UNIÓN EUROPEA
FONDO EUROPEO DE DESENVOLVEMENTO REXIONAL
"Unha maneira de facer Europa"

Recent results from heavy ion collisions at LHCb

Óscar Boente García on behalf of the LHCb collaboration

13/04/2021
DIS 2021 - Online

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The LHCb detector

LHCb JINST 3 (2008) S08005

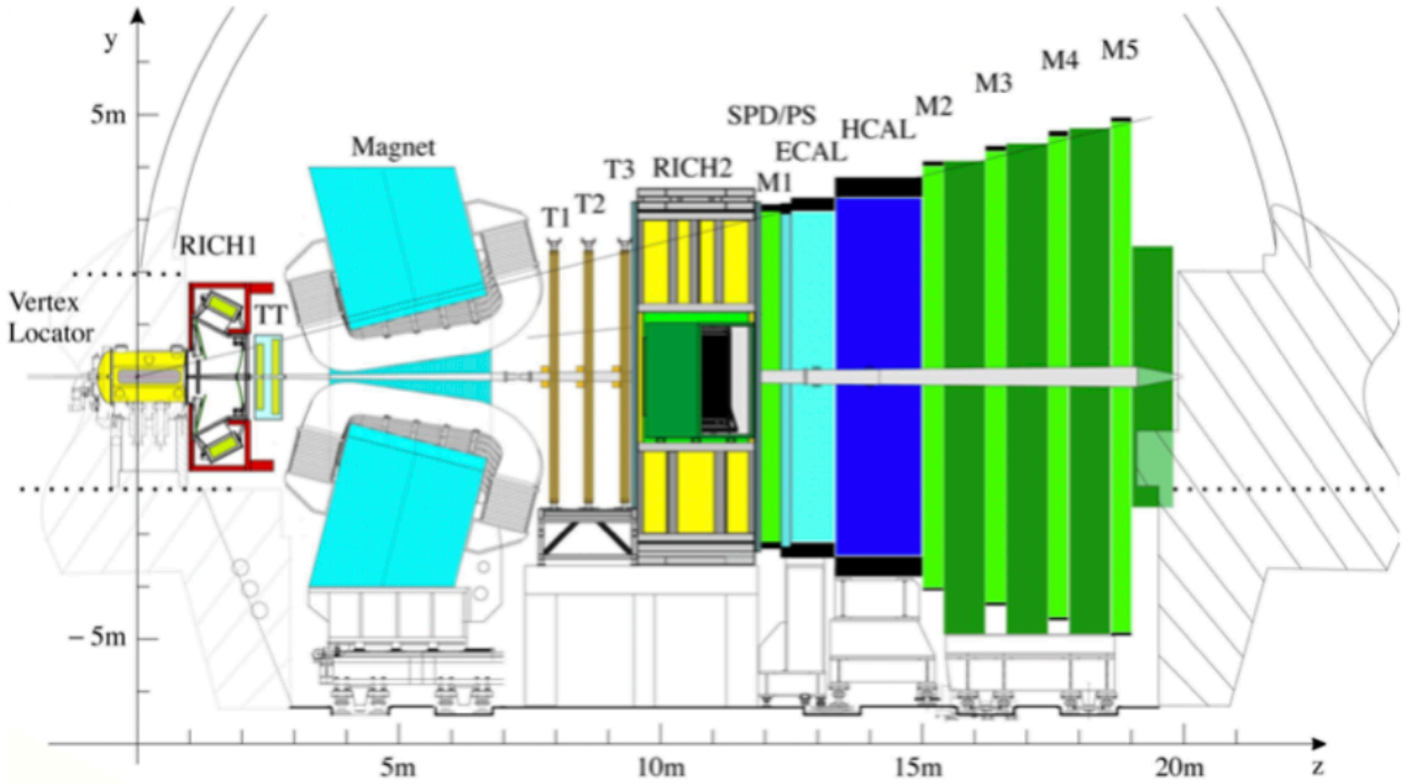
LHCb performance IJMPA 30 (2015) 1530022

- One-arm spectrometer at LHC fully instrumented in $2 < \eta < 5$
  - Tracking system with momentum resolution

    $\Delta p/p = 0.5 - 1\,\%$ from 2 to 200 GeV/c
  - Excellent hadron and muon ID

Muon
$$\begin{cases} \varepsilon(\mu \to \mu) \sim 97\,\% \\ \text{misID } \varepsilon(\pi \to \mu) \sim 1 - 3\,\% \end{cases}$$

Hadron
$$\begin{cases} \varepsilon(K \to K) \sim 95\,\% \\ \text{misID } \varepsilon(\pi \to K) \sim 5\,\% \end{cases}$$



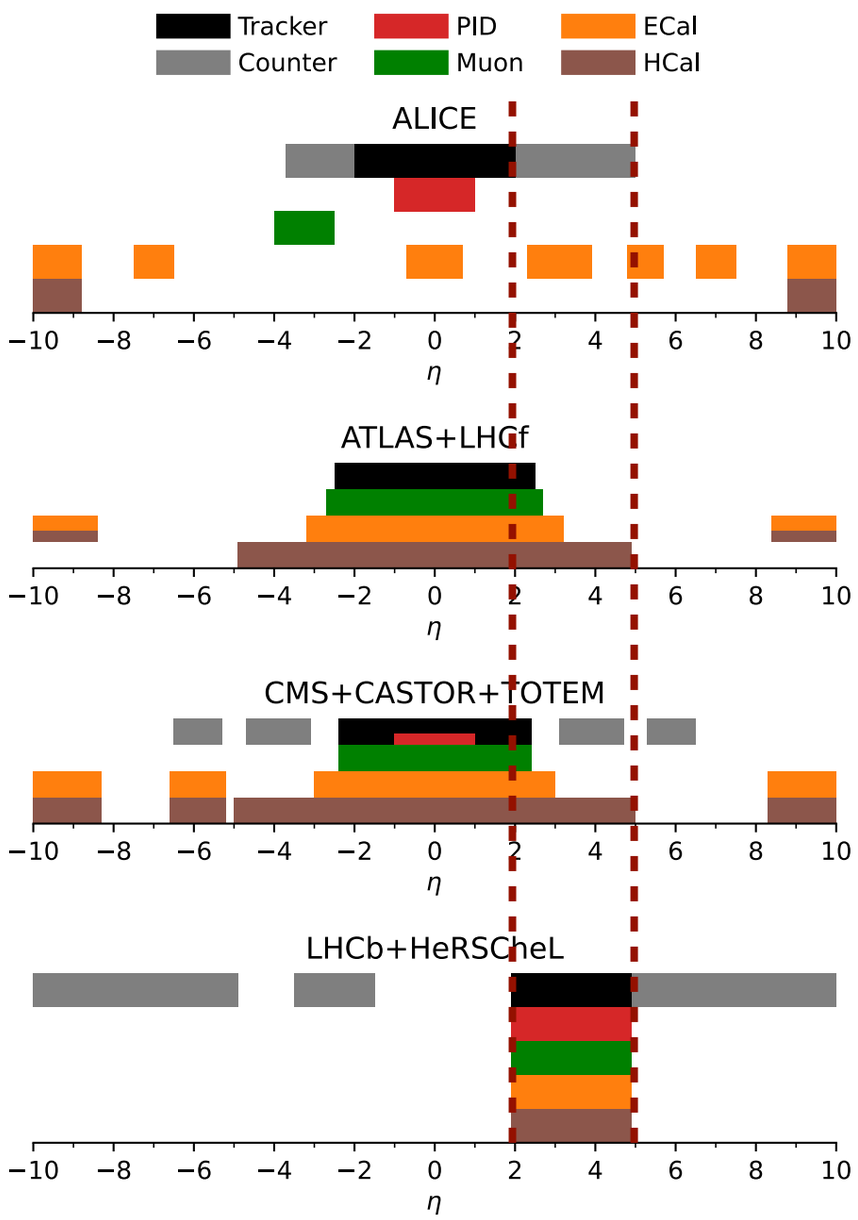
  - Precise vertexing

    impact parameter resolution $(15 + 29/p_{\mathrm{T}}[\mathrm{GeV}])\,\mu\mathrm{m}$
  - Calorimeters ECAL, HCAL

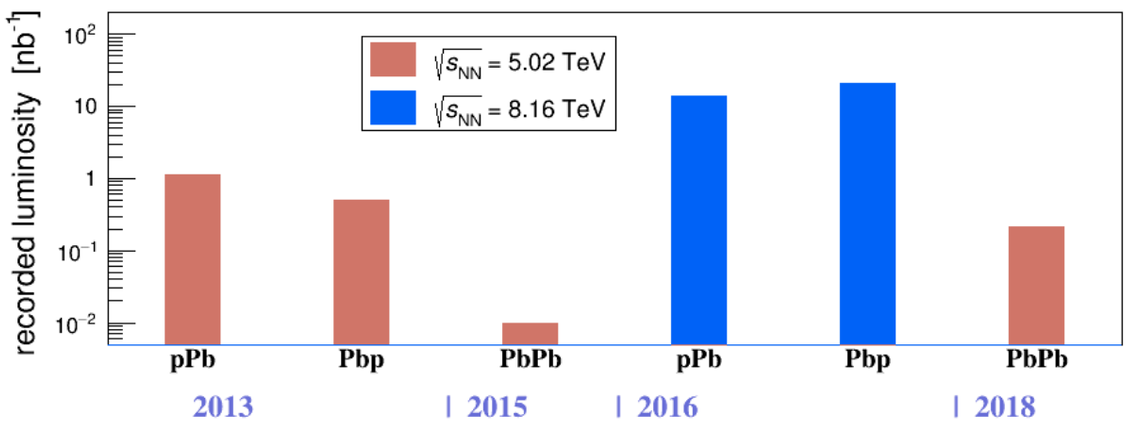
    for ECAL, $\Delta E/E = 1\% + 10\,\%/\sqrt{E[\mathrm{GeV}]}$
  - HeRSCheL detector: scintillating counters covering high rapidity region to veto background in UPC (ultra peripheral collisions)

Heavy ion collisions at LHCb

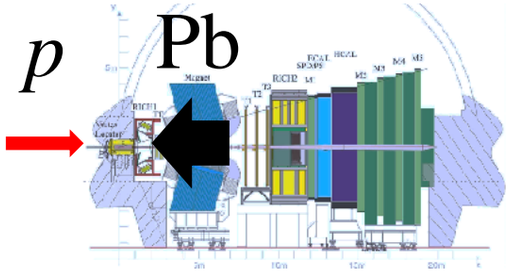
- Only detector at LHC fully equipped in forward region



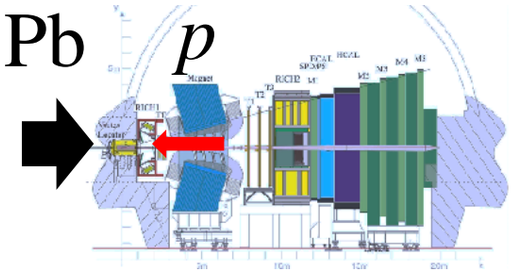
- Full run 1+2 dataset from HI collisions:



- Two configurations in pPb collisions:



Forward $\eta > 0$



Backward $\eta < 0$

Boost of nucleon-nucleon cms system: $\eta = \eta_{lab} - 0.465$

Results for today

1. Prompt charged particle production in $p\mathrm{Pb}$ and pp at $5.02\,\mathrm{TeV}$ **NEW!**
   - LHCb-PAPER-2021-015 (in preparation)

