-1}$
- p_T^{j} ($p_T^{j'}$) > 30(20) GeV/c, $\eta^{j,j'} < 2.4$, φ = angle

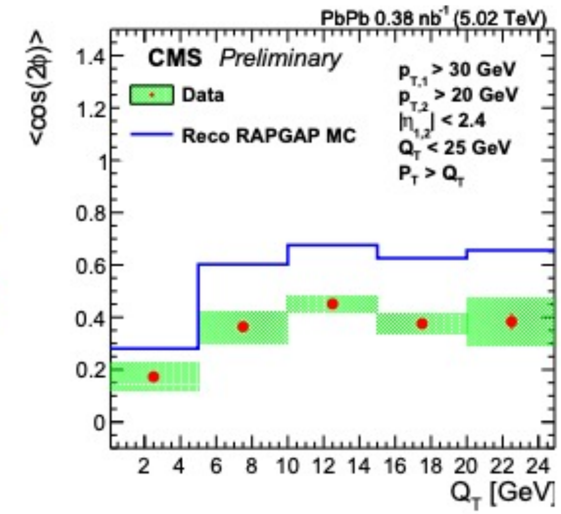
between $\mathbf{Q_T = p_T^{j} + p_T^{j'}}$ and $\mathbf{P_T = 1/2(p_T^{j} - p_T^{j'})}$

[CMS-PAS-HIN-18-011]

First step towards extraction of Wigner or Husimi gluon PDFs

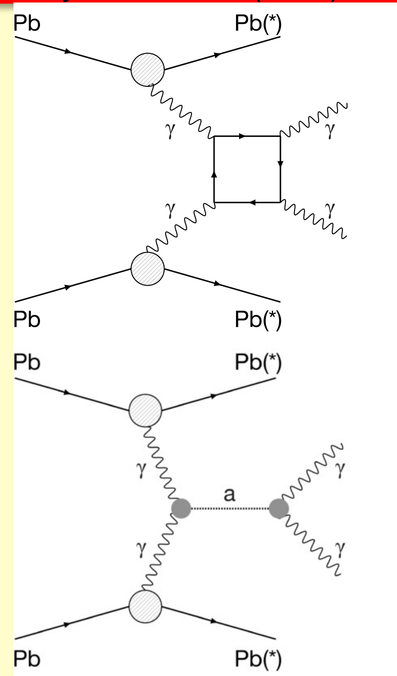






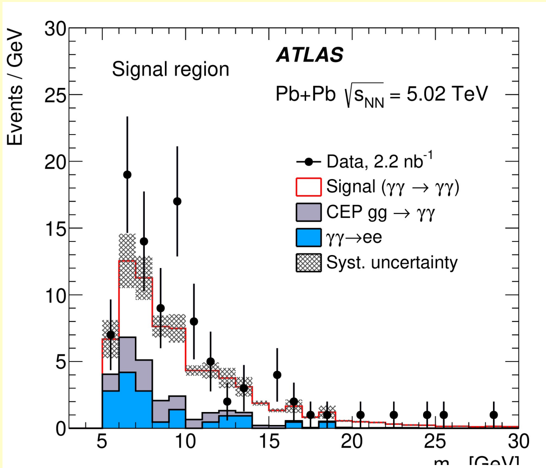
Light-by-light scattering

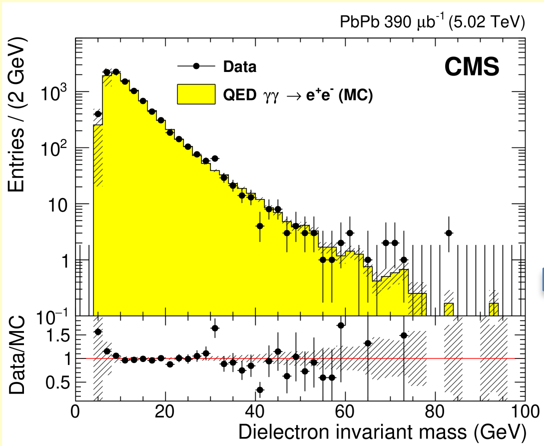
[JHEP 03(2021) 243, Phys.Lett.B 797 (2019) 134]

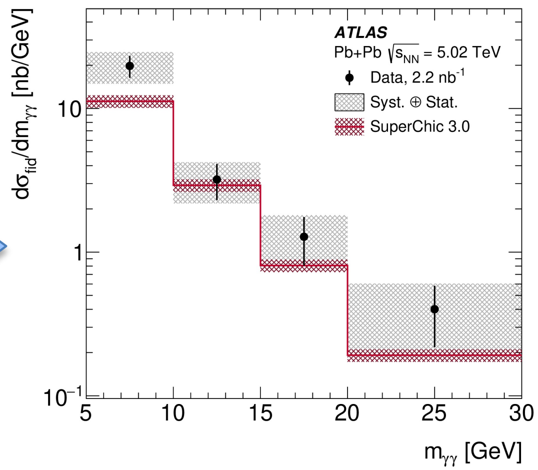


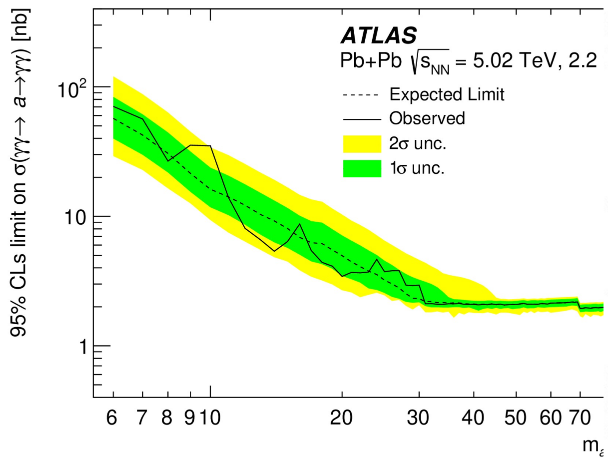
→ Measurement of light-by-light scattering and search for axion-like particles

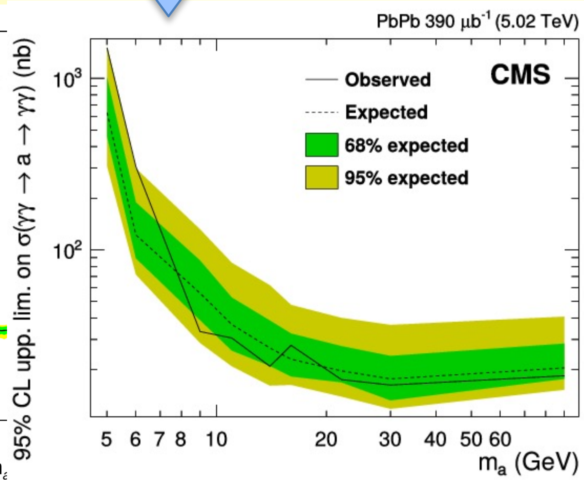
- $\mathcal{L} = 2.2\ nb^{-1}$ (ATLAS), $390\ \mu b^{-1}$(CMS)
- Two photons exclusively, $E_T^{\gamma} > 2.5$ GeV/c, $|\eta^{\gamma}| < 2.37$
- $M^{\mu\mu} > 5$ GeV/c^2, small $p_T^{\gamma\gamma}$ & $\alpha^{\gamma\gamma}$
- Cross-section $\gamma\gamma \rightarrow \gamma\gamma$: σ_{fid}=122±46(stat.)±29(syst.)±4(th) μb [CMS]







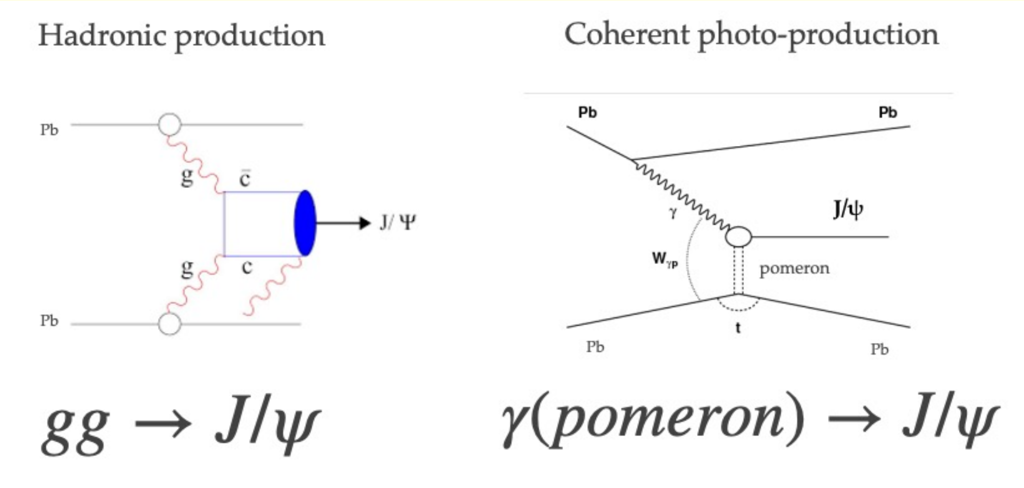


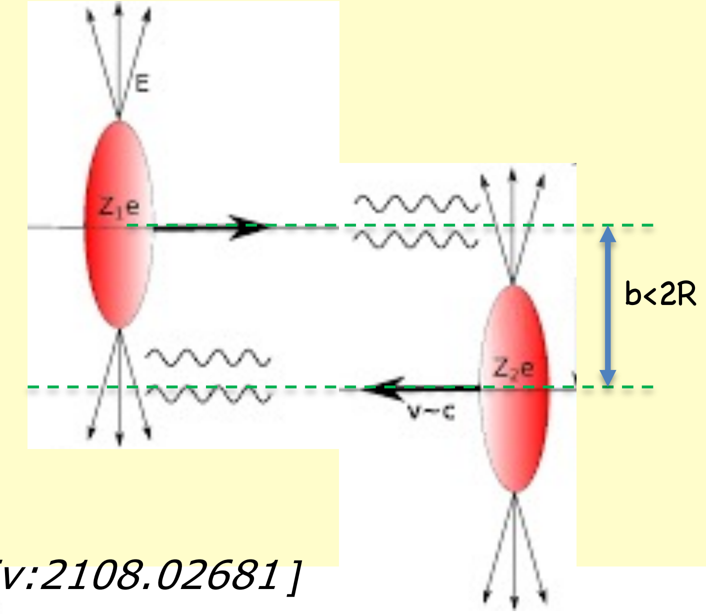


Prompt J/ψ production in peripheral PbPb collisions

→ Peripheral: the nuclei barely touch each other with < 2 R Pb

- Possible to identify also hadronic component !





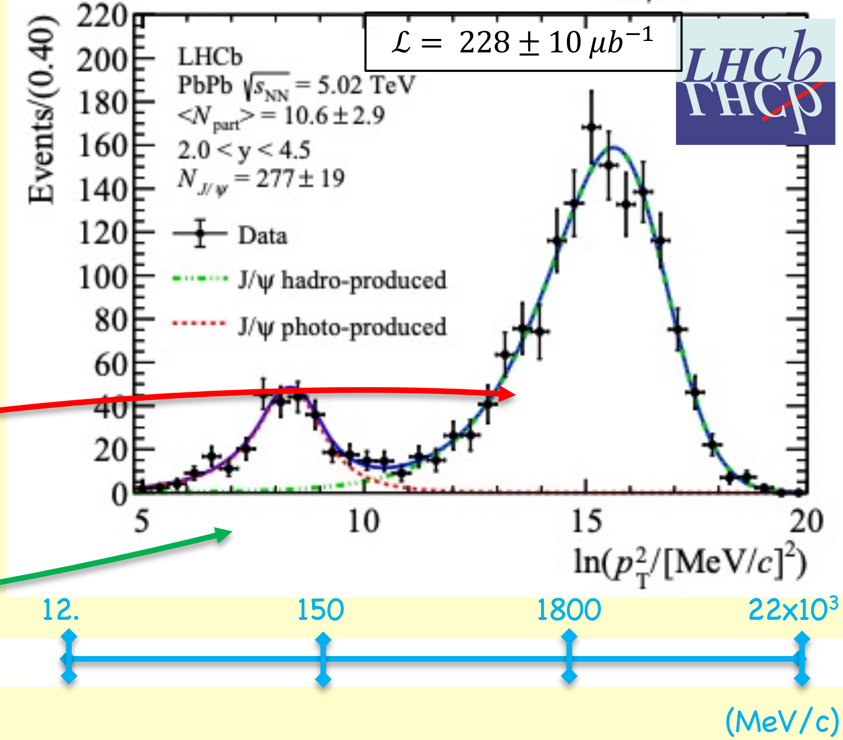
→ Motivated by excess seen by Alice [Phys. Rev. Lett. 116 (2016) 222301]]

→ Selection similar to UPC analyses, at very low p_T (< 0.3 GeV/c)

Use p_T distribution of the J/ψ mesons

- Hadronic : mean p_T 1-2 GeV/c,
- Coherent : mean p_T < 300 MeV/c

[arXiv:2108.02681]

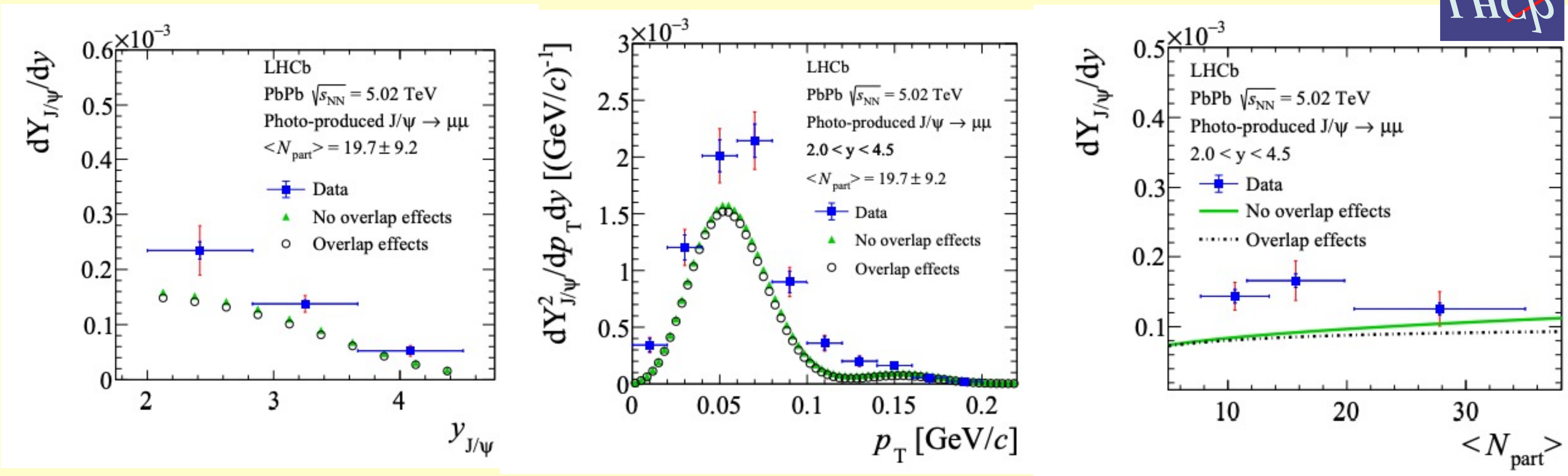


J/ψ production in peripheral PbPb collisions [arXiv:2108.02681]