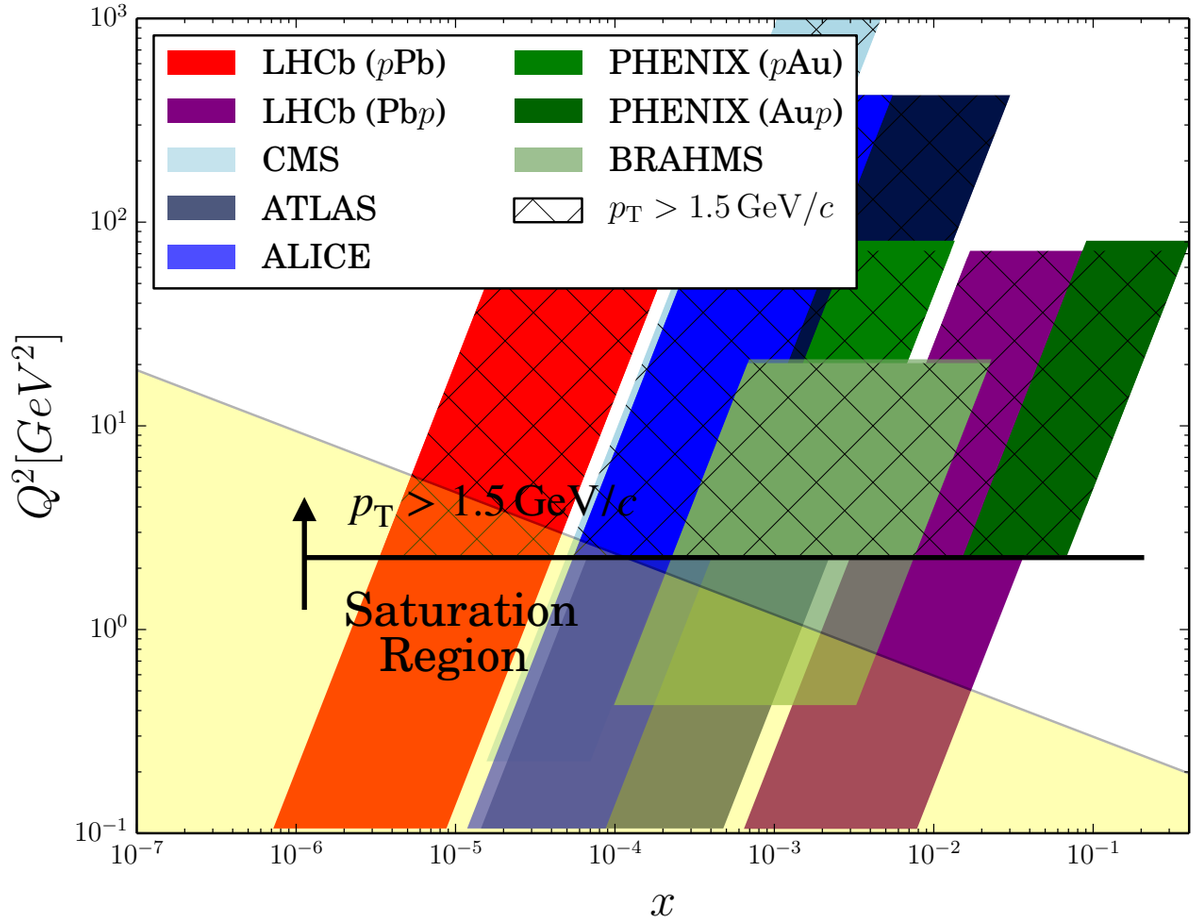
2. Prompt-production cross-section ratio χ_{c2}/χ_{c1} in $p\mathrm{Pb}$ at $8.16\,\mathrm{TeV}$
   - LHCb-PAPER-2020-048, arXiv:2103.07349

3. Photo-produced J/ψ in peripheral PbPb collisions **NEW!**
   - LHCb-PAPER-2020-043 (in preparation)

4. Coherent J/ψ production in PbPb UPC
   - LHCb-CONF-2018-003

Prompt charged particle production in pPb, pp

- Inclusive prompt charged particle spectra provides information of the initial state of the collision
- LHCb can probe unprecedented Bjorken-x range
  - forward, $10^{-6} \lesssim x \lesssim 10^{-4}$
  - backward, $10^{-3} \lesssim x \lesssim 10^{-1}$
- Possible access to saturation region in perturbative scale $p_{\mathrm{T}} > 1.5\,\mathrm{GeV}/c$
- Backward acceptance overlaps with (x, Q^2) at central BRAHMS (dAu) and backward PHENIX (Aup)
- Nuclear modification factor: $R_{p\mathrm{A}} \equiv \sigma_{p\mathrm{A}}/(A\sigma_{\mathrm{pp}})$



Saturation region:
PRD59, 014017 (1998),
PRL100, 022303 (2008)

Q^2: exchanged momentum between interacting partons

x: momentum fraction shared by the probed parton

$$Q^2 \sim m^2 + p_{\mathrm{T}}^2, \quad x \sim \frac{Q}{\sqrt{s_{NN}}} e^{-\eta}$$

$$m = 256\,\mathrm{MeV}/c^2$$

Prompt charged particle production in pPb, pp

LHCb-PAPER-2021-015
(in preparation)

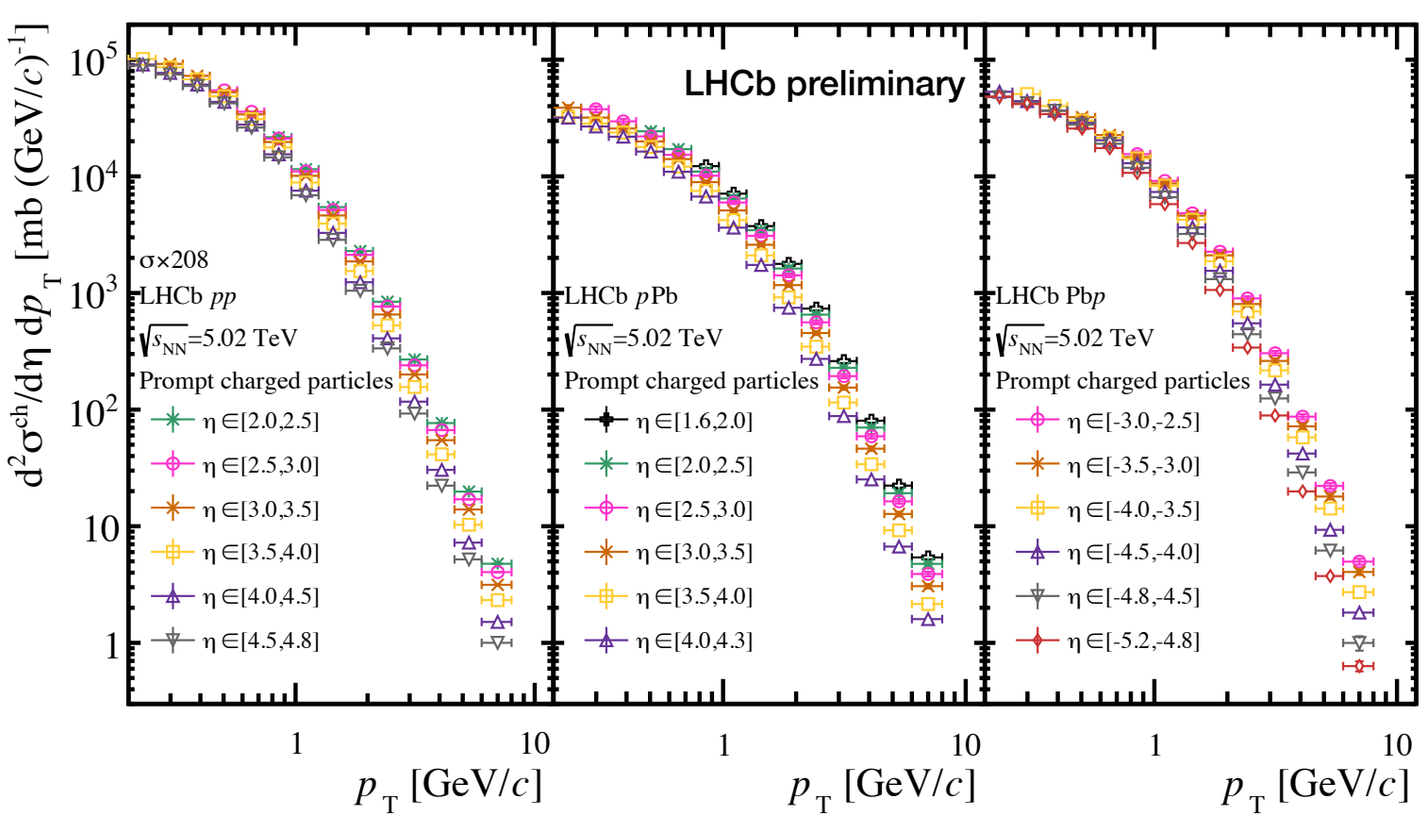
- $$\left.\frac{d^2\sigma}{dp_{\mathrm{T}}d\eta}\right|_{p\mathrm{Pb},\,pp} = \frac{1}{\mathscr{L}} \cdot \frac{N^{ch}(\eta, p_{\mathrm{T}})}{\Delta p_{\mathrm{T}} \Delta\eta},$$

$\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

$p > 2\,\mathrm{GeV}/c,\ 0.2 < p_{\mathrm{T}} < 8\,\mathrm{GeV}/c$

$$\begin{cases} pp\text{: } 2 < \eta < 4.8,\ \mathscr{L} = 3.49 \pm 0.07\,\mathrm{nb}^{-1} \\ p\mathrm{Pb}\text{, forward: } 1.5 < \eta < 4.3,\ \mathscr{L} = 42.73 \pm 0.98\,\mu\mathrm{b}^{-1} \\ \mathrm{Pb}p\text{, backward: } -2.5 < \eta < -5.3,\ \mathscr{L} = 38.71 \pm 0.97\,\mu\mathrm{b}^{1} \end{cases}$$

- Prompt charged particle yields measured with tracking system
- Raw yield corrected mainly by:
  - reconstruction and selection efficiencies
  - background from fake tracks and secondary particles



Total uncertainty:

- **down to** $2.8\,\%$ **in** $\mathrm{d}^2\sigma/\mathrm{d}\eta\mathrm{d}p_{\mathrm{T}}$
- **down to** $4.2\,\%$ **in** $R_{p\mathrm{Pb}}$

Uncertainty source	pPb [%]	Pbp [%]	pp [%]
Track finding efficiency	1.5-5.0	1.5-5.0	1.6-5.3
Detector occupancy	0.0-2.8	0.6-2.9	0.1-1.6
Particle composition	0.4-4.1	0.4-4.6	0.3-2.4
Selection efficiency	0.7-2.2	0.7-3.0	1.0-1.7
Purity	0.1-1.8	0.1-11.7	0.1-5.8
Truth-matching	0.0-0.1	0.0-0.1	0.1-0.2
Luminosity	2.3	2.5	2.0
Statistical uncertainty	0.0-0.6	0.0-1.0	0.0-1.1
Total (in $\mathrm{d}^2\sigma/\mathrm{d}\eta\mathrm{d}p_{\mathrm{T}}$)	3.0-6.7	3.3-14.5	2.8-8.7
Total (in $R_{p\mathrm{Pb}}$)	4.2-9.2	4.4-16.9	