- Consistent measurement J/ψ photo-production in PbPb hadronic collisions
  - Most precise pT measurement to date !
- Shape compatible with theoretical model under two assumptions:
  - "No effect of overlap between the nuclei (UPC interaction at small impact parameter)" or "The overlap has an effect

[W. Zha et al. Phys. Rev. C97 (2018) 044910 / Phy. Rev. C99, 06901(R)]

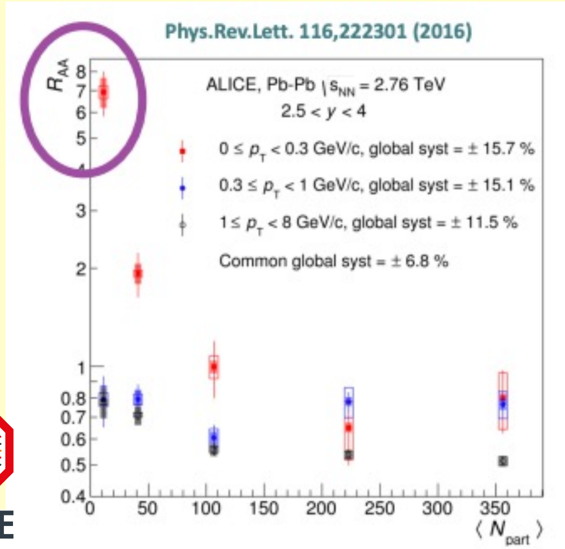
- Yields measured : $\frac{dY_i^{\psi}}{dy\ (dp_T)} = \frac{N_i^{\psi}}{\varepsilon_i^{tot} \cdot N_i^{MB} \mathcal{L} \cdot B(\psi \to \mu^+\mu^-) \cdot \Delta y (\cdot \Delta p_T)}$

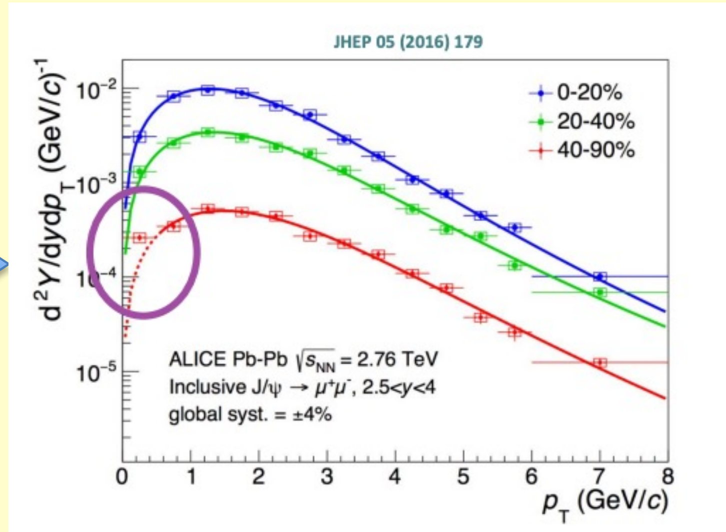


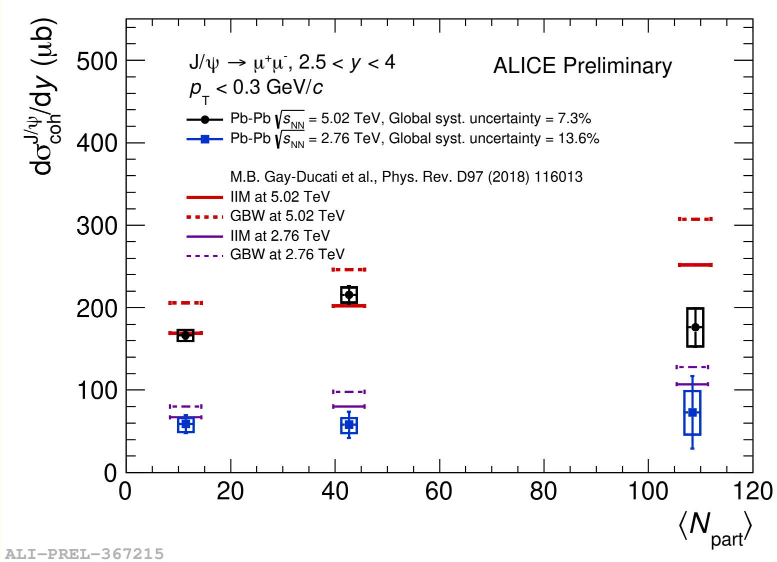
- J/ψ meson <pT> = 64.9 ± 2.4 MeV/c

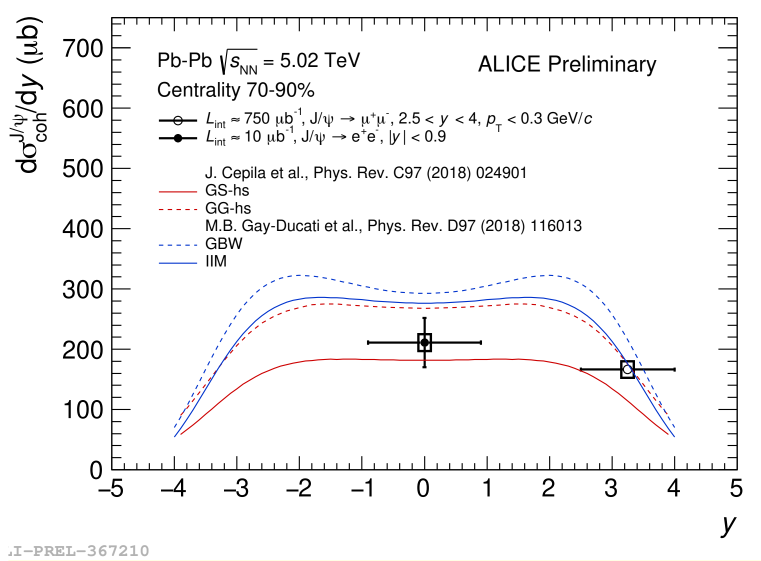
J/ψ production in peripheral PbPb collisions

→ ALICE updated measurement with the full RunII dataset

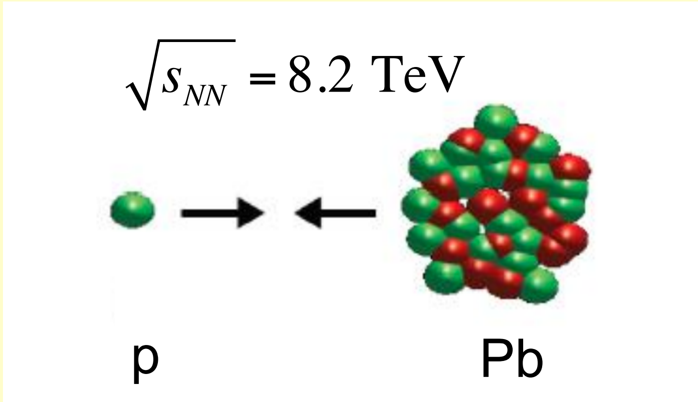








https://alice-figure.web.cern.ch/node/18568



pPb collisions

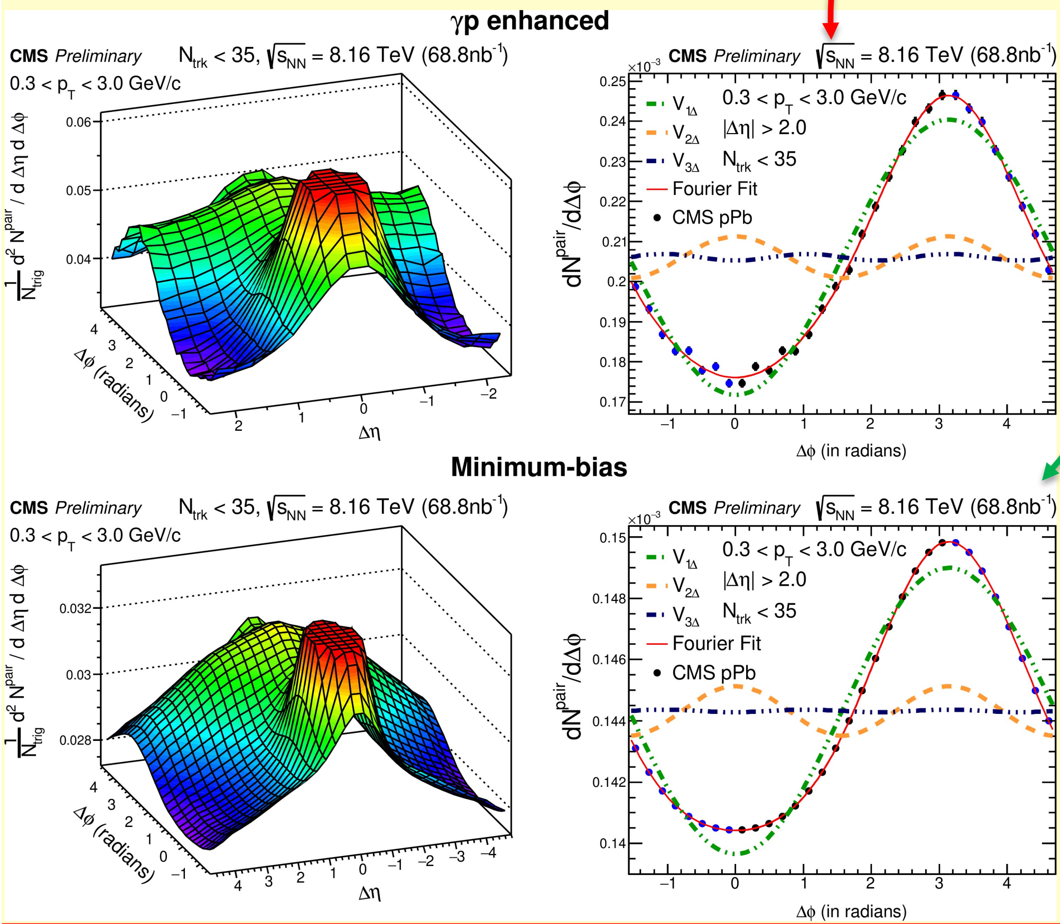
CMS: CMS-PAS-HIN-18-008

UPC in pPb

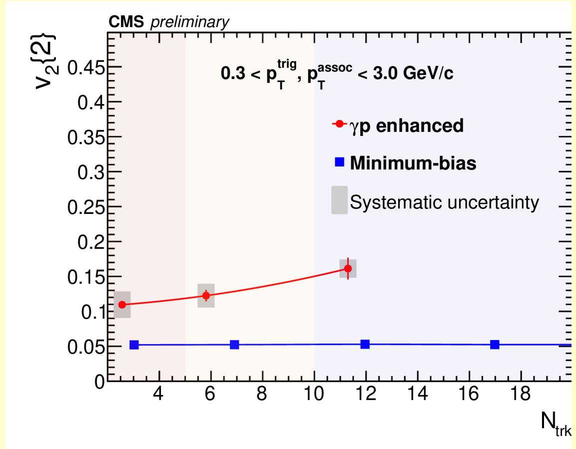
CMS-PAS-HIN-18-008

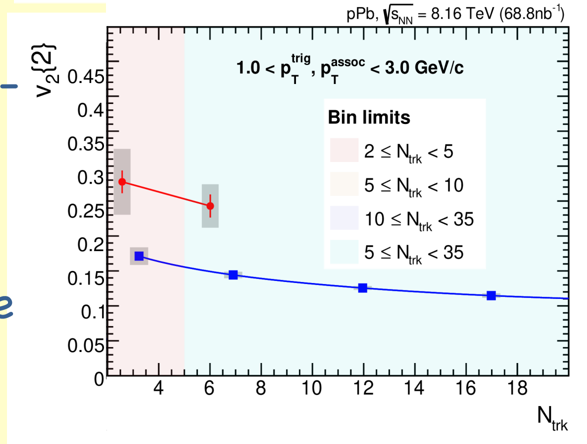
→ Elliptic azimuthal anisotropies in γp interactions

- Two particle (h^{+}) angular correlations in γp events selected with large rapidity gaps and no n-emission from pPb, compared with minimum bias events with similar multiplicity
- $\mathcal{L} = 69\, nb^{-1}$
- Ecal > 1 GeV/c, >= 2 tracks, with p_T^{track} > 0.4 GeV/c, $|\eta^{track}|$< 2.4



- v2(pT) increases with pT
- larger for γp-enhanced events than for MB events at the same multiplicity





ATLAS also observed v2 > 0 after non-flow subtraction in γ+Pb *[PRC 104(2021) 014903]*

Conclusions and Outlook

- All experiments have produced interesting results in peripheral and ultra-peripheral collisions, with LHCb showing PbPb results in this area for the first time !
  - More results not shown here !
- Interesting discussions ongoing among experiments with similar rapidity coverage
- With Run 3 approaching higher statistics is expected and broader coverage from the two updated experiments (LHCb and ALICE)
- Very exciting times ahead !