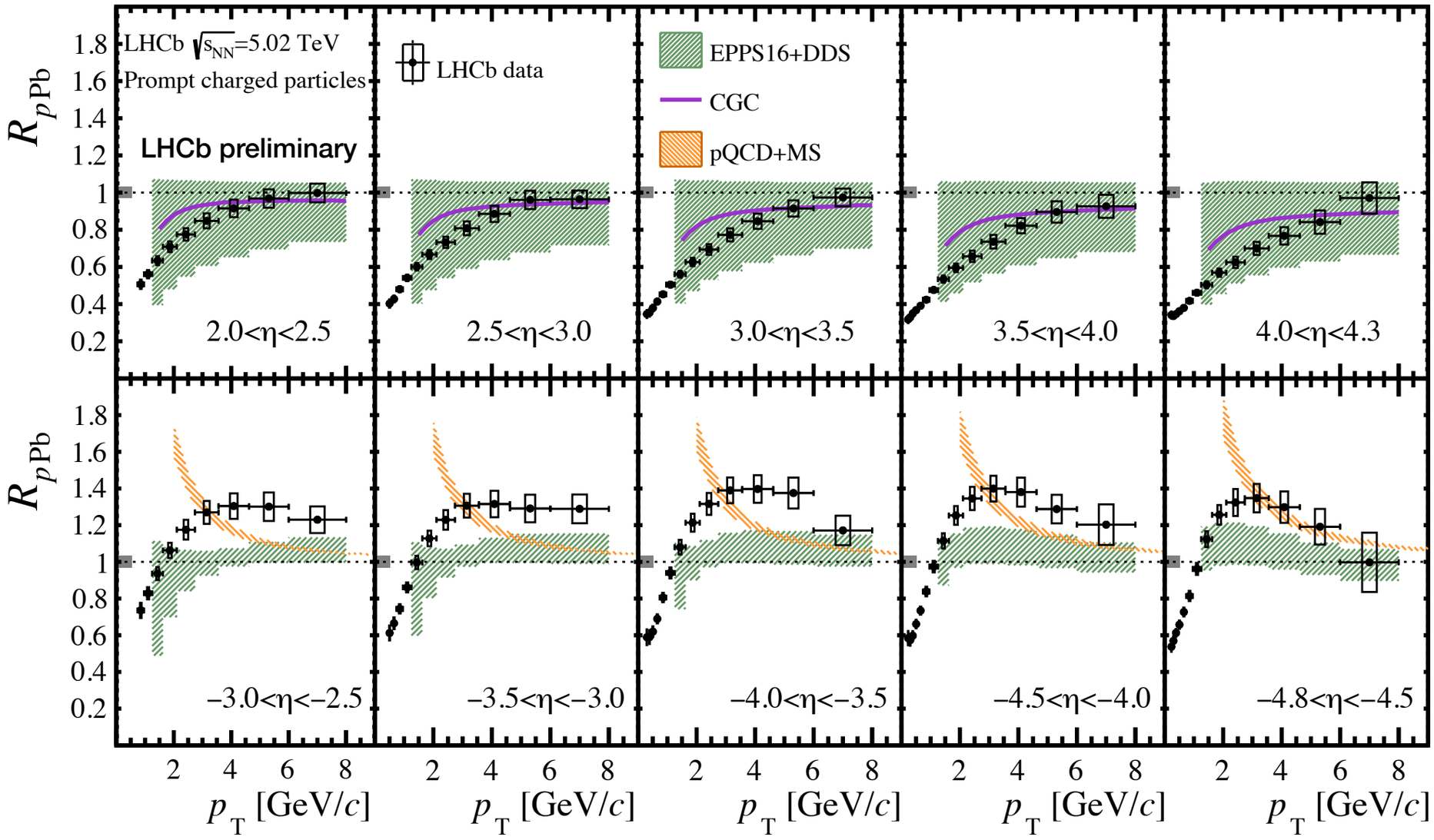
Prompt charged particle production in pPb, pp

LHCb-PAPER-2021-015
(in preparation)

- Nuclear modification factor: $R_{p\mathrm{Pb}}(\eta, p_{\mathrm{T}}) = \dfrac{1}{A}\dfrac{d^2\sigma_{p\mathrm{Pb}}(\eta, p_{\mathrm{T}})/dp_{\mathrm{T}}d\eta}{d^2\sigma_{pp}(\eta, p_{\mathrm{T}})/dp_{\mathrm{T}}d\eta}, \quad A = 208$
- **Strong suppression** at forward η
- **Enhancement** at backward for $p_{\mathrm{T}} > 1.5\,\mathrm{GeV}/c$, as observed by PHENIX in $\mathrm{Au}p$

Models:

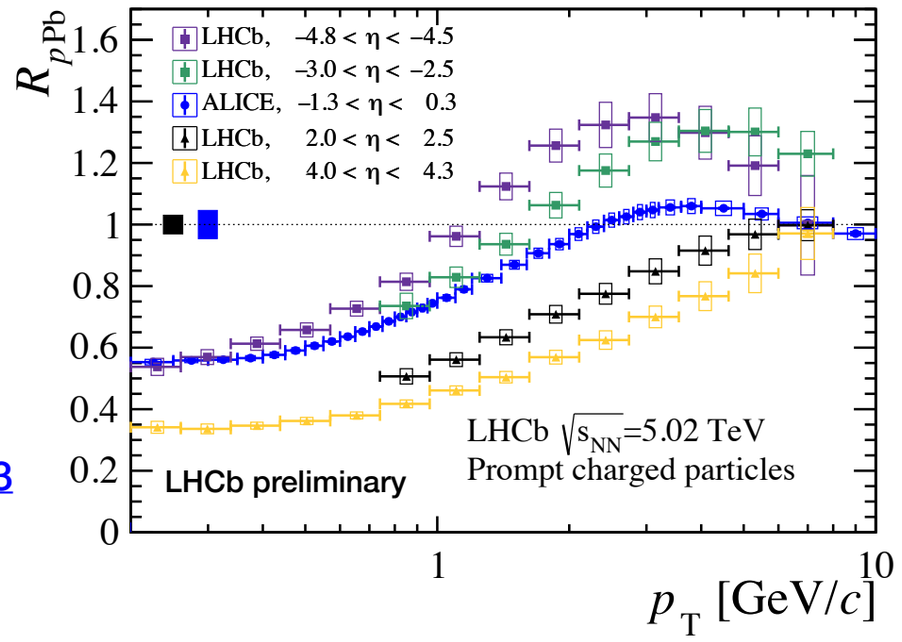
- EPPS16+DDS: I. Helenius *et. al.* JHEP09(2014) 138
- CGC: T. Lappi *et. al.* PR D88, 114020
- pQCD calculation with MS: Z. B. Kang *et. al.* PR D88(2013) 054010 PL B740(2015) 23



Prompt charged particle production in pPb, pp

LHCb-PAPER-2021-015 (in preparation)

- Continuous trend from forward to backward η, including ALICE result
- Enhancement in backward region starts at different p_{T} for different η



ALICE: JHEP 1811 (2018) 013

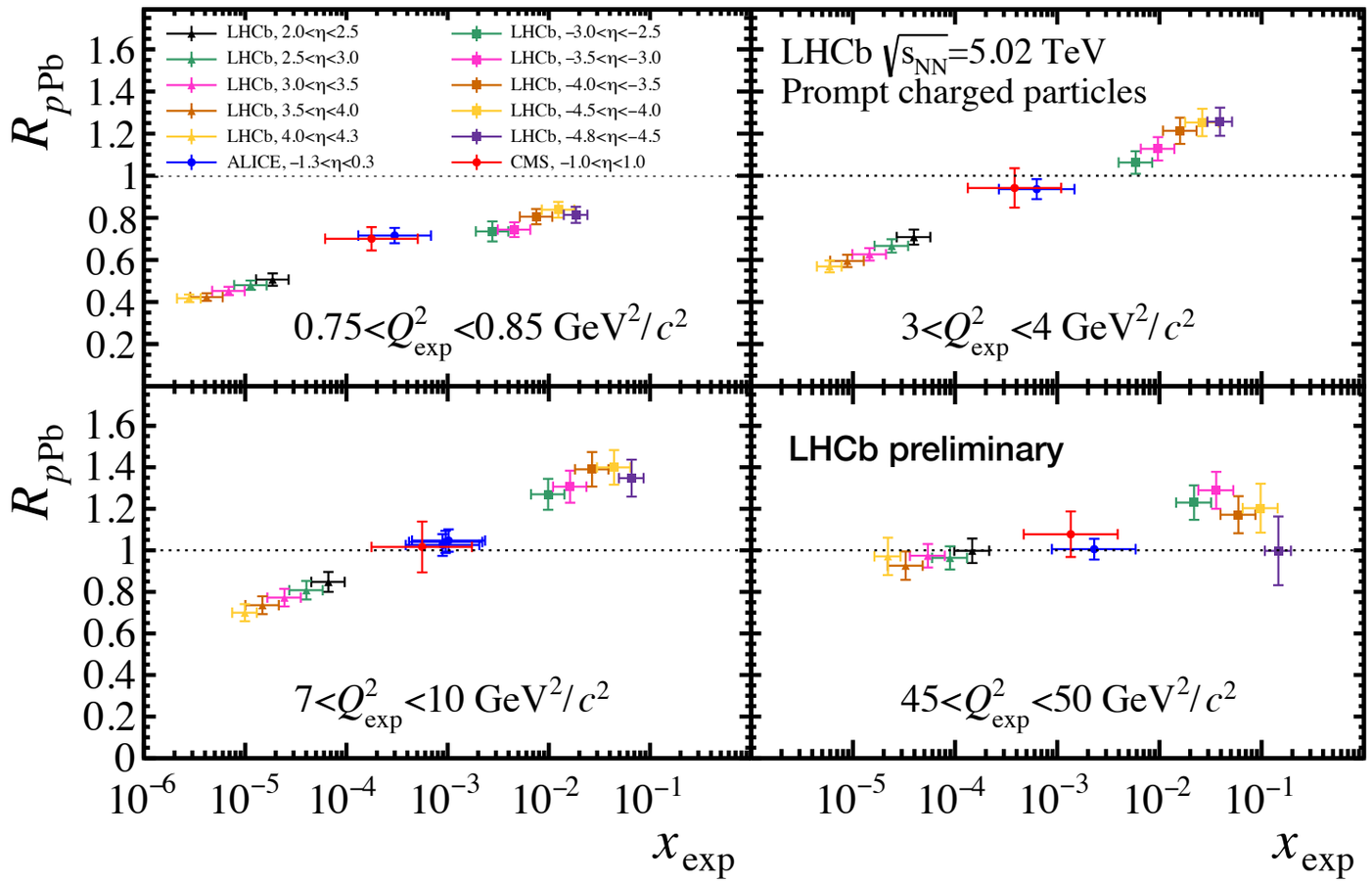
CMS: JHEP 04 (2017) 039

- Defining auxiliary variables x_{exp} and Q^2_{exp}:

$$Q^2_{exp} \equiv m^2 + p^2_{\mathrm{T}} \quad \text{and} \quad x_{exp} \equiv \frac{Q_{exp}}{\sqrt{s_{\mathrm{nn}}}} e^{-\eta}$$

  - with η and p_{T} the center of each bin and $m = 256\,\mathrm{MeV}/c^2$,
  - Indirect study of the evolution of $R_{p\mathrm{Pb}}$ with x and Q^2

- Continuous evolution of $R_{p\mathrm{Pb}}$ with x_{exp} at different Q^2_{exp}, between forward, central and backward η regions