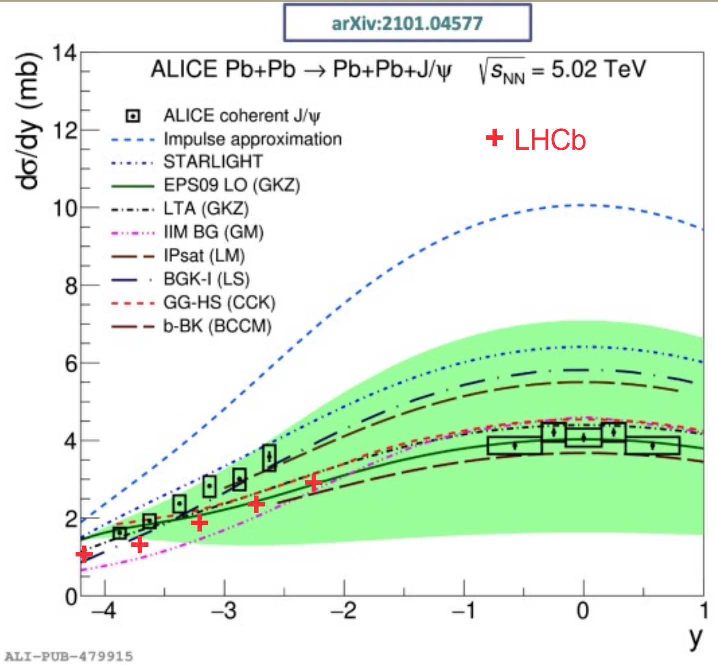
Back-up

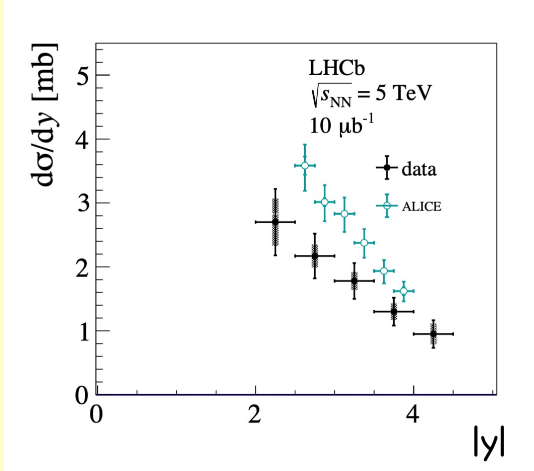
→ References

LHCb: arXiv:2107.03223, arXiv:2108.02681
ALICE: Eur.Phys.J.C 81 (2021), PLB 817 (2021) 136280 (http://alice-figure.web.cern.ch/node/18568, http://alice-figure.web.cern.ch/node/19575)
ATLAS: Phys.Rev. C 104 (2021) 024906, ATLAS-CONF-2019-051,Phys. Rev. C. 104 014903 JHEP 03 (2021) 243)
CMS: CMS-PAS-HIN-18-011, CMS-PAS-HIN-19-014, *Phys.Lett.B 797 (2019) 134826*, CMS-PAS-HIN-18-008

Results

- Impulse approximation: Exclusive photoproduction data off protons, neglecting all nuclear effects except coherence.
- STARlight: Vector Meson Dominance model with Glauber-like formalism to calculate cross section in Pb-Pb
- GKZ: EPS09 LO parametrization of the nuclear shadowing data
- GKZ: Leading twist approximation (LTA) of nuclear shadowing
- CCK: Color dipole model with the structure of the nucleon described by the hot spots
- BCCM: Color dipole approach coupled to the solutions of the Balitsky-Kovchegov equation
- GM, LM, LS: Color dipole approach coupled to the Color Glass Condensate formalism with different assumptions on the dipole-proton scattering amplitude





→ *Results within 1.3σ*

→ pQCD calculation

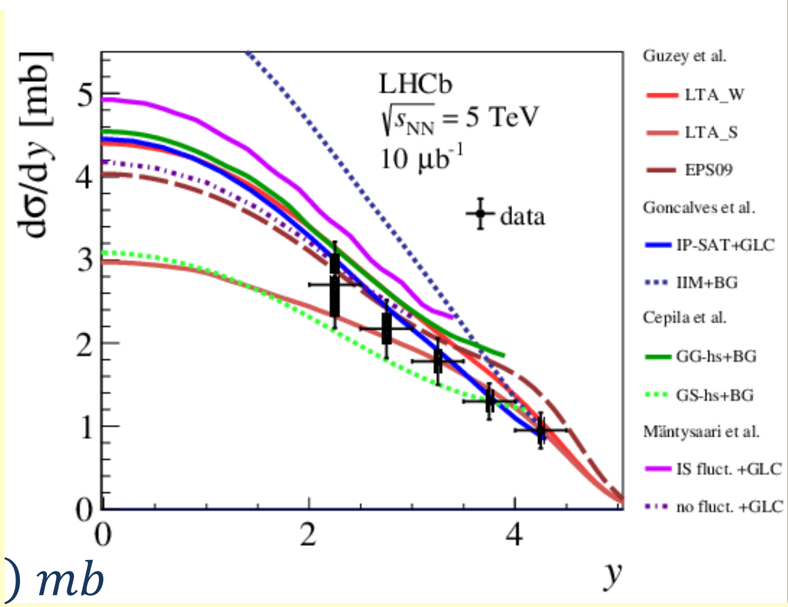
[PRC 93 (2016) 055206]

→ Color dipole models

[PRD 96 (2017) 094027]

[PRC 97 (2018) 024901]

[PLB 772 (2017) 832]

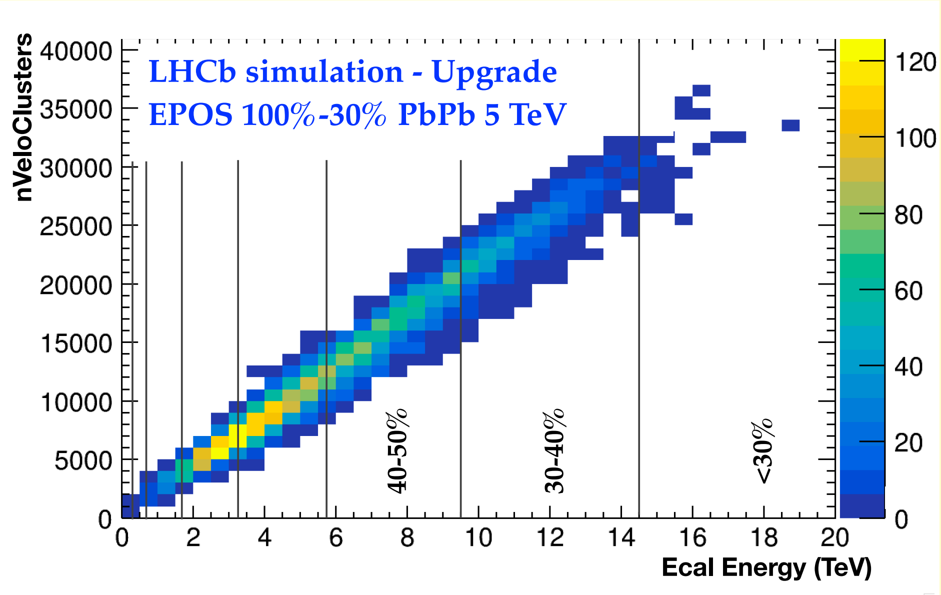


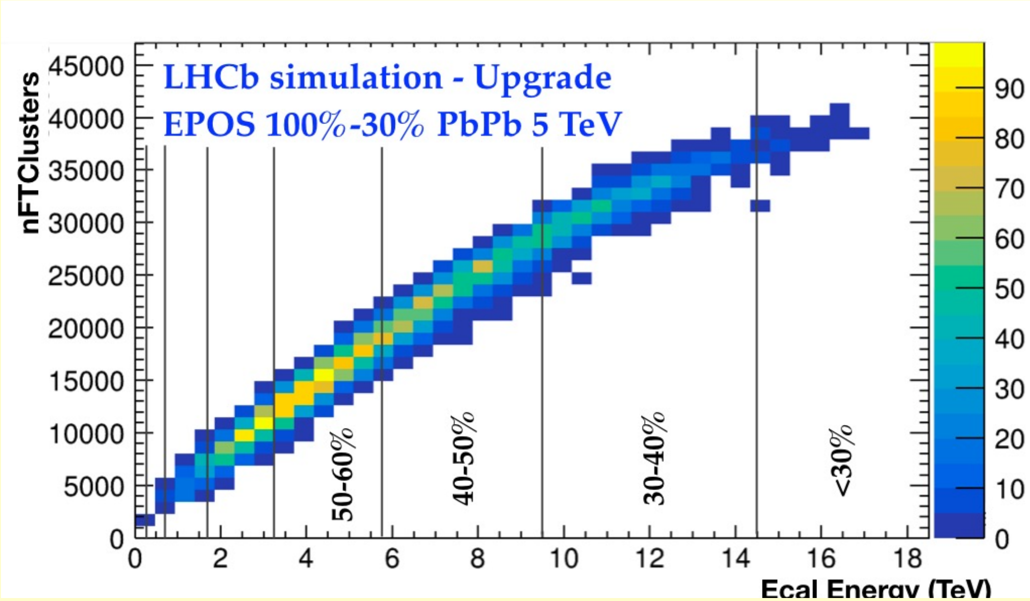
→ Integrated over y [2.0-4.5]:

$$\sigma^{\psi}_{coherent} = 4.45 \pm 0.24(stat) \pm 0.18(syst) \pm 0.58(lumi)\ mb$$

LHCb Outlook

- LHCb successfully participated in heavy ion data-taking in 2015,2016 & 2018
  - Collected good statistics → could benefit from larger data samples
  - Many measurements performed; first ones with PbPb collisions ever!!
- Charmonium production in PbPb ultra peripheral collisions: refined analysis, good agreement with theory; 2018 results on the way!
- J/ψ studies in PbPb peripheral (hadronic!) collisions using centrality for the first time ! Results with 2018 dataset compared with theoretical predictions, discussion with theorists very lively
- More new results soon with these data
- Many results also studied in view of the new detector in Run3/4
  - Yellow report on the way *LHCB-TDR-12 – 17; CERN-LHCC-2018-026; LHCB-TDR-019*





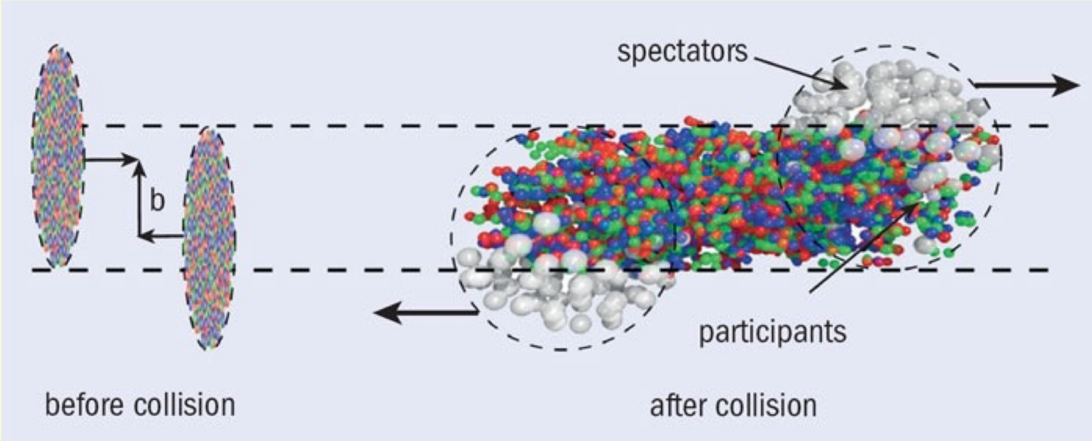
LHCB-FIGURE-2019-021

$$\sqrt{s_{NN}} = 13 \text{ TeV}$$

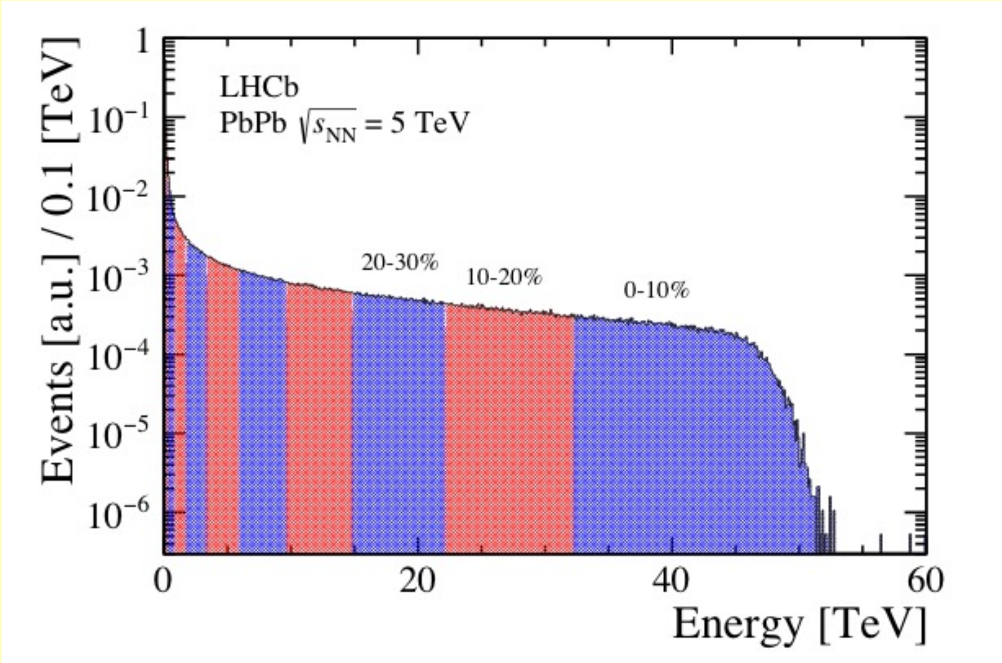
pp collisions

Centrality determination in LHCb

CERN-LHCb-DP-2021-002

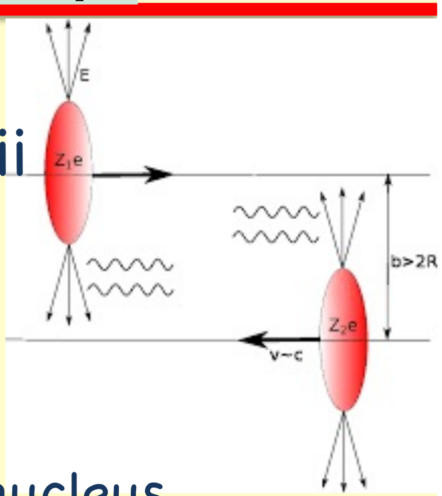


- A proxy of the impact parameter b of the collisions can be given by "centrality" classes, defined as percentile of the inelastic PbPb cross section as f($\sqrt{s}$)
- We use the Glauber model to derive Nparticipants (<Npart>), the impact parameter (<b>), etc.
- We use the energy deposit in the Electromagnetic calorimeter to extract the centrality value through the Glauber model



Ultra-Peripheral PbPb Collisions

[Arxiv:2107.03223]



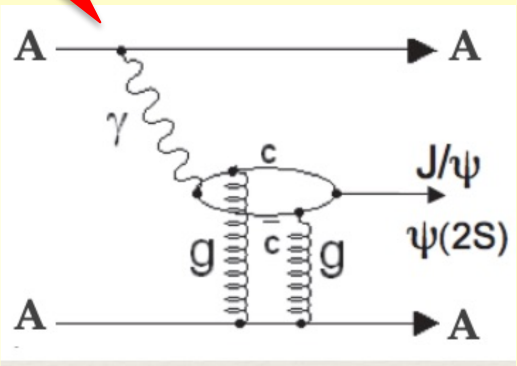
→ UPC: Two nuclei collide with each-other with impact parameter larger than the sum of their radii

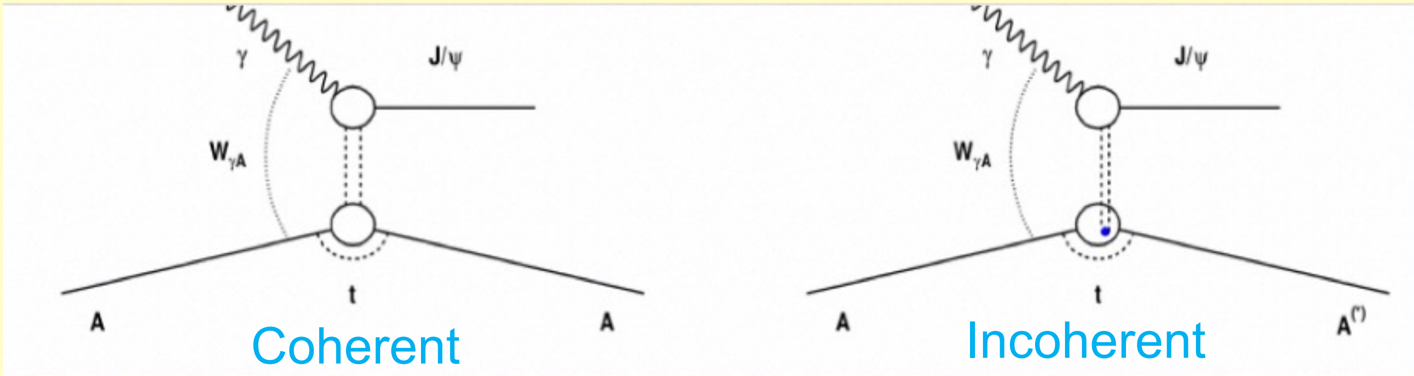
→ Can exchange a photon ! => Photon induced interactions enhanced by strong EM field of nucleus.

- Coherent: photon interacts with nucleus as a whole
- Incoherent: photon interacts with the nucleons in the nucleus

→ Coherent charmonia production (J/ψ and $\psi(2S)$)

- Constraints on gluon PDFs
- Ratio of the two indicates the correct vector meson wave function in dipole scattering models [PLB 772 (2017) 832, PRC (2011) 011902]





Charmonium production in UPC
[Arxiv:2107.03223]

→ Measurement of coherent cross-section:

$$\frac{d\sigma^{\psi}_{coherent}}{dy} = \frac{N^{\psi}_{coherent}}{\varepsilon_{total} \cdot B(\psi \to \mu^+\mu^-) \cdot \mathcal{L} \cdot \Delta y}, \qquad \psi = J/\psi, \psi(2S)$$

→ Signal: essentially two tracks and nothing else in the detector!

- Herschel used to further reduce the background [JINST 13 (2018) 04 P04017]

→ N signal events extracted from fit on $M_{\mu\mu}$; (coherent+incoherent)

→ Kinematic range of acceptance:

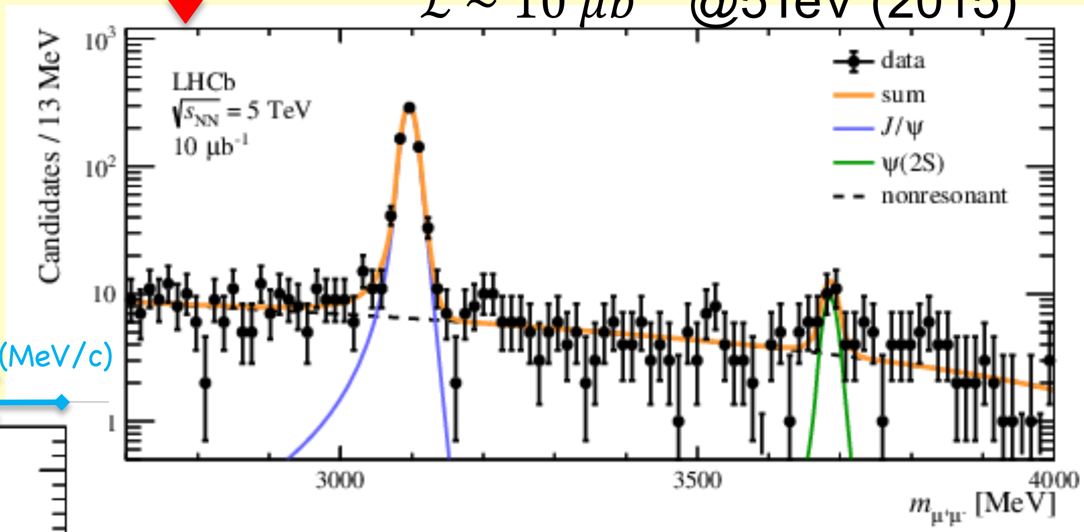
Muons:

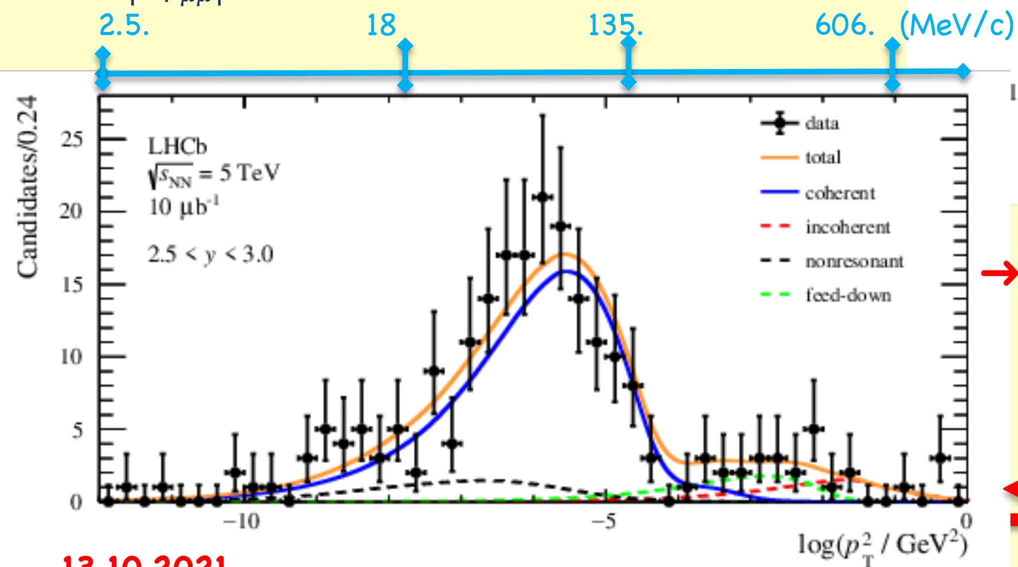
- $2.0 < \eta^{\mu} < 4.5$,
- $p_T^{\mu} > 700$ MeV/c

Dimuons:

- $p_T^{\mu\mu} < 1$ GeV/c,
- $|\Delta\phi_{\mu\mu}| > 0.9\pi$

$\mathcal{L} \sim 10\ \mu b^{-1}$@5TeV (2015)





→ Coherent component extracted using template fits from STARlight on the natural logarithm of the momentum distribution

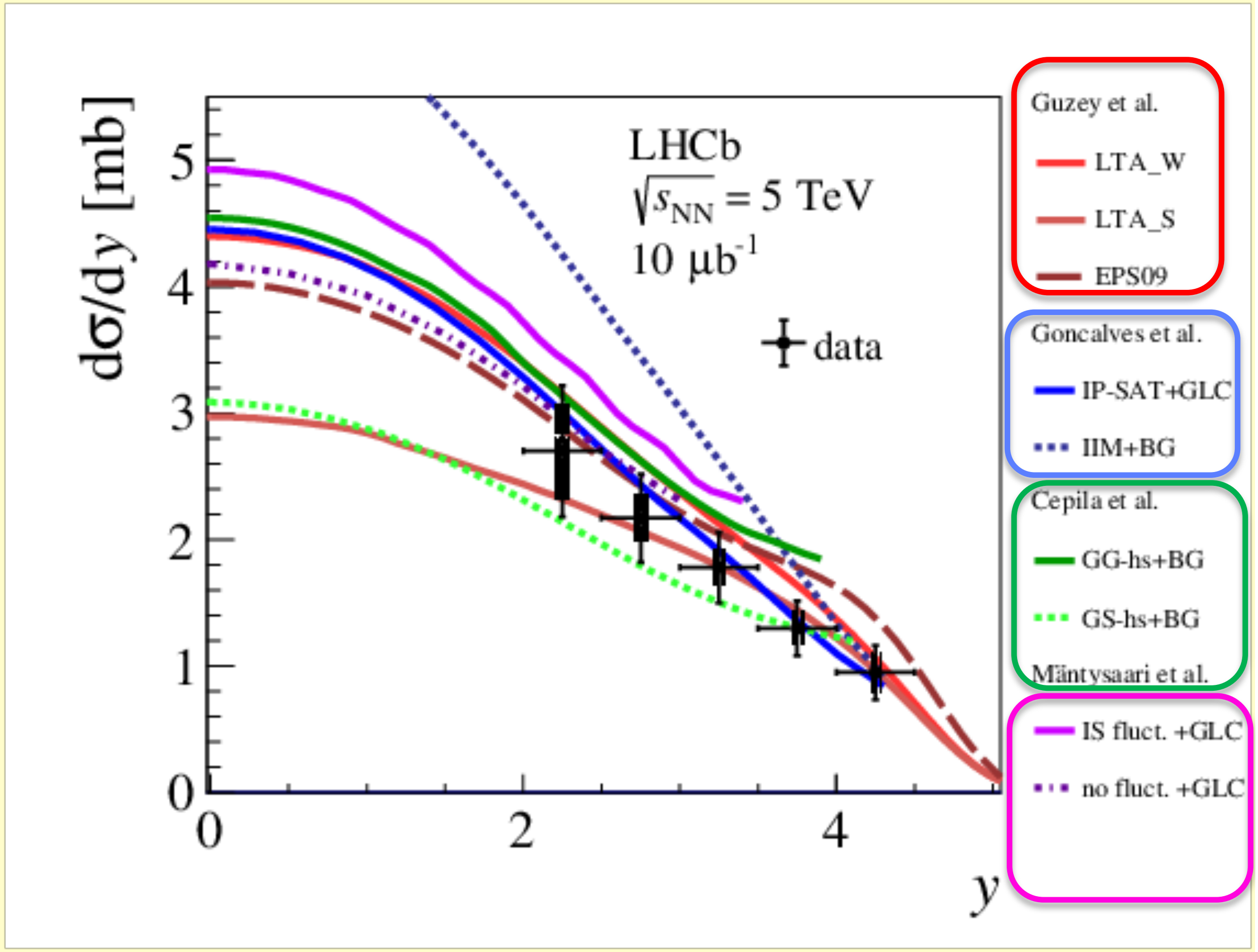
Charmonium production in UPC : Results

[Arxiv:2107.03223]

- Coherent J/ψ cross-section measured as a function of rapidity
- Integrated over y [2.0-4.5]:

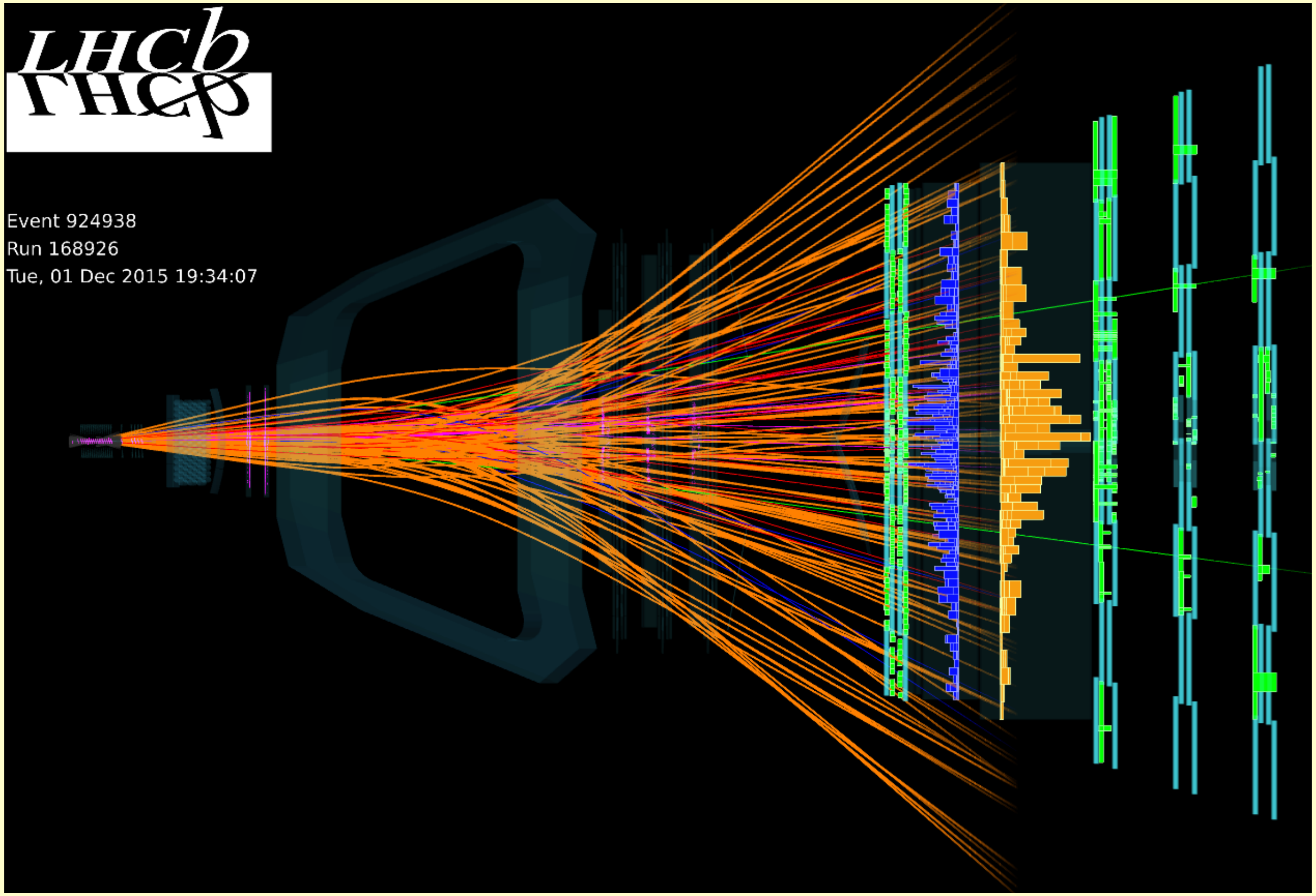
$$\sigma^{\psi}_{coherent} = 4.45 \pm 0.24(stat) \pm 0.18(syst) \pm 0.58(lumi)\ mb$$

- Forward LHCb acceptance allows great discrimination among the theory models
- pQCD calculation
  [PRC 93 (2016) 055206]
- Color dipole models
  [PRD 96 (2017) 094027]
  [PRC 97 (2018) 024901]
  [PLB 772 (2017) 832]
- Analysis update with higher statistics on the way (2018 PbPb data)



Study of J/ψ production in peripheral PbPb collisions

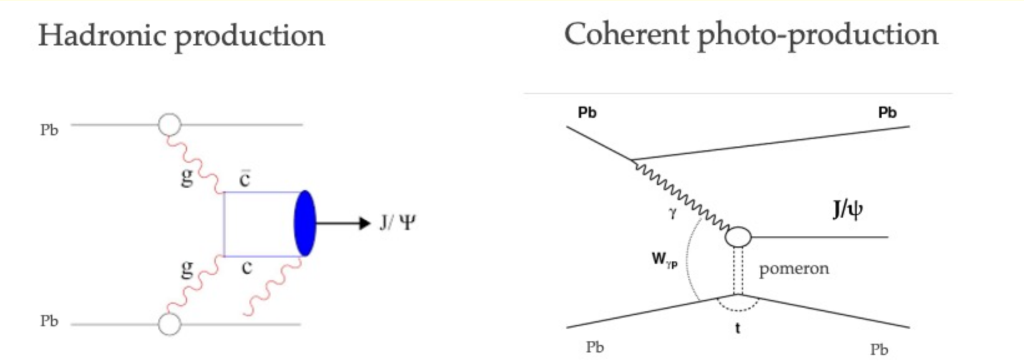
[arXiv:2107.03223,LHCb-PAPER-2020-043 (in preparation)]



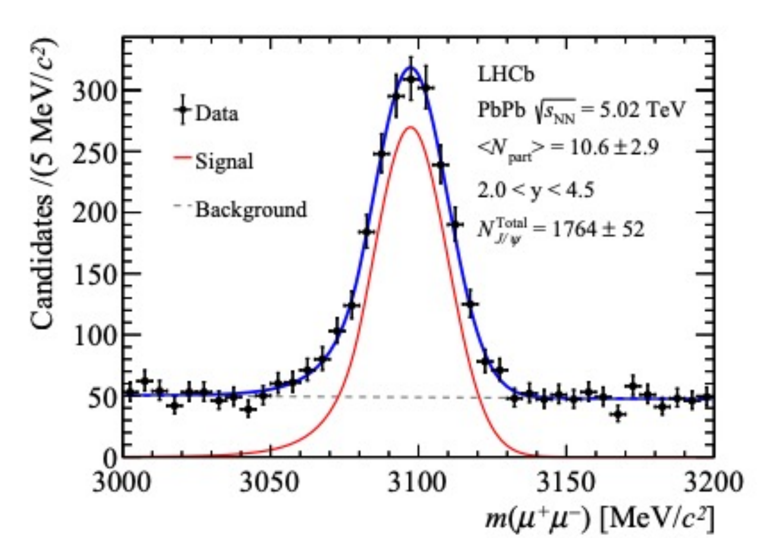
Prompt J/ψ production in peripheral PbPb collisions

→ When b < 2 R Pb the collision is "peripheral"

- Possible to identify also hadronic component !