Prompt-production cross-section ratio χ_{c2}/χ_{c1} in pPb

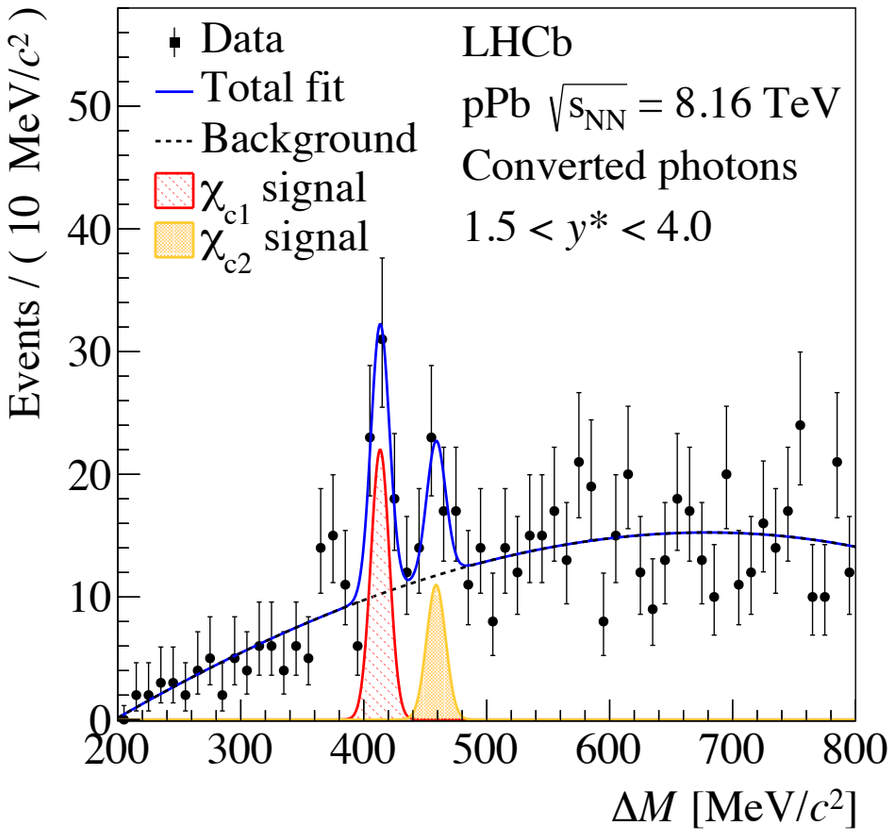
- **First χ_{c2}, χ_{c1} measurement in nuclear collisions at LHC!** $\sqrt{s_{\rm NN}} = 8.16\,\text{TeV}$, $14\,\mu\text{b}^{-1}$ (pPb), $21\,\mu\text{b}^{-1}$ (Pbp)
- Complements measurements of J/ψ, $\psi(2S)$, $\Upsilon(nS)$ production in pPb at LHCb
- Using radiative decay $\chi_{cn} \to J/\psi(\to \mu^+\mu^-)\,\gamma$, two strategies to detect γ

arXiv:2103.07349
submitted to PRC Lett.

- Prompt candidates selected with t_z requirement, $t_z = \dfrac{(z_{decay} - z_{\rm PV}) \times M_{\chi_{c1}}}{p_z}$

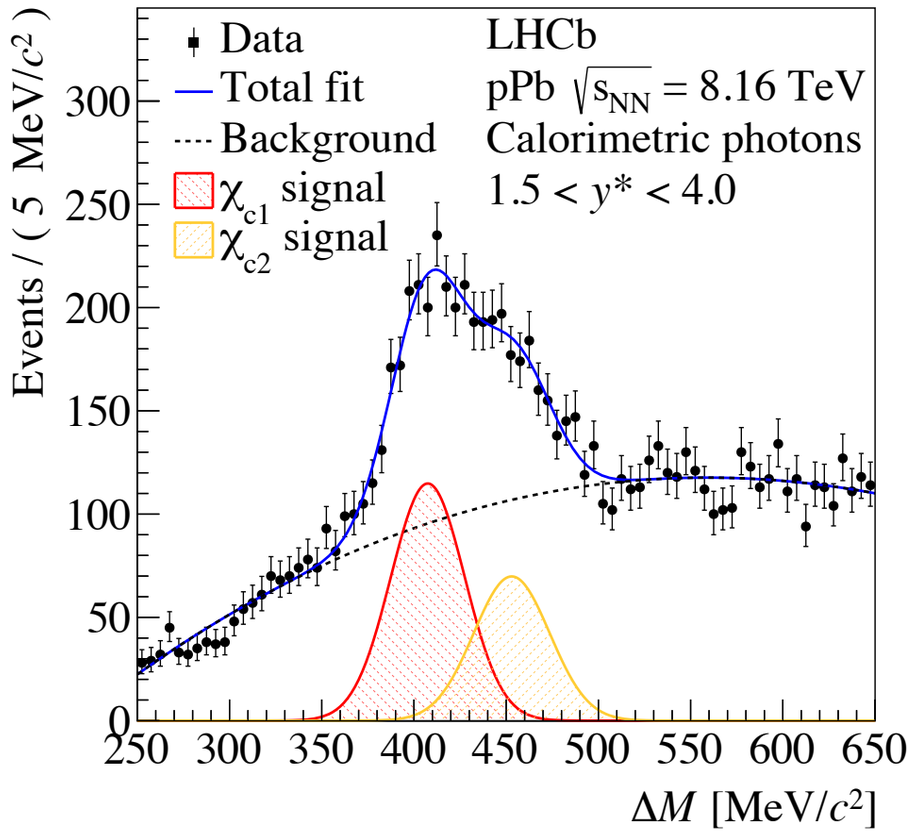
- **converted photons** ($\gamma \to e^{\pm}$, material interaction)

Excellent mass resolution, low statistics



- **calorimetric photons** (using calorimeter)

Reasonable statistics, worse mass resolution



$$\Delta M \equiv M(\mu^+\mu^-\gamma) - M(\mu^+\mu^-)$$

Prompt-production cross-section ratio χ_{c2}/χ_{c1} in pPb

arXiv:2103.07349
submitted to PRC Lett.

$$\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = \frac{N_{\chi_{c2}}}{N_{\chi_{c1}}} \frac{\varepsilon_{\chi_{c2}}}{\varepsilon_{\chi_{c1}}} \frac{\mathcal{B}(\chi_{c2} \to J/\psi\gamma)}{\mathcal{B}(\chi_{c1} \to J/\psi\gamma)}, \quad \text{where} \quad \frac{\varepsilon_{\chi_{c1}}}{\varepsilon_{\chi_{c2}}} = \frac{\varepsilon^{\text{acc}}_{\chi_{c1}}}{\varepsilon^{\text{acc}}_{\chi_{c2}}} \frac{\varepsilon^{\text{reco}}_{\chi_{c1}}}{\varepsilon^{\text{reco}}_{\chi_{c2}}}$$

- Cancellation of efficiencies in cross-section ratio
- Ratio consistent with unity
  - No rapidity dependence within uncertainty
- Consistent with pp 7 TeV ratio within 2σ (JHEP10(2013) 115)

$$\mathcal{R} = \frac{\sigma(\chi_{c2})/\sigma(\chi_{c1})\,|_{p\text{Pb}}}{\sigma(\chi_{c2})/\sigma(\chi_{c1})\,|_{pp}}$$

$$\mathcal{R} = 1.41 \pm 0.21 \pm 0.18 \quad \text{(forward)}$$

$$\mathcal{R} = 1.44 \pm 0.24 \pm 0.25 \quad \text{(backward)}$$

➡ Nuclear effects affect similarly to both states

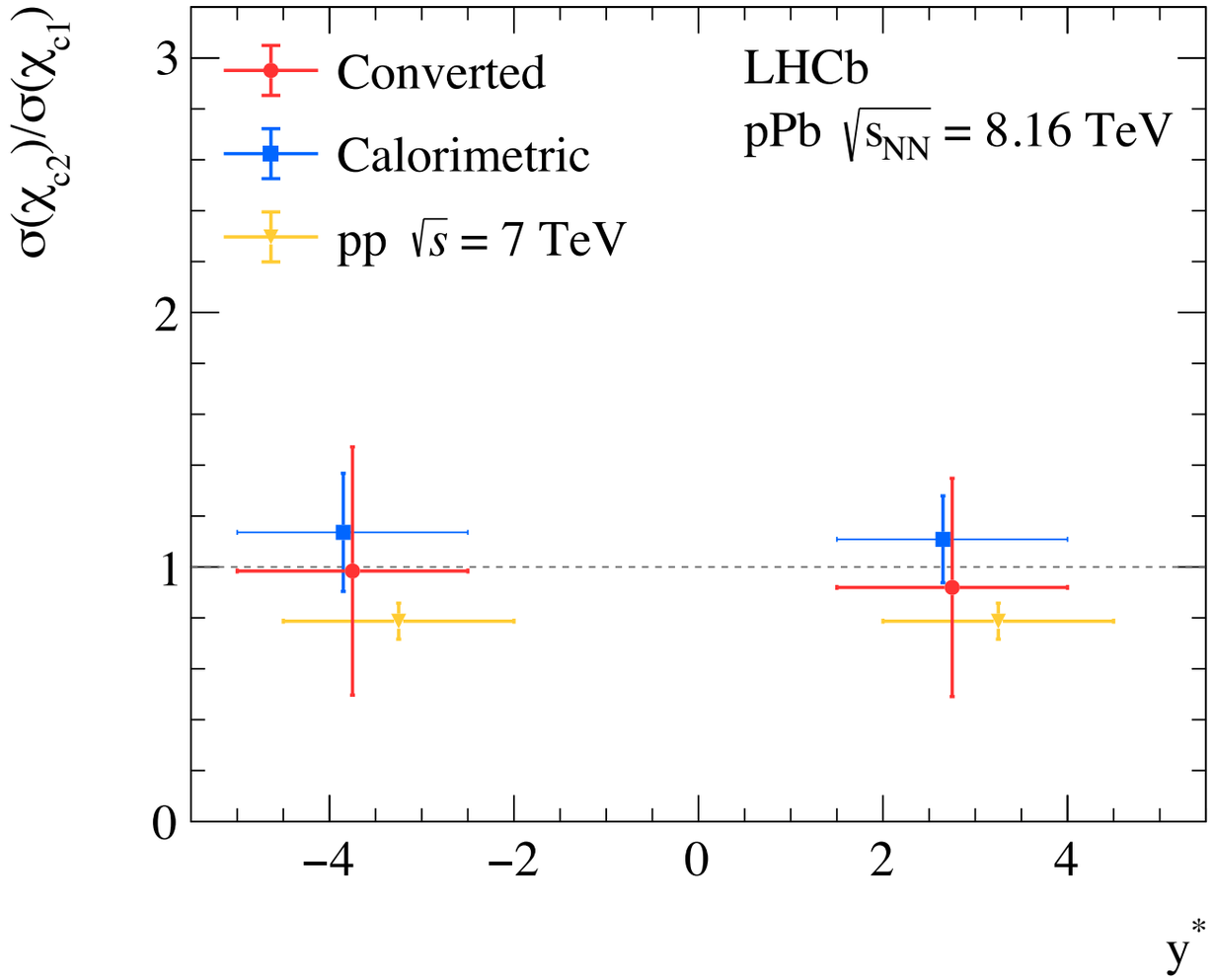
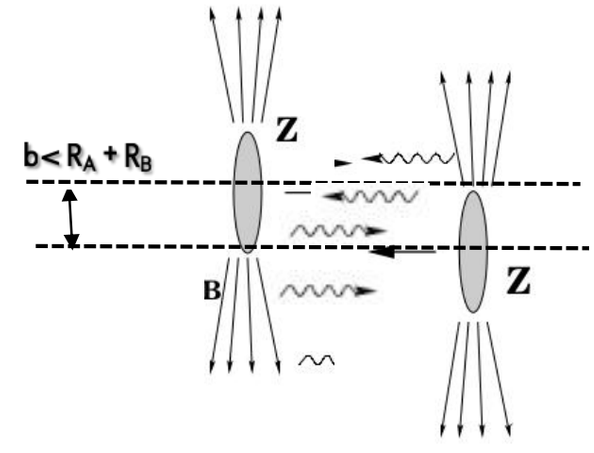