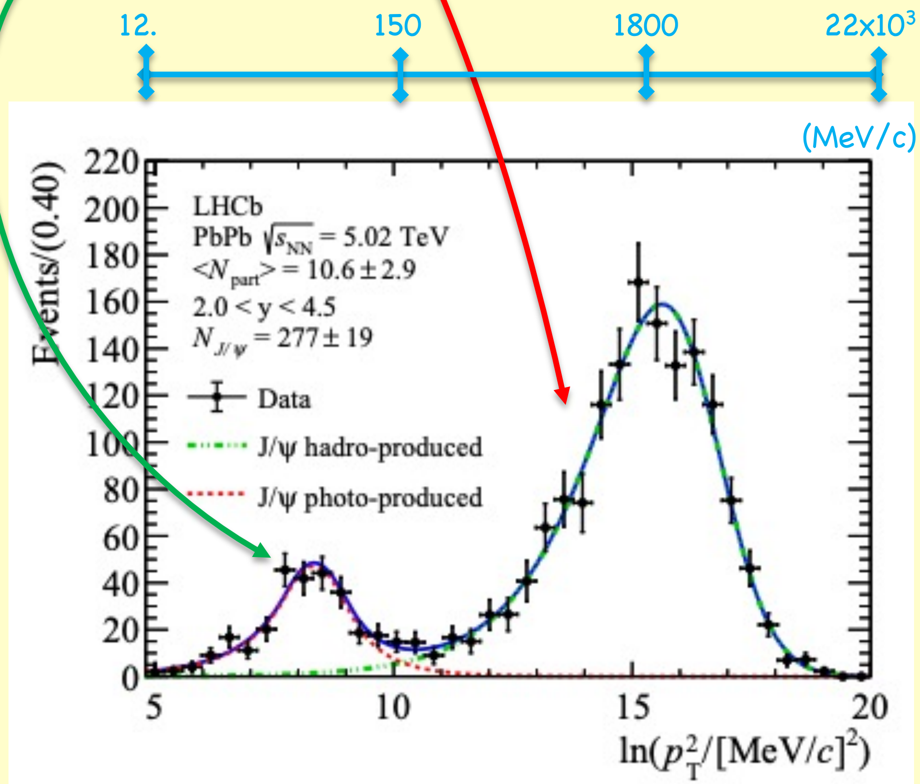


$gg \to J/\psi$ $\gamma(pomeron) \to J/\psi$



Use p_T distribution of the J/ψ mesons

- Hadronic : mean p_T 1-2 GeV/c,
- Coherent : mean p_T < 300 MeV/c



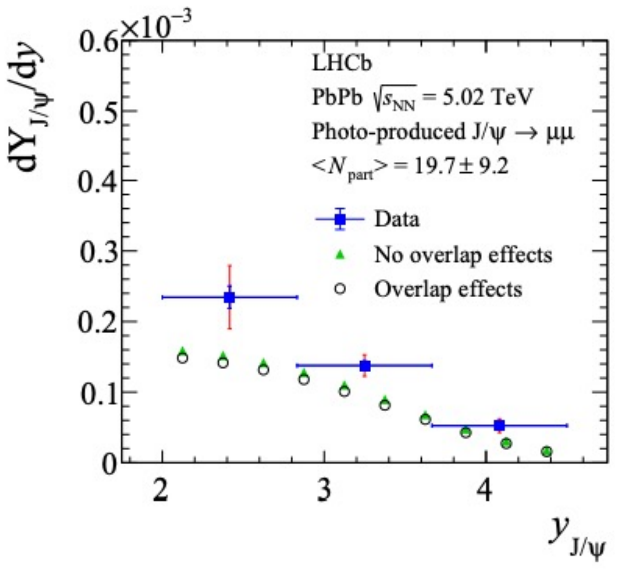
$\mathcal{L} \sim 210\ \mu b^{-1}$@5TeV (2018)

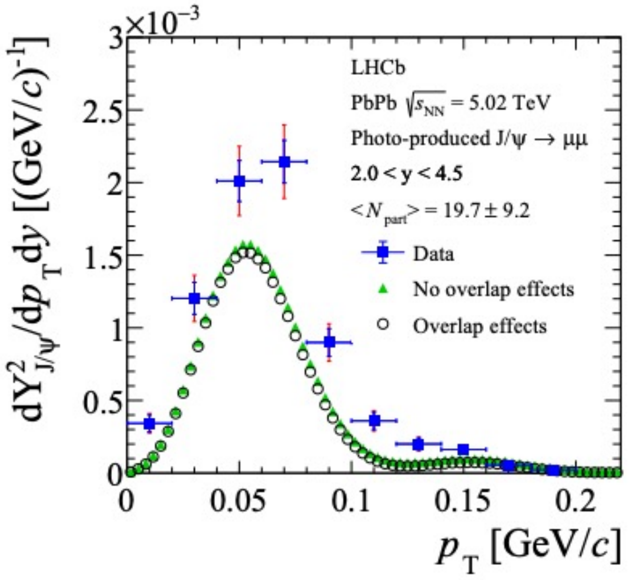
J/ψ production in peripheral PbPb collisions

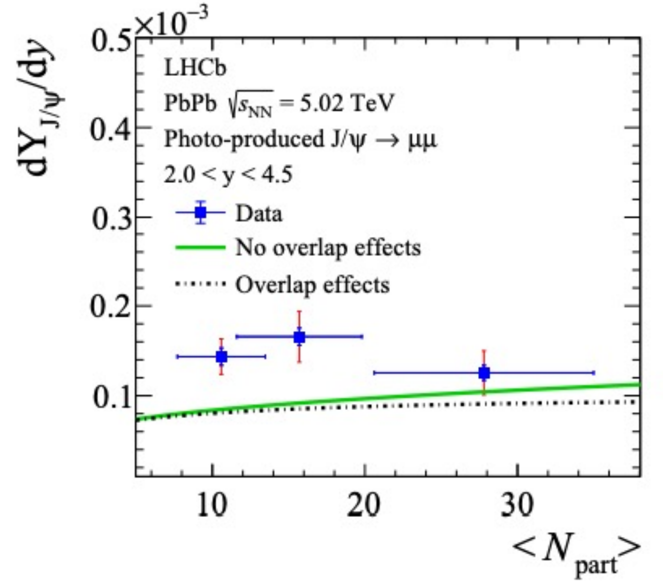
- Consistent measurement J/ψ photo-production in PbPb hadronic collisions
  - Most precise pT measurement to date !
- Shape compatible with theoretical model under two assumptions:
  - "No effect of overlap between the nuclei (UPC interaction at small impact parameter)" or "The overlap has an effect

[W. Zha et al. Phys. Rev. C97 (2018) 044910 / Phy. Rev. C99, 06901(R)]

- Yields measured : $\frac{dY_i^{\psi}}{dy\ (dp_T)} = \frac{N_i^{\psi}}{\varepsilon_i^{tot} \cdot N_i^{MB} \mathcal{L} \cdot B(\psi \to \mu^+\mu^-) \cdot \Delta y (\cdot \Delta p_T)}$







- J/ψ meson <pT> = 64.9 ± 2.4 MeV/c

Summary and Outlook

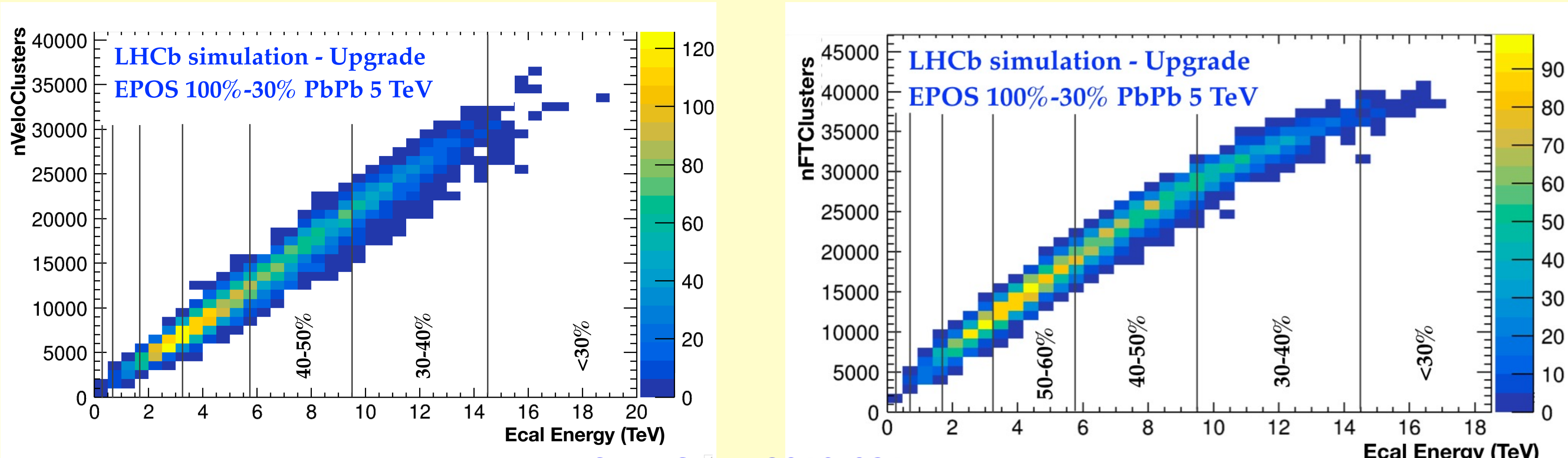
→ LHCb successfully participated in heavy ion data-taking in 2015,2016 & 2018
- Collected good statistics → could benefit from larger data samples
- Many measurements performed; first ones with PbPb collisions ever!!

→ Charmonium production in PbPb ultra peripheral collisions: refined analysis, good agreement with theory; 2018 results on the way!

→ J/ψ studies in PbPb peripheral (hadronic!) collisions using centrality for the first time ! Results with 2018 dataset compared with theoretical predictions, discussion with theorists very lively

→ More new results soon with these data

→ Many results also studied in view of the new detector in Run3/4
- Yellow report on the way *LHCB-TDR-12 – 17; CERN-LHCC-2018-026; LHCB-TDR-019*



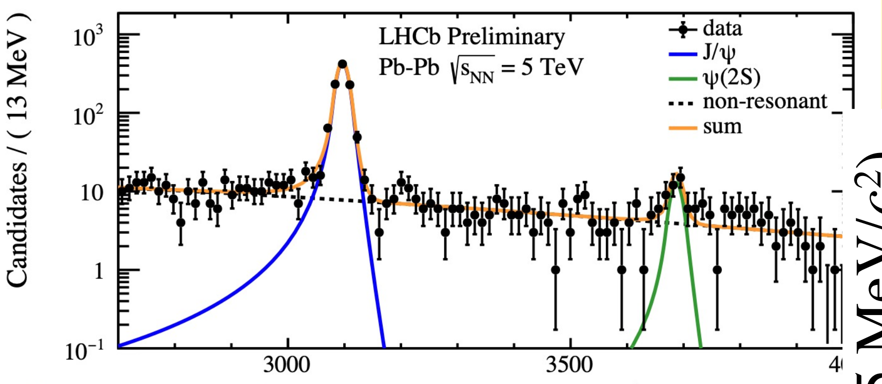
LHCB-FIGURE-2019-021

References

Status and Prospects for Fixed Target Physics (PBC)	LHCB-PUB-2018-015	
SMOG2 Technical Design Report	LHCB-TDR-020	
Projections for pPb analyses in Run 3 and Run 4	LHCB-CONF-2018-005	

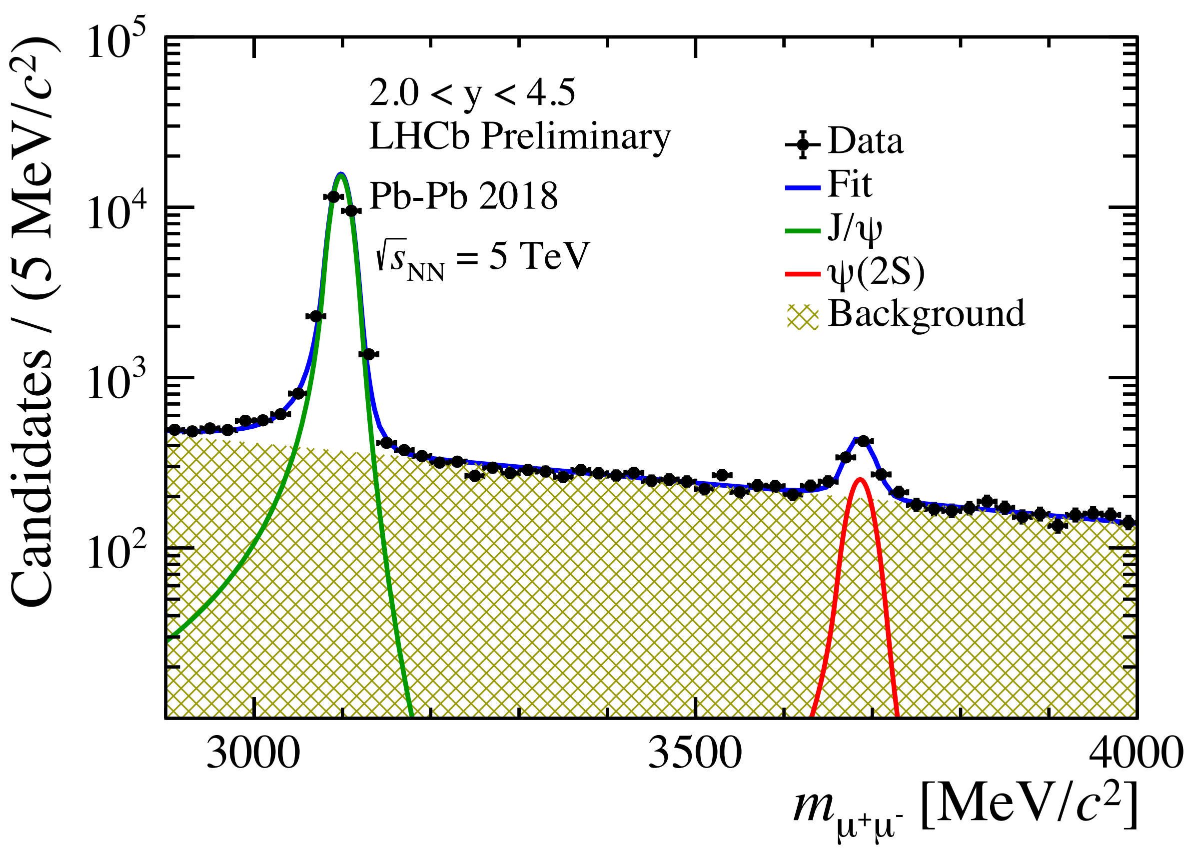
2018 PbPb data upcoming !