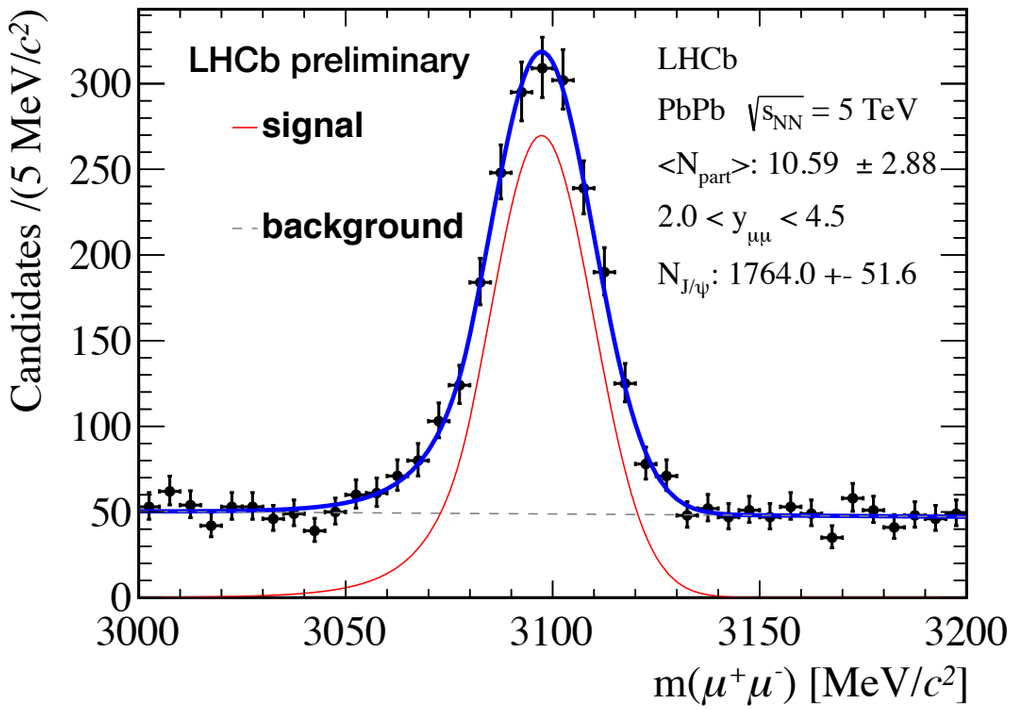
Photo-produced J/ψ in peripheral PbPb collisions

LHCb-PAPER-2020-043
(in preparation)

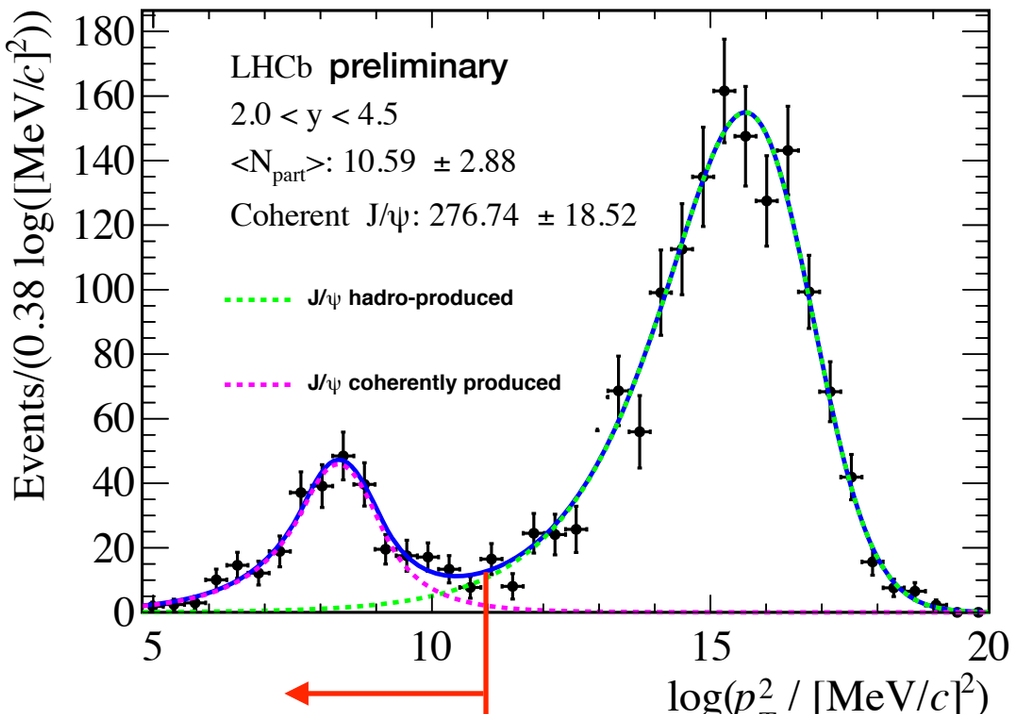
- Studied coherently photo-produced J/ψ in peripheral PbPb collisions
  - Could this be an explanation for the low-p_{T} excess observed by ALICE in PbPb and STAR in AuAu? (PRL 123, 132302, PRL 116, 222301)
- **First PbPb measurement at LHCb!**
- Using 2018 PbPb sample, $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$, $\sim 210\,\mu\mathrm{b}^{-1}$, 85 % to 60 % centrality
- Centrality determination based on energy deposited in ECAL and Glauber calculation
- Non-prompt J/ψ removed with t_z selection
- Coherently-produced J/ψ contribution obtained with fit to $\log(p_{\mathrm{T}}^2)$ distribution of background-subtracted candidates



Peripheral Collision

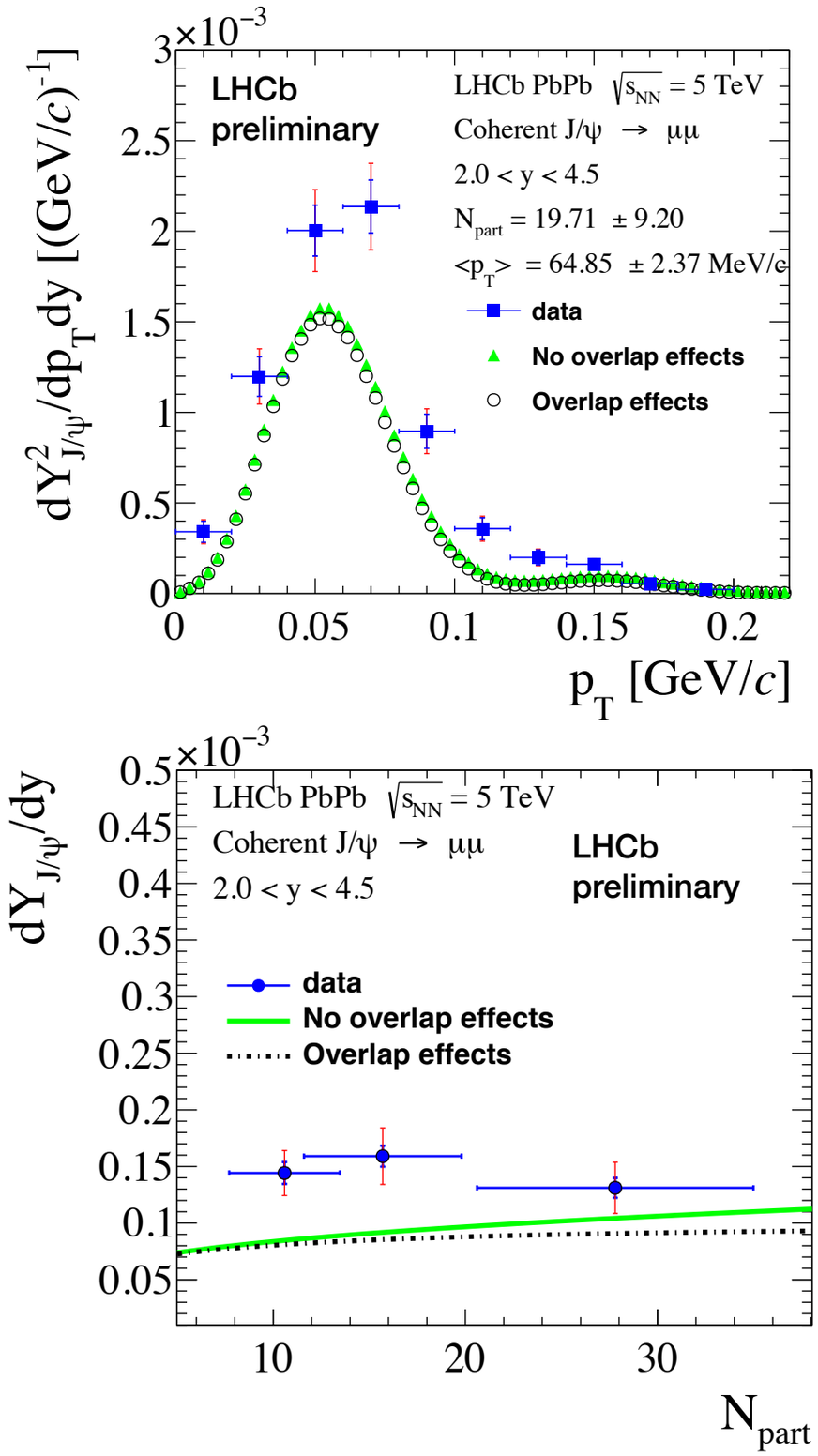


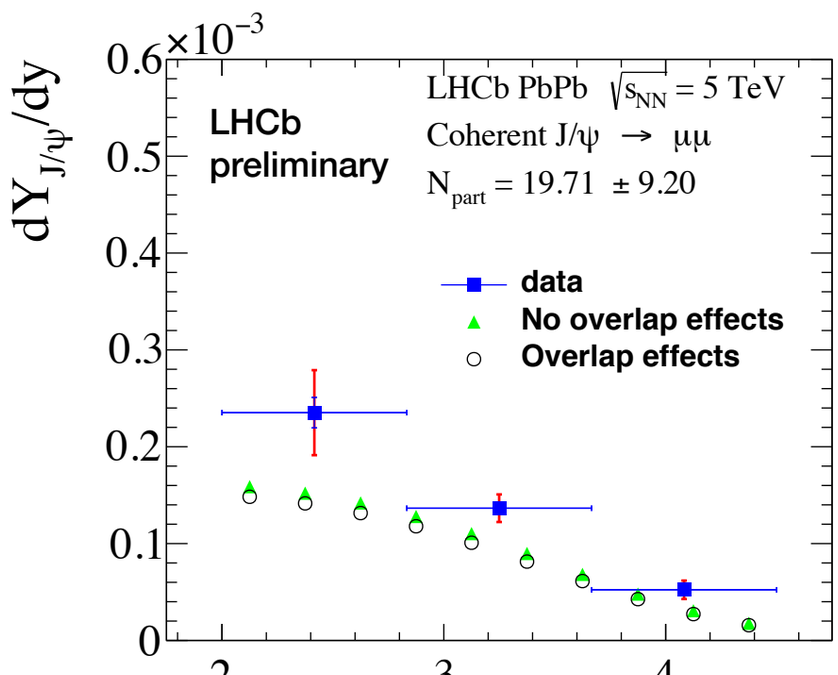
$p_{\mathrm{T}} < 15\,\mathrm{GeV}/c$



$p_{\mathrm{T}} \sim 250\,\mathrm{MeV}/c$

Photo-produced J/ψ in peripheral PbPb collisions





LHCb-PAPER-2020-043 (in preparation)

$$\frac{dY^i_{J/\psi}}{dy} = \frac{N^i_{J/\psi}}{\mathcal{B} N^i_{\mathrm{MB}} \varepsilon^i_{\mathrm{tot}} \Delta y}$$

$$\frac{dY^i_{J/\psi}}{dy dp_{\mathrm{T}}} = \frac{dY^i_{J/\psi}}{dy} \times \frac{1}{\Delta p_{\mathrm{T}}}$$