→ 20 times more collisions collected in 2018 @5TeV



【LHCb-CONF-2018-003】

【 https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlotsQM2019 】



→ Differential cross-section measurement will be possible in 5 bins of y

→ Also cross-section ratio of two charmonium states

→ Stay tuned !

Centrality

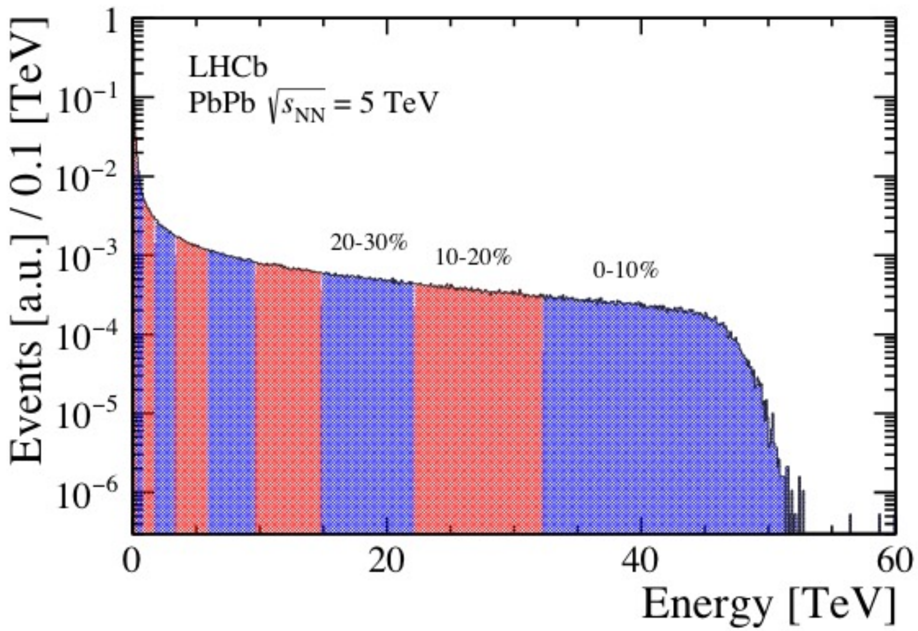


Figure 3: Distribution of the PbPb minimum bias events as a function of the total energy deposit in the electromagnetic calorimeter. The events are assigned to the defined centrality classes, 0-10% representing the 10% most central collisions (low impact parameter).

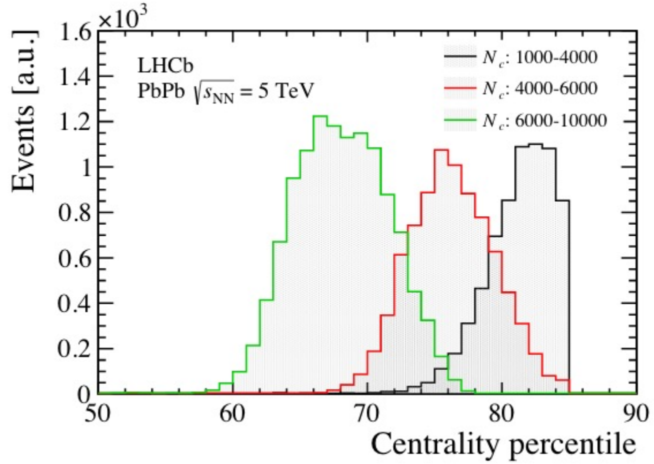


Figure 4: Distribution of the centrality percentiles in three N_c intervals of the minimum bias events.

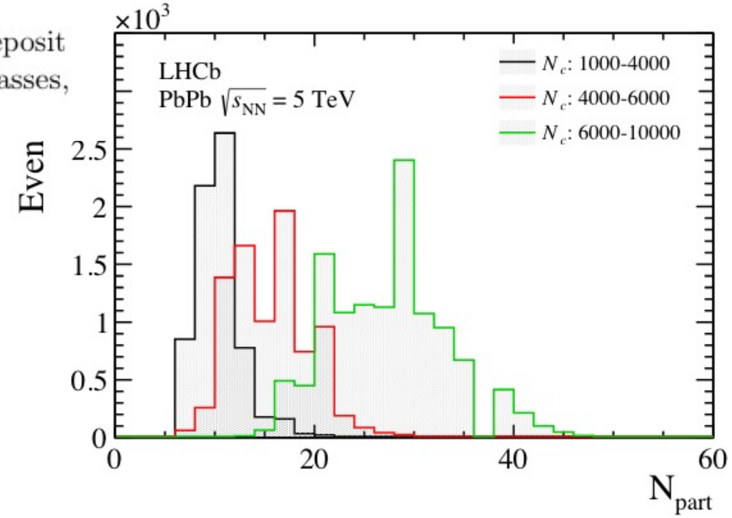
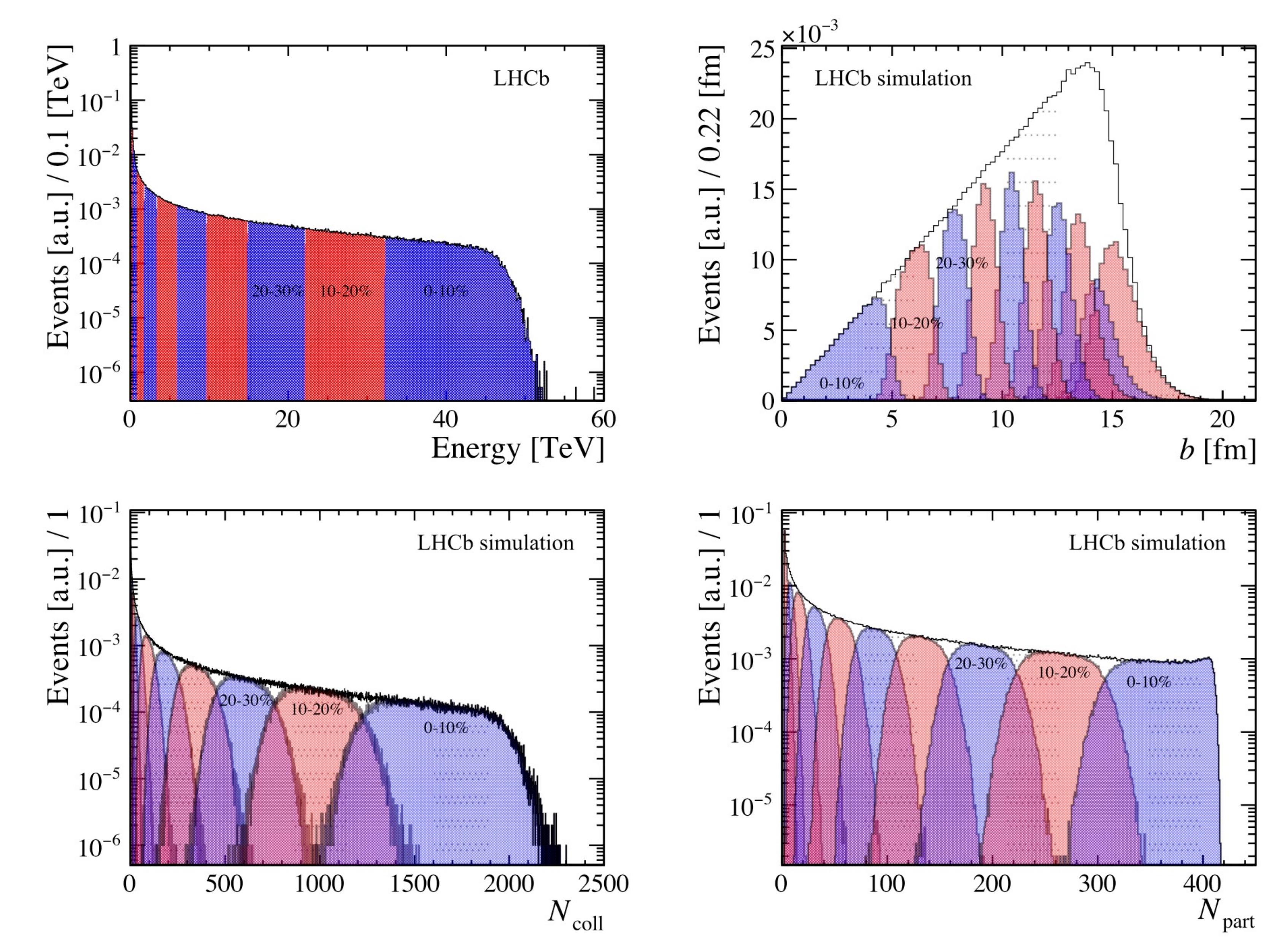


Figure 5: Distribution of N_{part} in three N_c intervals of the minimum bias events.

Centrality determination in LHCb

CERN-LHCb-DP-2021-002



Systematics

→ Systematic uncertainties

- Bin width dependence (dominant for PbPb)
- Hadronic cross section
- Fit on Ecal distribution
- Negative Binomial Distibution used to model the particle production

Table 2: Geometric quantities (N_{part}, N_{coll} and b) of PbPb collisions for centrality classes defined from a Glauber MC model fitted to the data. The classes correspond to sharp cuts in the energy deposited in the ECAL. Here σ stands for the standard deviation of the corresponding distributions.

Centrality %	E [GeV]	N_{part}	$\sigma_{N_{\text{part}}}$	N_{coll}	$\sigma_{N_{\text{coll}}}$	b	σ_b
100 – 90	0 – 310	2.9	1.2	1.8	1.2	15.4	1.0
90 – 80	310 – 800	7.0	2.9	5.8	3.1	14.6	0.9
80 – 70	800 – 1750	15.9	4.8	16.4	7.0	13.6	0.7
70 – 60	1750 – 3360	31.3	7.1	41.3	14.7	12.6	0.6
60 – 50	3360 – 5900	54.7	10.0	92.6	27.7	11.6	0.5
50 – 40	5900 – 9630	87.5	13.3	187.5	46.7	10.5	0.5
40 – 30	9630 – 14860	131.2	16.9	345.5	71.6	9.2	0.5
30 – 20	14860 – 22150	188.0	21.5	593.9	105.2	7.8	0.6
20 – 10	22150 – 32280	261.8	27.1	972.5	151.9	6.0	0.7
10 – 0	32280 – ∞	357.2	32.2	1570.3	236.8	3.3	1.2

Table 5: Total uncertainties for the geometric quantities (N_{part}, N_{coll} and b) of PbNe collisions for centrality classes defined from a MC Glauber model fit to the data. The statistical and systematic uncertainties are added in quadrature, and shown individually as well.

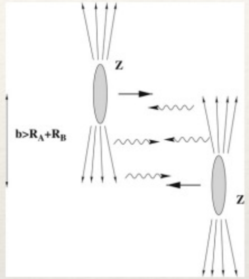
Centrality %	$N_{\text{part}} \pm \sigma^{\text{stat.}}_{\text{syst.}}$	$N_{\text{coll}} \pm \sigma^{\text{stat.}}_{\text{syst.}}$	$b \pm \sigma^{\text{stat.}}_{\text{syst.}}$
100 – 90	$2.5 \pm 0.1^{0.0}_{0.1}$	$1.4 \pm 0.0^{0.0}_{0.0}$	$10.9 \pm 0.3^{0.0}_{0.3}$
90 – 80	$3.9 \pm 0.1^{0.0}_{0.1}$	$2.7 \pm 0.1^{0.0}_{0.1}$	$10.4 \pm 0.4^{0.0}_{0.4}$
80 – 70	$6.8 \pm 0.3^{0.0}_{0.3}$	$5.2 \pm 0.2^{0.0}_{0.2}$	$9.7 \pm 0.3^{0.0}_{0.3}$
70 – 60	$11.3 \pm 0.3^{0.0}_{0.3}$	$9.7 \pm 0.3^{0.0}_{0.3}$	$9.0 \pm 0.2^{0.0}_{0.2}$
60 – 50	$17.9 \pm 0.3^{0.0}_{0.3}$	$17.3 \pm 0.4^{0.0}_{0.4}$	$8.2 \pm 0.1^{0.0}_{0.1}$
50 – 40	$26.7 \pm 0.3^{0.0}_{0.3}$	$29.0 \pm 0.6^{0.0}_{0.6}$	$7.4 \pm 0.1^{0.0}_{0.1}$
40 – 30	$38.0 \pm 0.6^{0.0}_{0.6}$	$45.6 \pm 1.1^{0.0}_{1.1}$	$6.5 \pm 0.1^{0.0}_{0.1}$
30 – 20	$51.7 \pm 0.6^{0.0}_{0.6}$	$67.8 \pm 1.6^{0.1}_{1.6}$	$5.4 \pm 0.0^{0.0}_{0.0}$
20 – 10	$67.3 \pm 0.8^{0.0}_{0.8}$	$94.1 \pm 2.3^{0.1}_{2.3}$	$4.1 \pm 0.0^{0.0}_{0.0}$
10 – 0	$84.8 \pm 1.0^{0.0}_{1.0}$	$120.4 \pm 3.0^{0.1}_{3.0}$	$2.7 \pm 0.0^{0.0}_{0.0}$

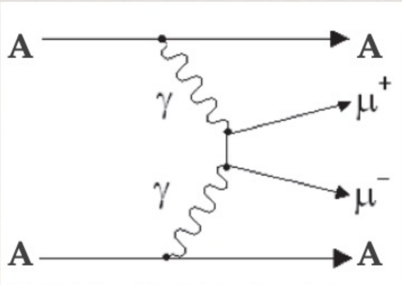
The uncertainties on the geometric quantities in both cases are dominated by the systematic uncertainties, as expected. In the PbPb case, the dominant one is the uncertainty due to the binning effect, while in the PbNe case, the dominant one is

Ultra peripheral PbPb collisions

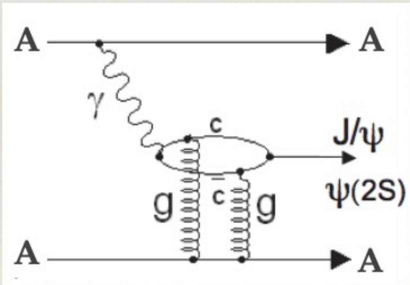
→ How does it happen?