- Photo-produced J/ψ yields measured in p_{T}, y and centrality bins
- Most precise p_{T}-dependent measurement to date
- Data qualitatively well reproduced in models, with and without nuclear overlap effects

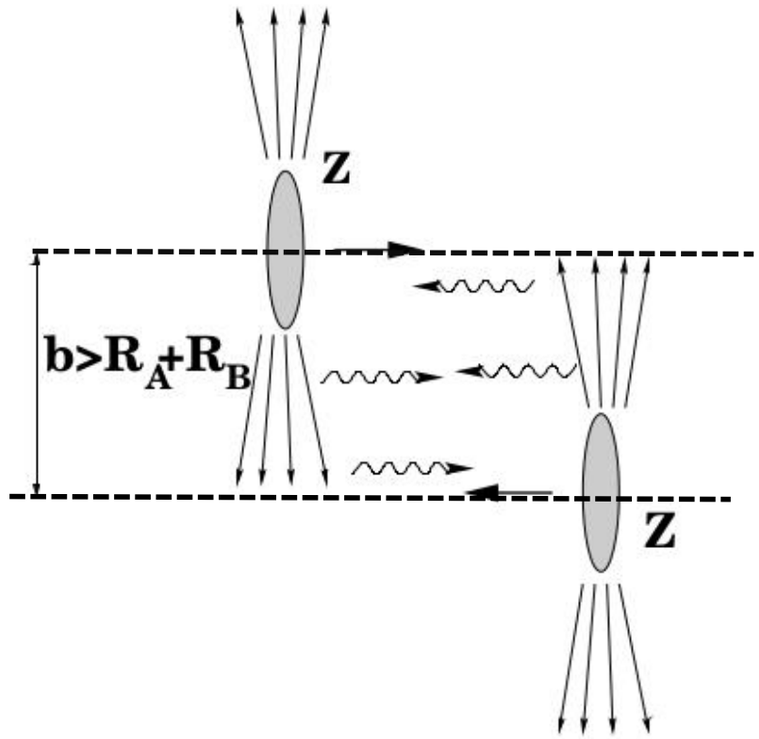
  W. Zha et al. Phys. Rev. C97 (2018) 044910
  W. Zha *et. al.* Phys. Rev. C99, 061901(R)

- Photo-produced J/ψ confirmed as source of the excess

Coherent J/ψ production in PbPb UPC

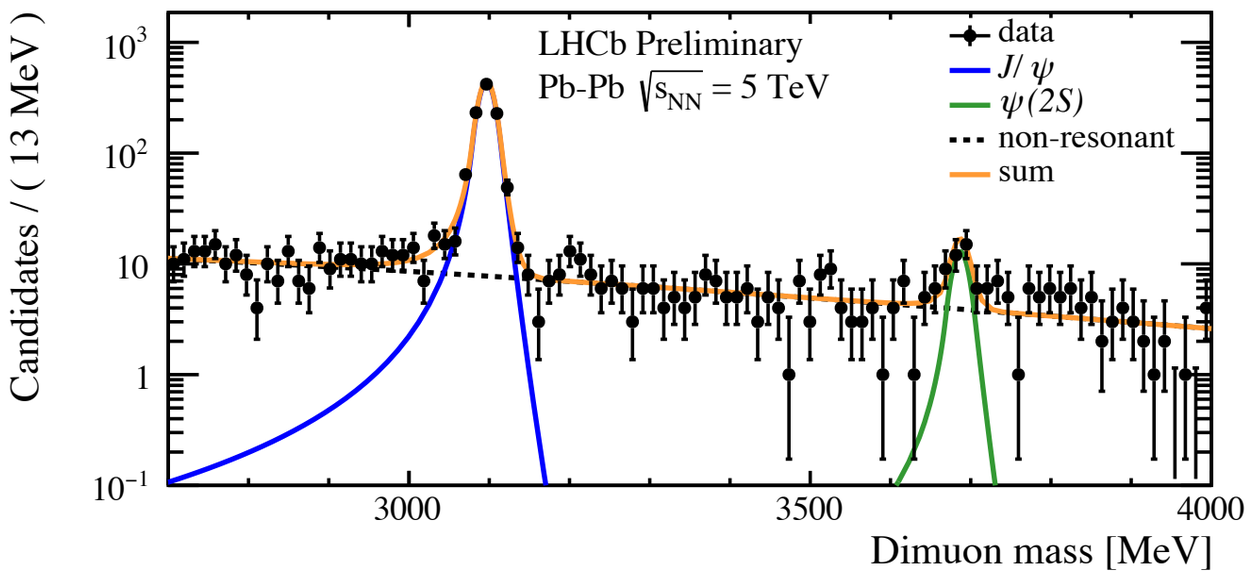
LHCb-CONF-2018-003

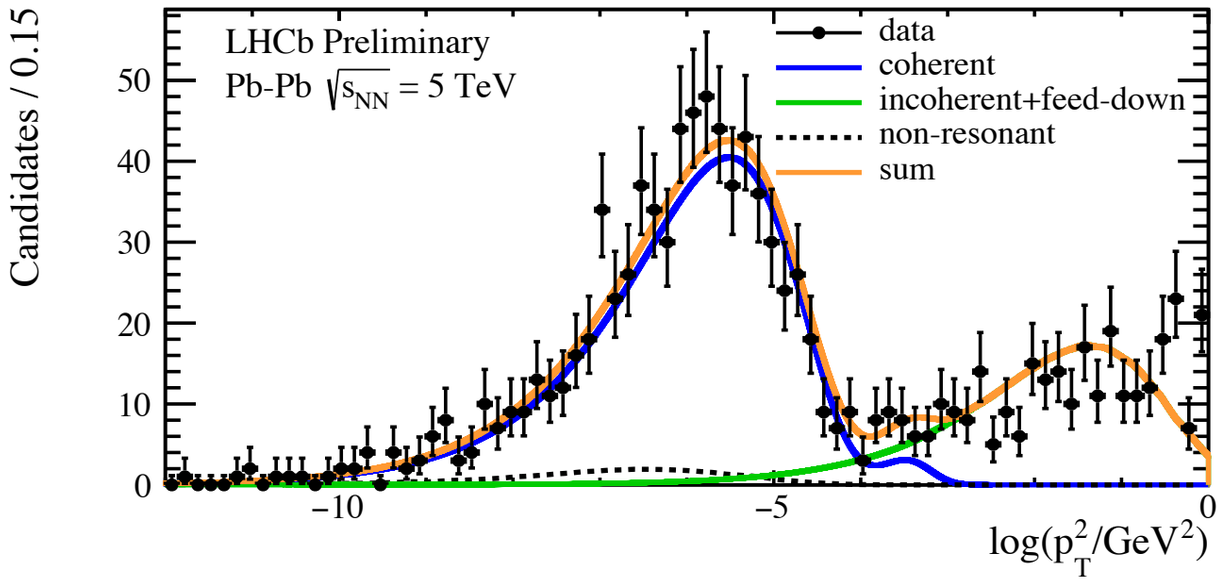
- Measured coherently produced J/ψ in ultra-peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$
- UPC events selected requiring minimal activity in calorimeters
- Using small 2015 PbPb sample of $\mathscr{L} = 10.1 \pm 1.3\,\mu\mathrm{b}^{-1}$
- Signal from $J/\psi \to \mu^+\mu^-$ extracted with fit
- Template fit to $\log(p_{\mathrm{T}}^2)$ distribution to extract coherent contribution



- Templates from STARLight generator (Comput.Phys.Commun. 212 (2017) 258-268)

Ultra-Peripheral Collision





Coherent J/ψ production in PbPb UPC

LHCb-CONF-2018-003

- Coherent J/ψ yields corrected with detection efficiencies
- Selection will be improved in final publication using HeRSCheL detector (JINST 13 (2018) 04, P04017)
- Total cross-section in $2.0 < y < 4.5$:

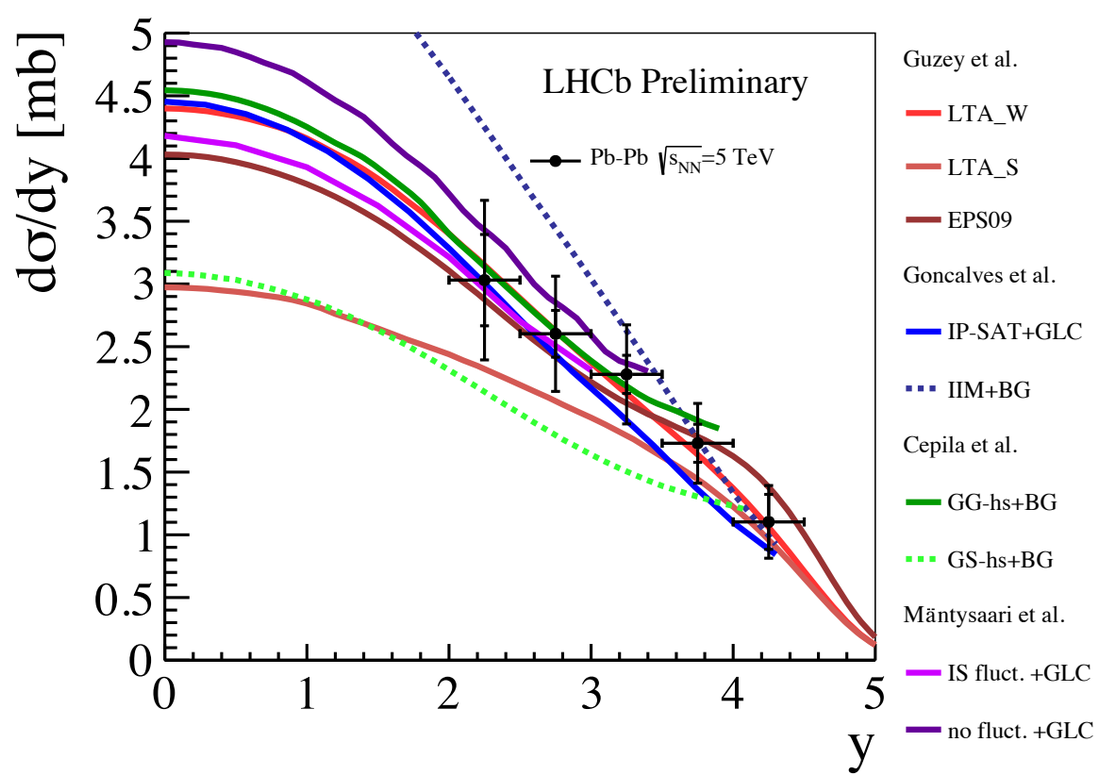
$$\sigma = 5.3 \pm 0.2(stat) \pm 0.5(syst) \pm 0.7(lumi)\ \text{mb}$$