- Ultra-peripheral collisions: Two nuclei bypass each other with an impact parameter larger than the sum of their radii.
- Photon-induced interactions are enhanced by the strong electromagnetic field of the nucleus
- Coherent J/ψ production gives constraints on the gluon Probability Density Functions
- The (J/ψ) / ψ(2S) ratio measurement is helpful to constrain the choice of the vector meson wave function in dipole scattering models [e.g. PLB 772 (2017) 832, PRC (2011) 011902]



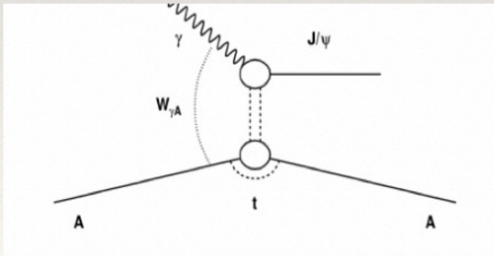


Photon-Photon interactions
Precisely know at p-QED

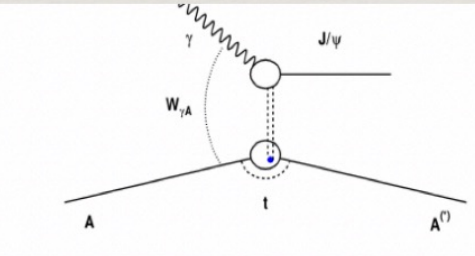


Photon-induced quarkonium production:
A $q\bar{q}$ loop created by the photon interactions with a pair of gluon exchange (pomeron) to produce a quarkonium ($c\bar{c}$, $b\bar{b}$, etc.)

Coherent J/ψ production:
photon interact with the whole nucleus coherently



Incoherent J/ψ production:
photon interact with particular nucleons in the nucleus



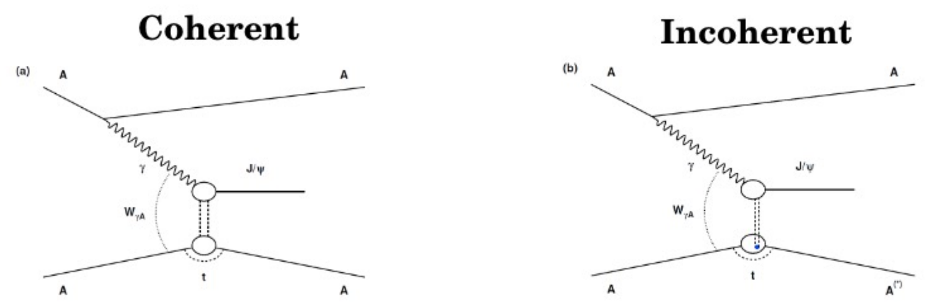
Charmonium in ultra-peripheral PbPb collisions

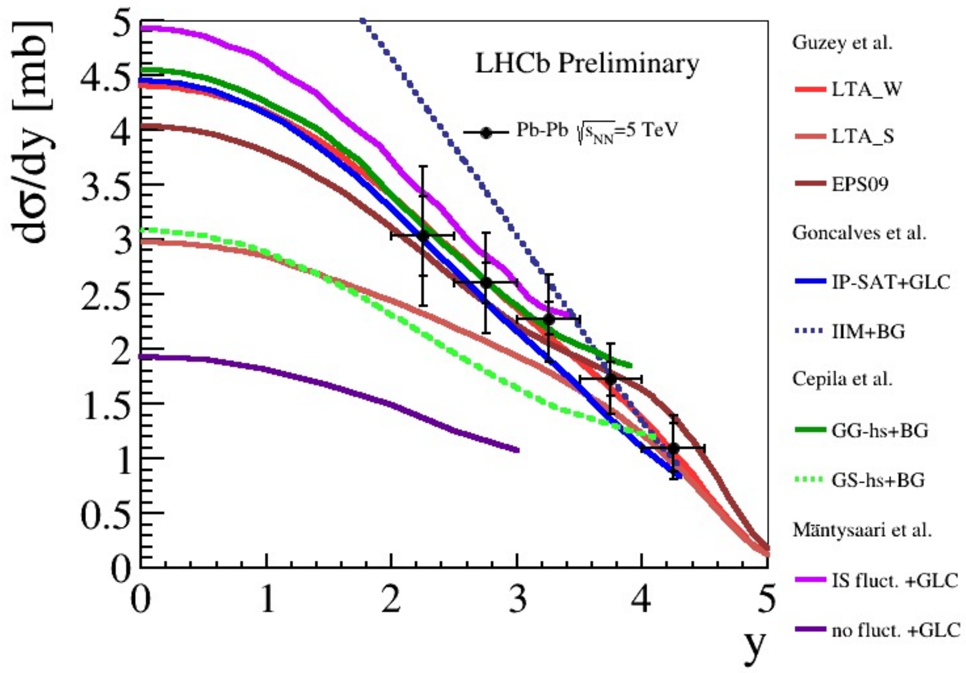
LHCb-CONF-2018-003

→ Interaction electromagnetic field ions: coherent J/ψ photoproduction (exclusive production)

→ Sensitive to nPDF

→ Analysis being finalised



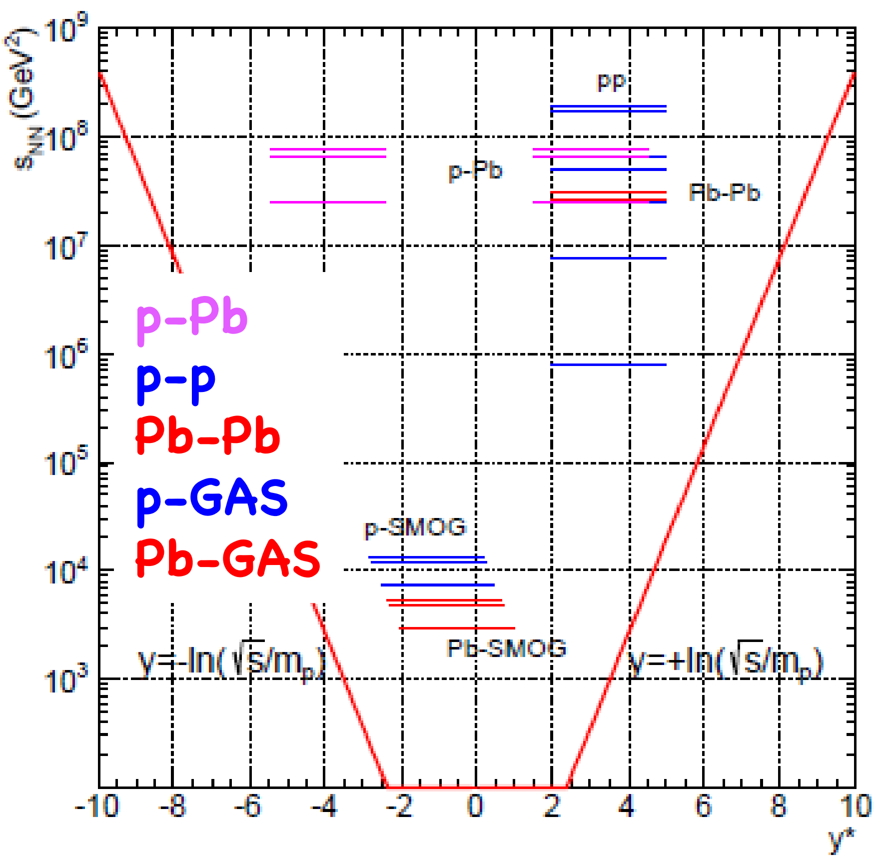


Cepila et al. PRC 97 024901 (2018), Goncalves et al. PRD 96, 094027 (2017), Guzey et al. PRC 93, 055206 (2016), Mäntysaari et al. PLB 772 (2017) 832-838 → Model without subnucleonic fluctuations disfavoured

More modes to be explored with larger 2018 PbPb data sample

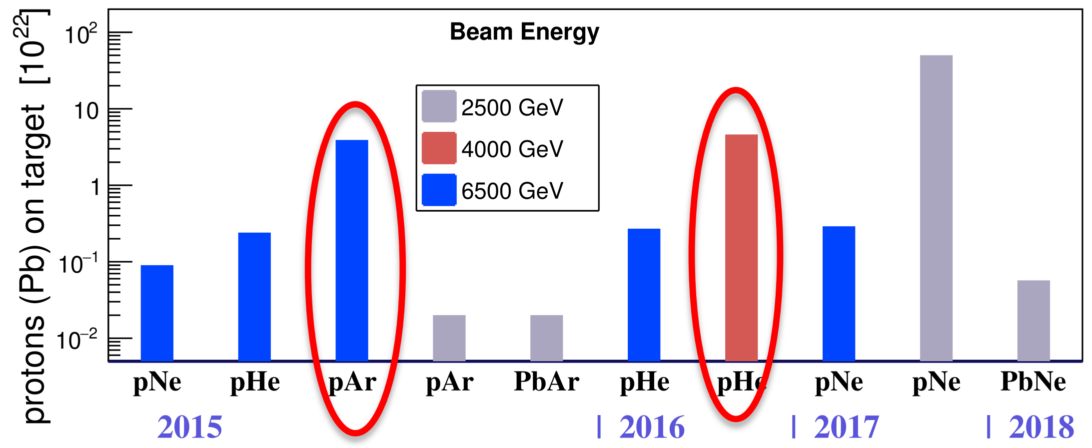
Phase Space Coverage and Running Modes

- Kinematic acceptance & (existing/future) beam-target combinations



E_{beam}(p)	pp	p-GAS	p-Pb/Pb-p	Pb-GAS	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5 TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

p/Pb-GAS operation so far:



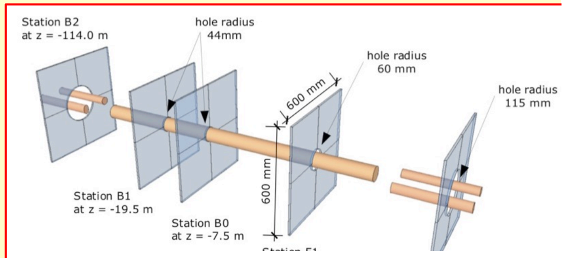
- y*: rapidity in nucleon-nucleon centre-of-mass system

LHCb Detector at the LHC

→ Single arm spectrometer in forward direction

- Designed for b-physics, becoming a General Purpose Detector
- Forward and backward coverage for asymmetric beams
- Precision in the forward region not achievable by others yet

[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]



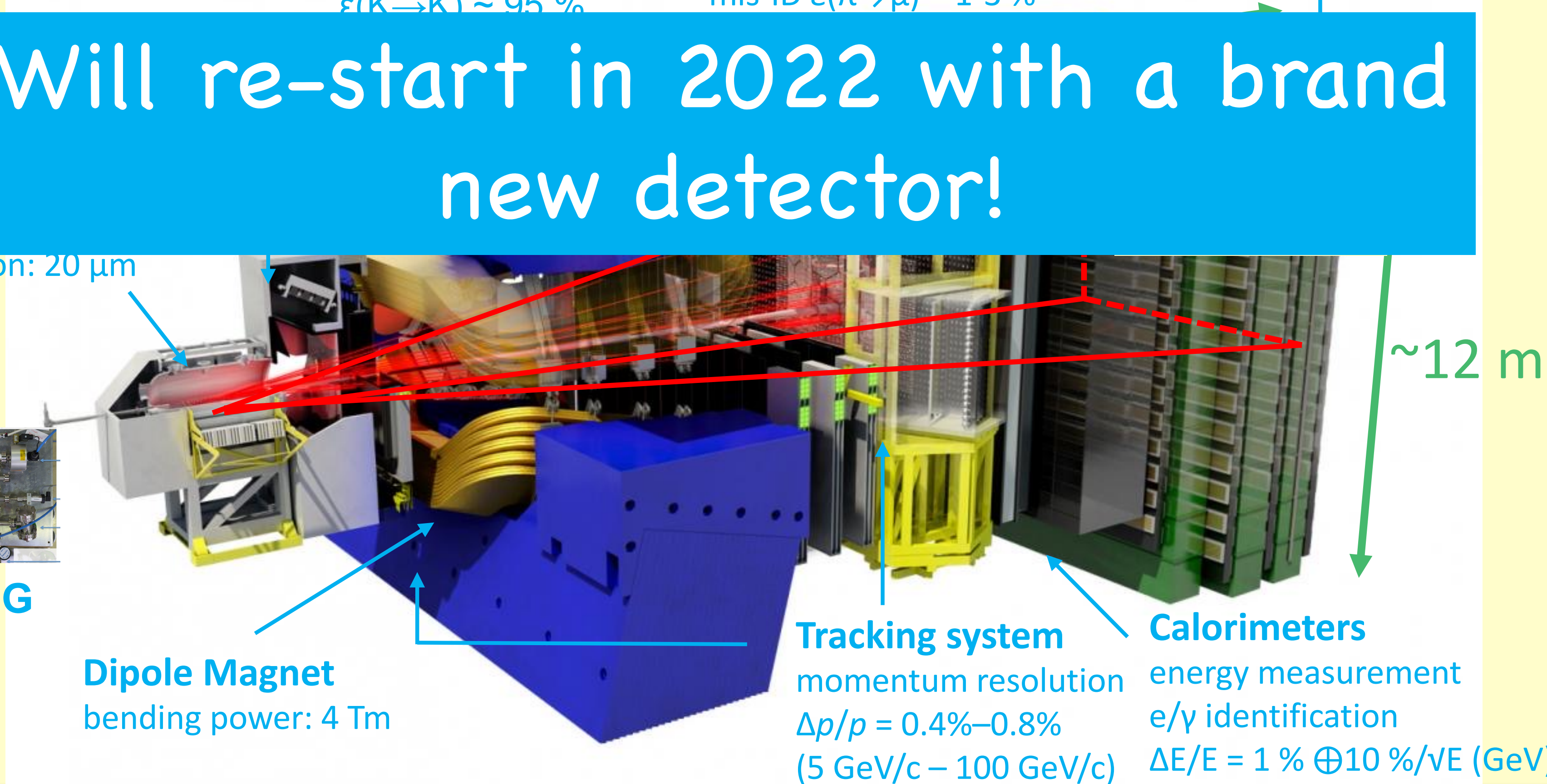
HERSCHEL @± 114 m IP

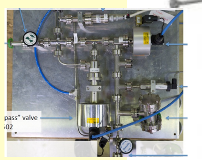
RICH detectors
K/π/p separation
ε(K→K) ~ 95 %

Muon system
μ identification ε(μ→μ) ~ 97 %,
mis-ID ε(π→μ) ~ 1-3 %

Will re-start in 2022 with a brand new detector!