- Largest uncertainty contribution from luminosity determination

Source	Relative uncertainty (%)
Reconstruction efficiency	2.1–4.5
Selection efficiency	3.2
Hardware trigger efficiency	3.0
Software trigger efficiency	1.6–5.3
Momentum smearing	3.3
Mass fit model	3.9
Feed-down background	5.8
Branching Fraction	0.6
Luminosity	13.0

- Comparison with predictions from different models:

  Cepila *et al.* PR C97 024901 (2018)
  Gonçalves *et al.* PR D96 094027 (2017)
  Guzey *et al.* PR C93 055206 (2016)
  Mäntysaari *et al.* PL B772 (2017) 832



Conclusions

New results from LHCb in heavy ion collisions were presented

- Full list of published results here

- First determination of $R_{p\mathrm{Pb}}$ for prompt charged particles in forward and backward regions at LHC!
  - Measured prompt charged particle production cross-section in pp and $p\mathrm{Pb}$ at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$
  - Measurement down to $4.2\,\%$ total relative uncertainty in $R_{p\mathrm{Pb}}$
  - Strong constrains to nuclear PDFs and saturation models down to very low x
- First measurement of χ_{c2} and χ_{c1} production in nuclear collisions at LHC at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$
- Measurement of photo-produced J/ψ in peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$
  - First PbPb result at LHCb
  - Most precise determination of p_{T} spectrum to date
  - Confirmation of the source of the excess in J/ψ production at low p_{T}
- Measurement of coherent J/ψ production in ultra-peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

Backup slides

Previous results of $R_{p\mathrm{Pb}}$ for charged particles

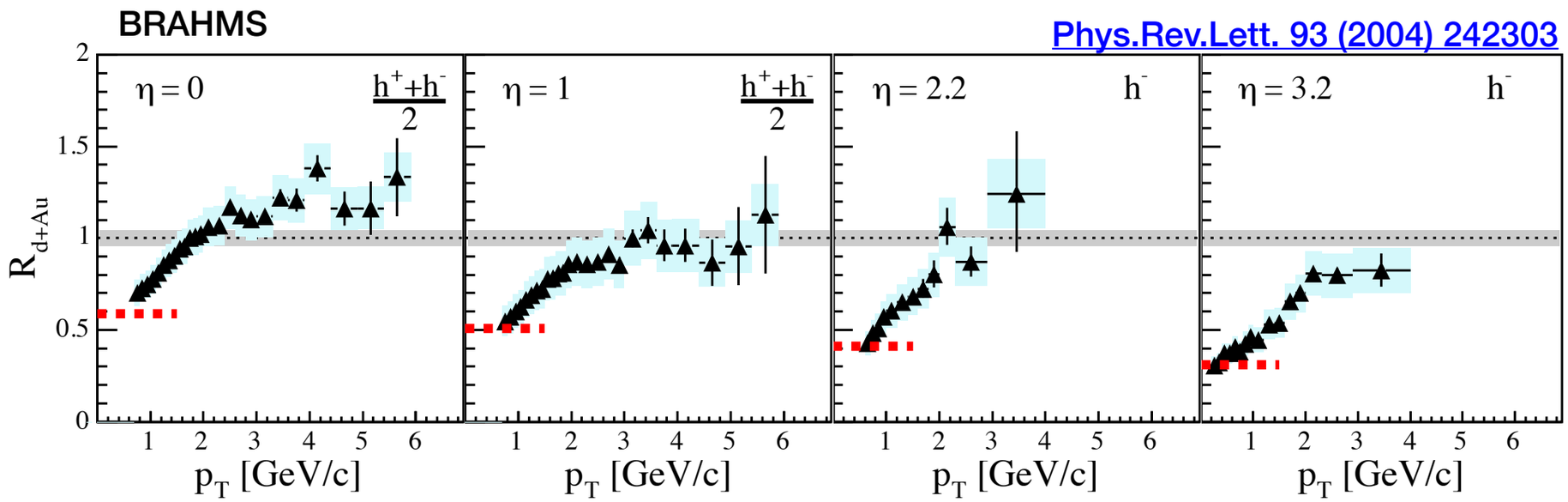
BRAHMS: Phys.Rev.Lett. 93 (2004) 242303

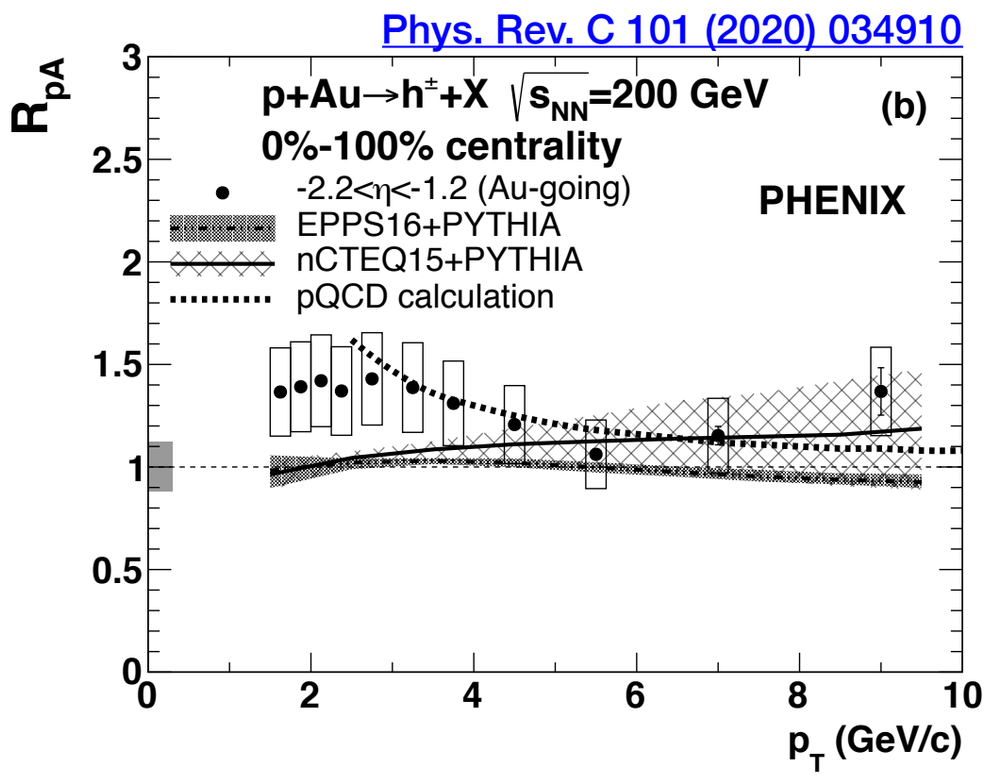
PHENIX: Phys. Rev. C 101 (2020) 034910

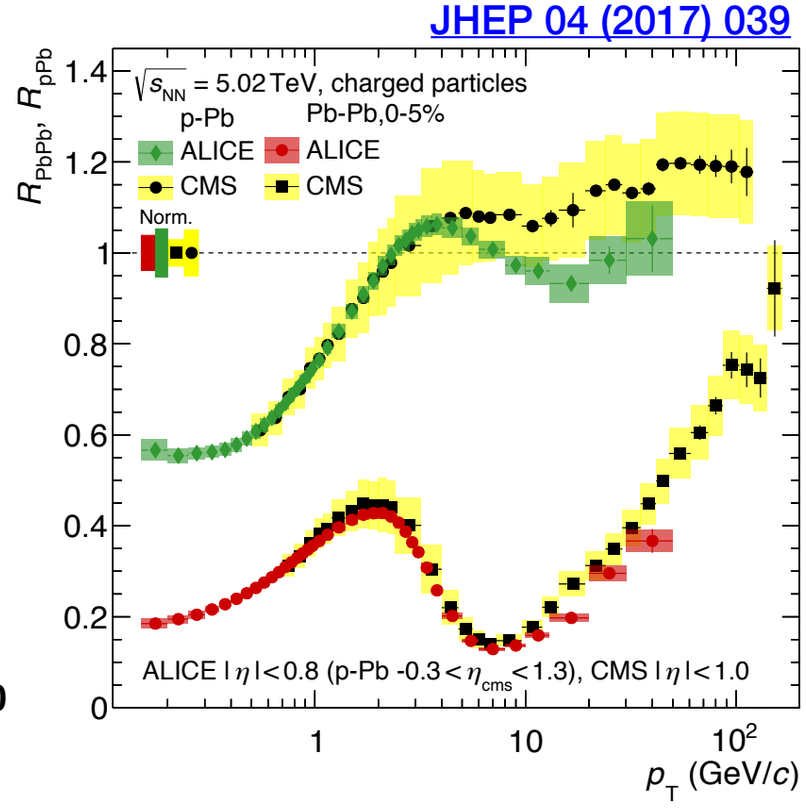
CMS: JHEP 04 (2017) 039

ALICE: JHEP 1811 (2018) 013

ATLAS: Phys. Lett. B 763 (2016) 313

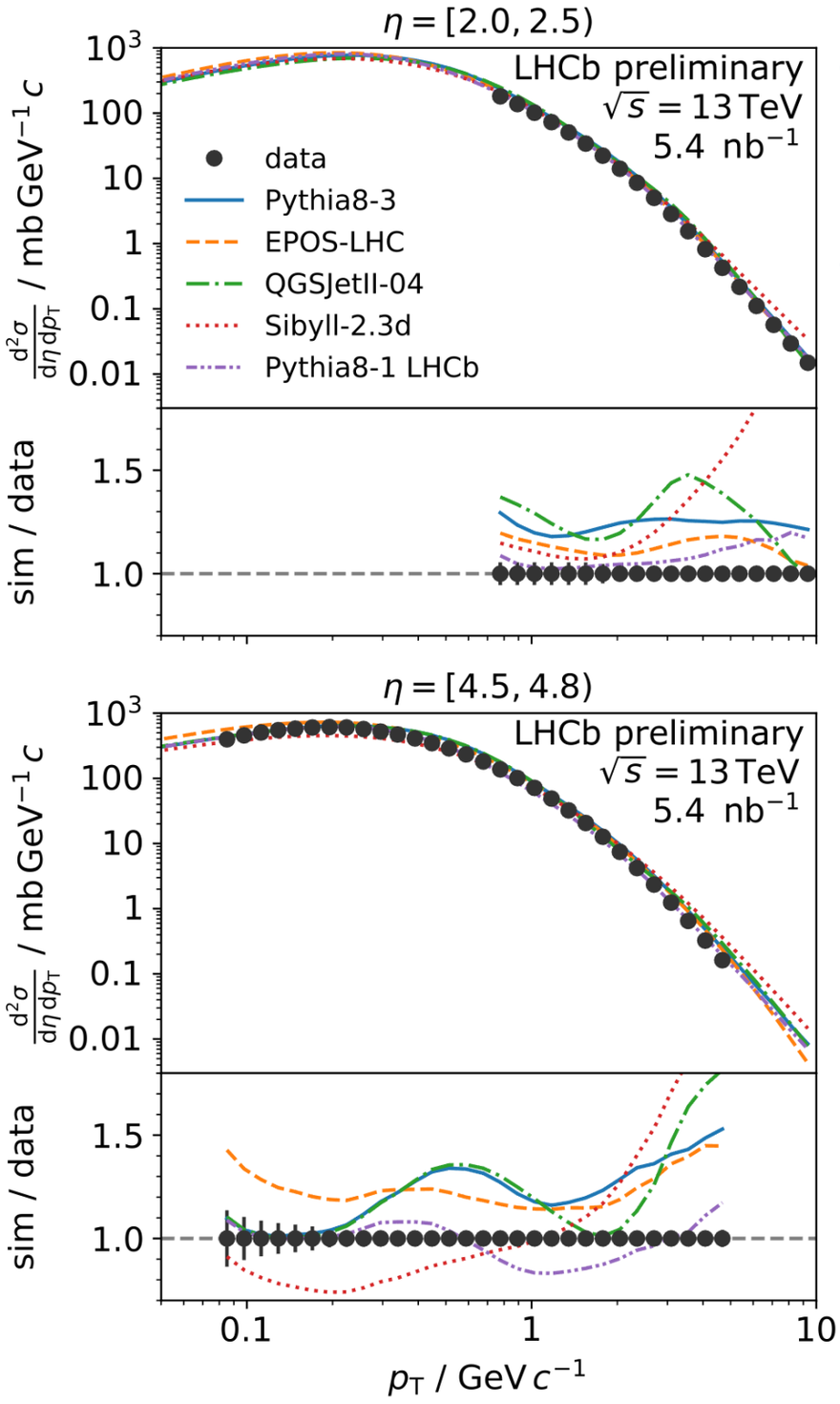






Prompt charged particle production at 13 TeV

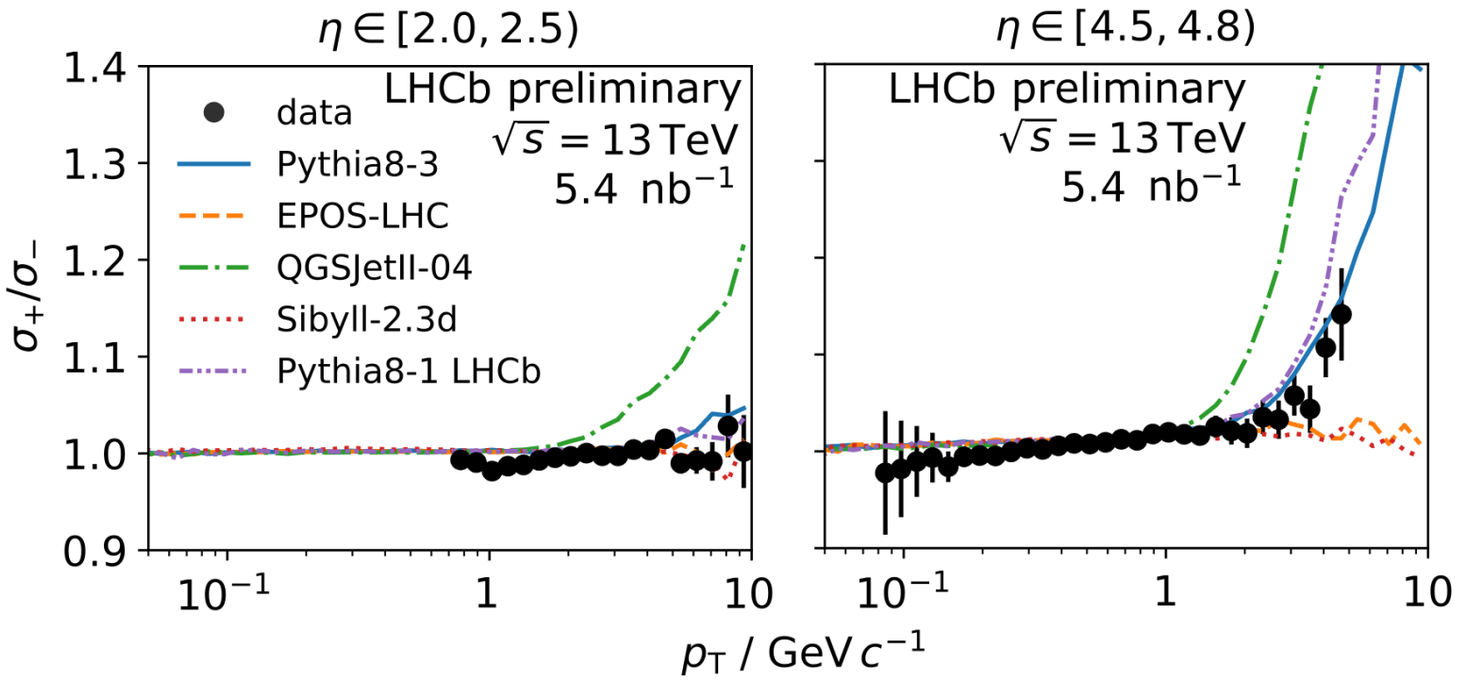
LHCb-PAPER-2021-010 (in preparation)



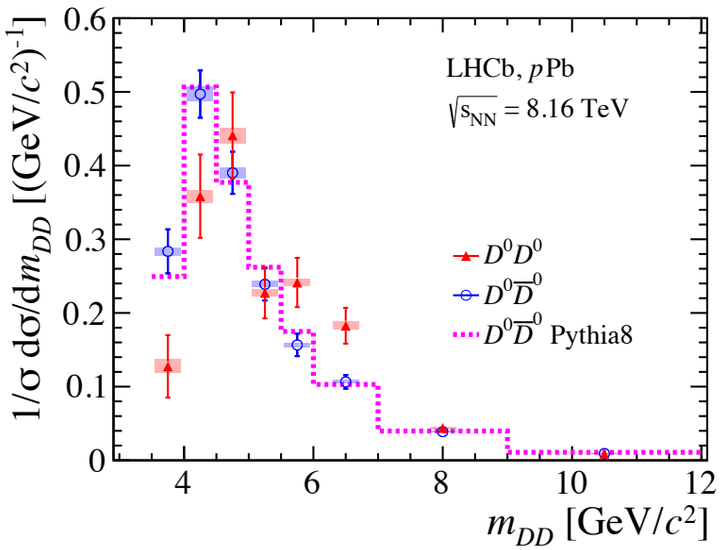
- First double-differential measurement of forward charged particle spectrum at $\sqrt{s} = 13\,\text{TeV}$
- Fundamental measurement for QCD, generator tuning and astroparticle physics

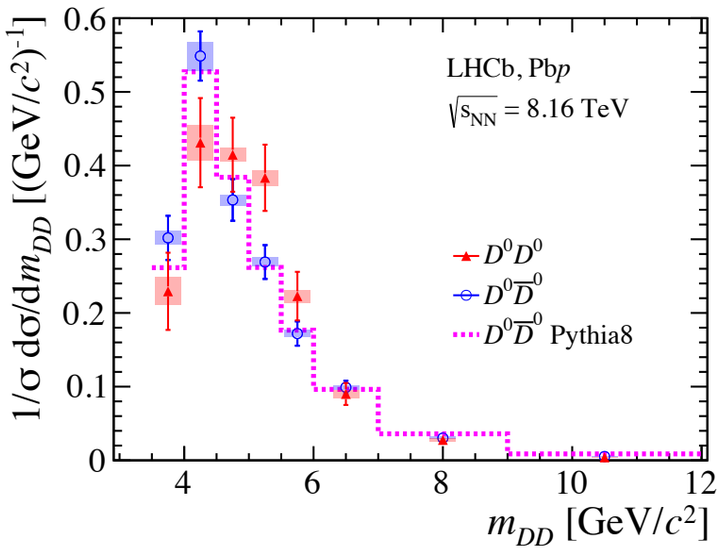
$$\frac{d^2\sigma}{dp_T d\eta} = \frac{1}{\mathscr{L}} \cdot \frac{n}{\Delta p_T \Delta\eta}$$

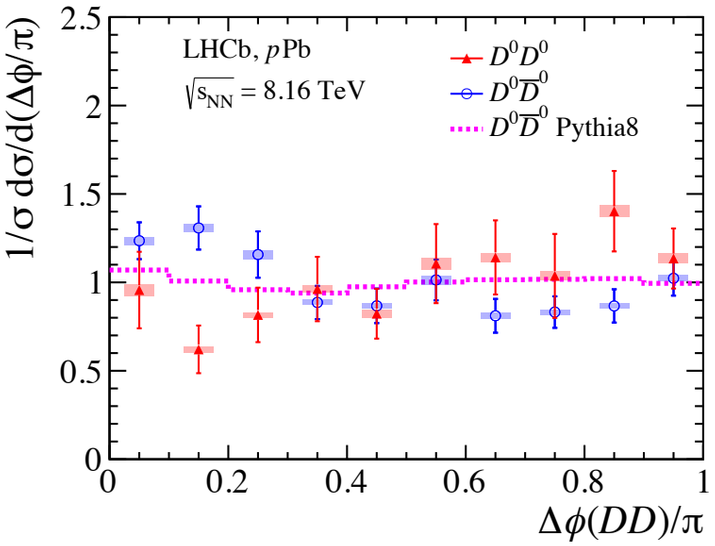
$$n_{\text{cand}} = \varepsilon n + \sum_i n_{\text{backgr,i}}$$

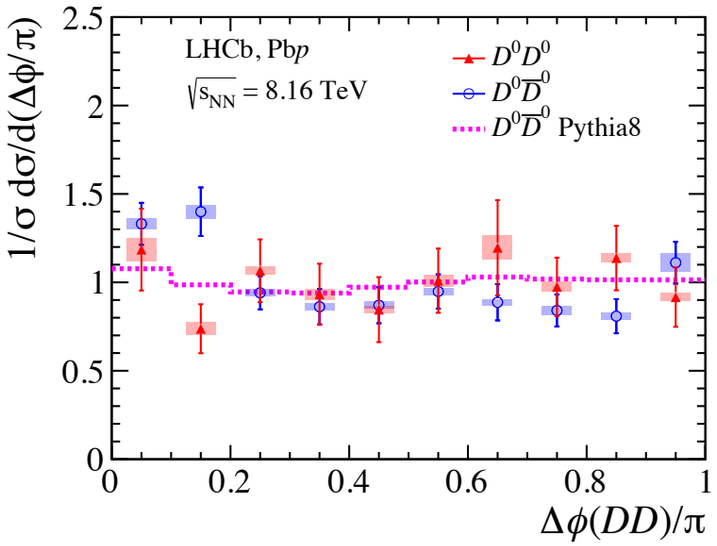


Charm pair production and DPS scattering in pPb









For 1 b:

Pairs	$-5 < y(H_c) < -2.5$	$1.5 < y(H_c) < 4$	pp extrapolation
D^0D^0	$0.99 \pm 0.09 \pm 0.09$	$1.41 \pm 0.11 \pm 0.10$	4.3 ± 0.5
$J/\psi D^0$	$0.64 \pm 0.10 \pm 0.06$	$0.92 \pm 0.22 \pm 0.06$	3.1 ± 0.3

(σ_{eff} in b)

Result assuming SPS and no nuclear effects

[Phys. Rev. Lett. 125, 212001]

- First measurement of charm pair production in pPb at $\sqrt{s_{\rm NN}} = 8.16\,\text{TeV}$
- Study Double Parton Scattering (DPS):

$$\sigma^{AB}_{\rm DPS} = \frac{1}{1+\delta_{AB}}\frac{\sigma^A\sigma^B}{\sigma_{\rm eff}}$$

- DPS enhanced about a factor 3 with respect to Single Parton Scattering (SPS) in pPb
- Study combinations of D_1D_2 and DJ/ψ pairs ($D = D^0, D^+, D_s^+$)

SPS →enhanced in opposite-sign pairs

DPS →enhanced in same-sign pairs