Vertex
reconstr
decay ti
IP resolution: 20 μm





SMOG

Dipole Magnet
bending power: 4 Tm

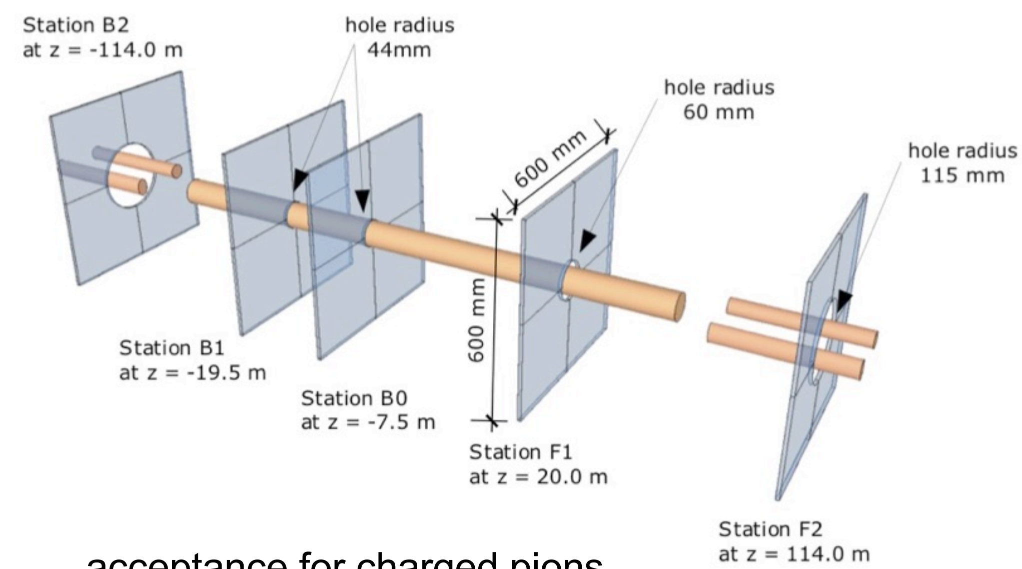
Tracking system
momentum resolution
Δp/p = 0.4%–0.8%
(5 GeV/c – 100 GeV/c)

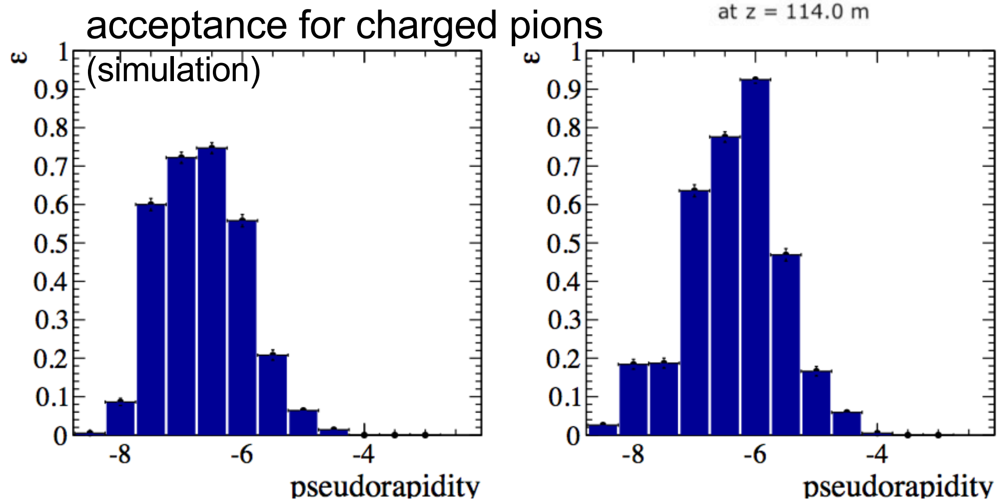
Calorimeters
energy measurement
e/γ identification
ΔE/E = 1 % ⊕10 %/√E (GeV)

Forward Extension of LHCb

[JINST 13 (2018) 04 P04017]

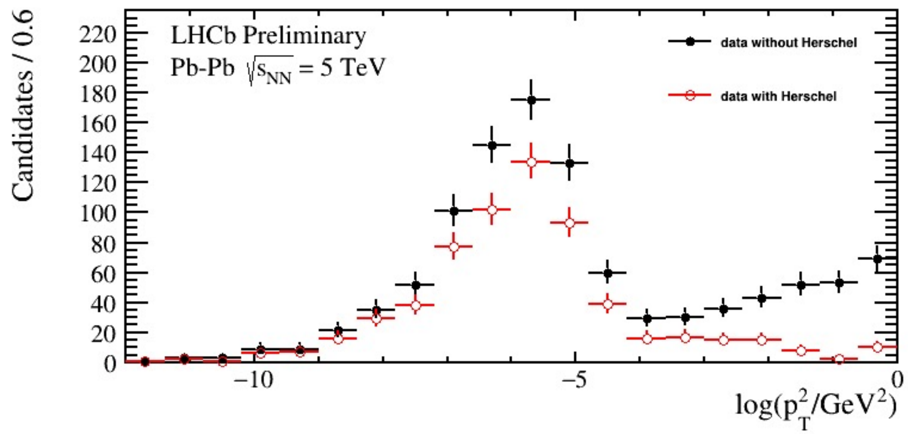
HeRSCheL: High Rapidity Shower Counters for LHCb





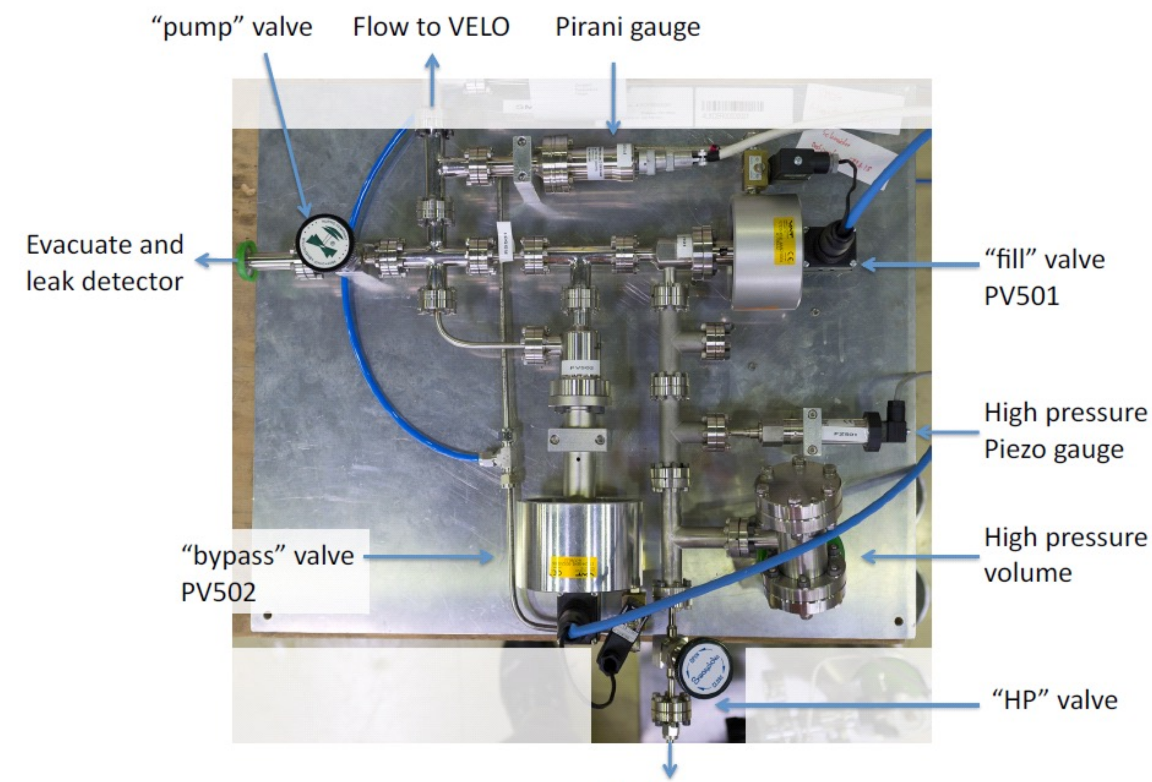
$p_T > 0.5$ GeV/c $p_T > 1.5$ GeV/c

- → forward scintillators for selecting rapidity gaps
- → up to ± 114m from IP
- → central region not covered
- → gap size 2 < η < 8
  - → huge gain for diffractive physics and central exclusive production



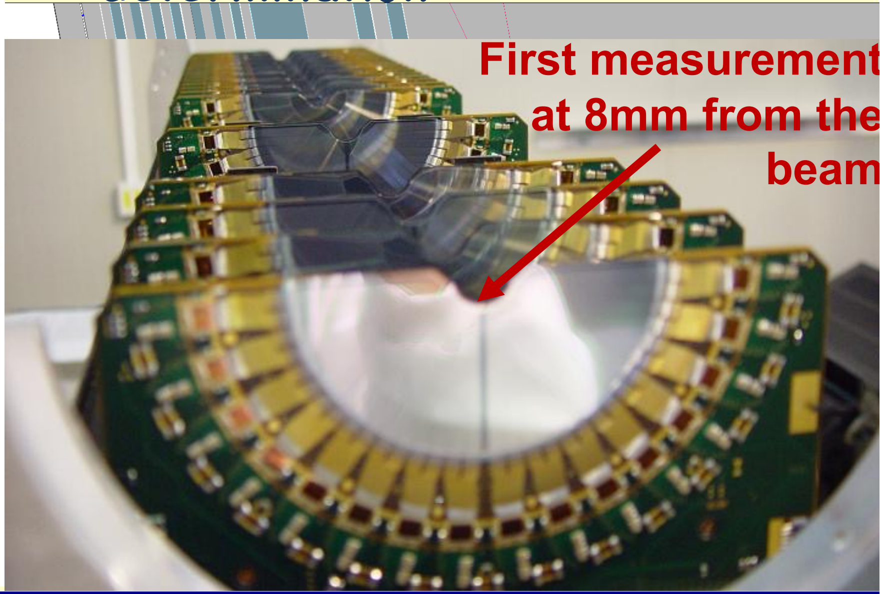
The SMOG System

SMOG : System for Measuring the Overlap with Gas



Gas pressure~ 10^{-7} mbar

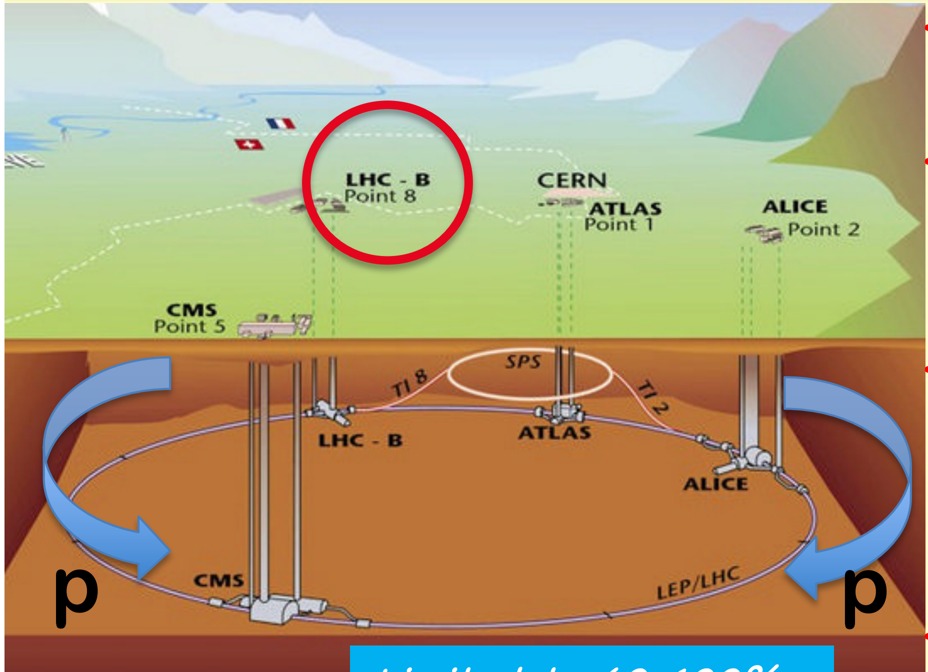
- Injection of noble gas into interaction region
- Very simple robust system
- Used for a precise luminosity determination



SMOG can be used for fixed target physics:

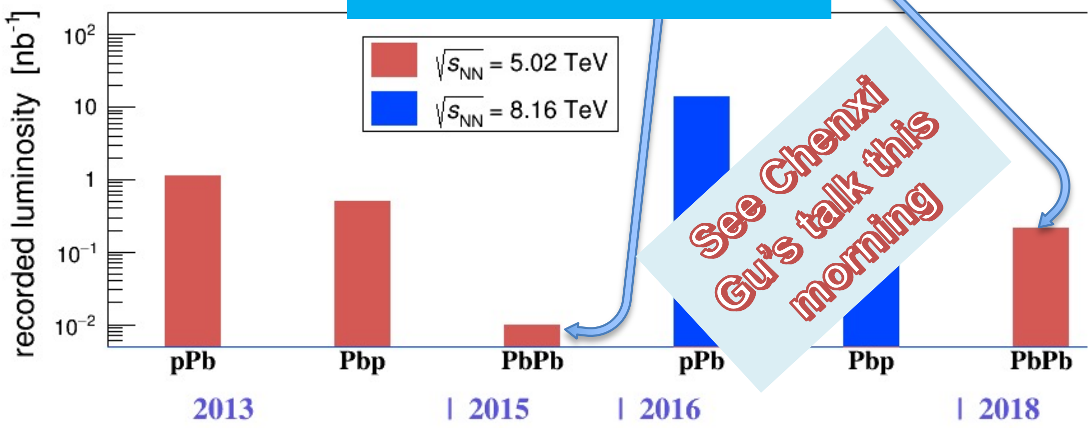
- Precise vertexing allows to separate beam-beam and beam-gas contributions

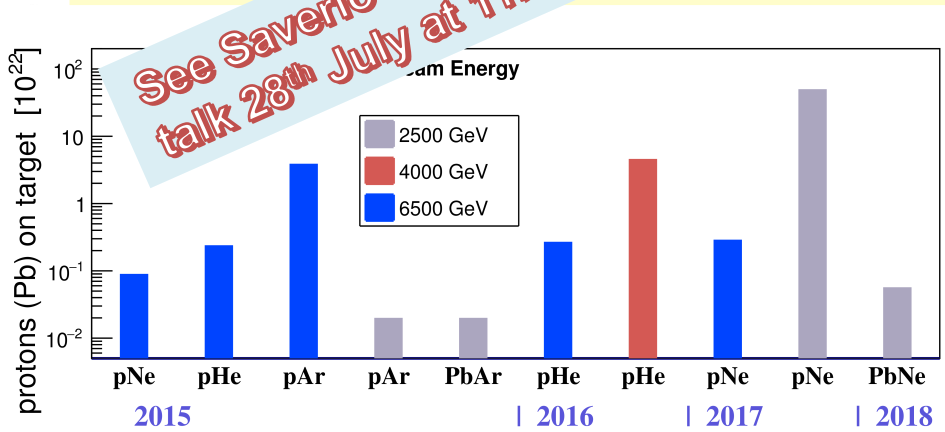
LHC and LHCb



- pp collider 2010-18@$\sqrt{s}$ = 2.76, 5, 7, 8, 13 TeV, L ≈ 9 fb^{-1}
- In 2013 & 2016 collected pPb/Pbp data @ $\sqrt{s_{NN}}$=5 and 8.16 TeV, L=1.6 & 34 nb^{-1}
  - 10^9 minimum bias collisions, ≈1M J/ψ's
- PbPb collisions @ $\sqrt{s}$=5TeV, L ≈ 10 μb^{-1} successfully collected at LHCb for the first time in 2015; already 20x in 2018 (!)
  - XeXe collisions @$\sqrt{s}$=5.4 TeV, L≈0.4 μb^{-1}
- LHCb also able to collect data in "fixed target" mode (SMOG)

Limited to 60-100% in centrality due to detector saturation





Multiplicities