DIS 2018

Kobe, Japan, April 16 - 20, 2018

Particle production at LHCb

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on behalf of the LHCb collaboration

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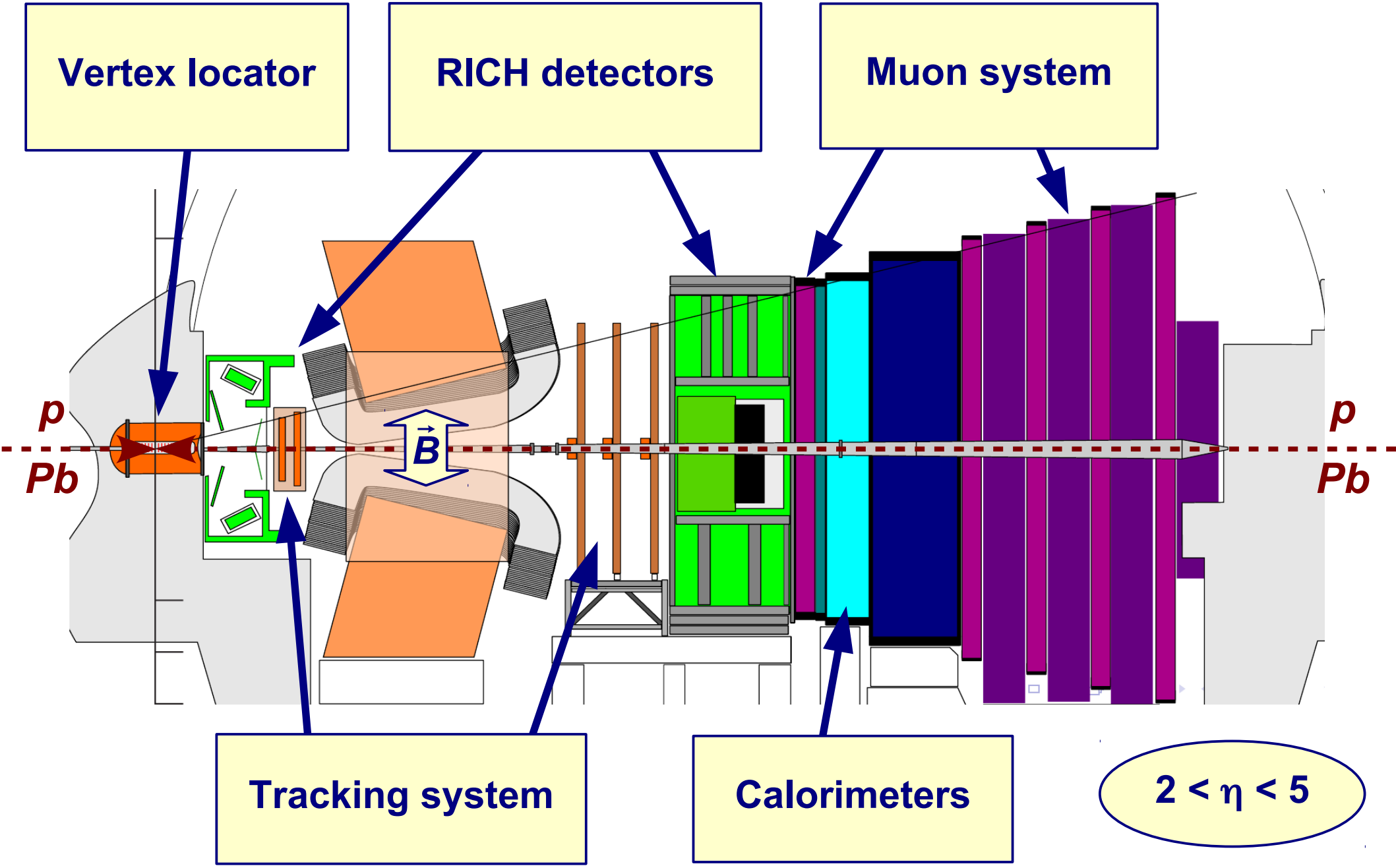
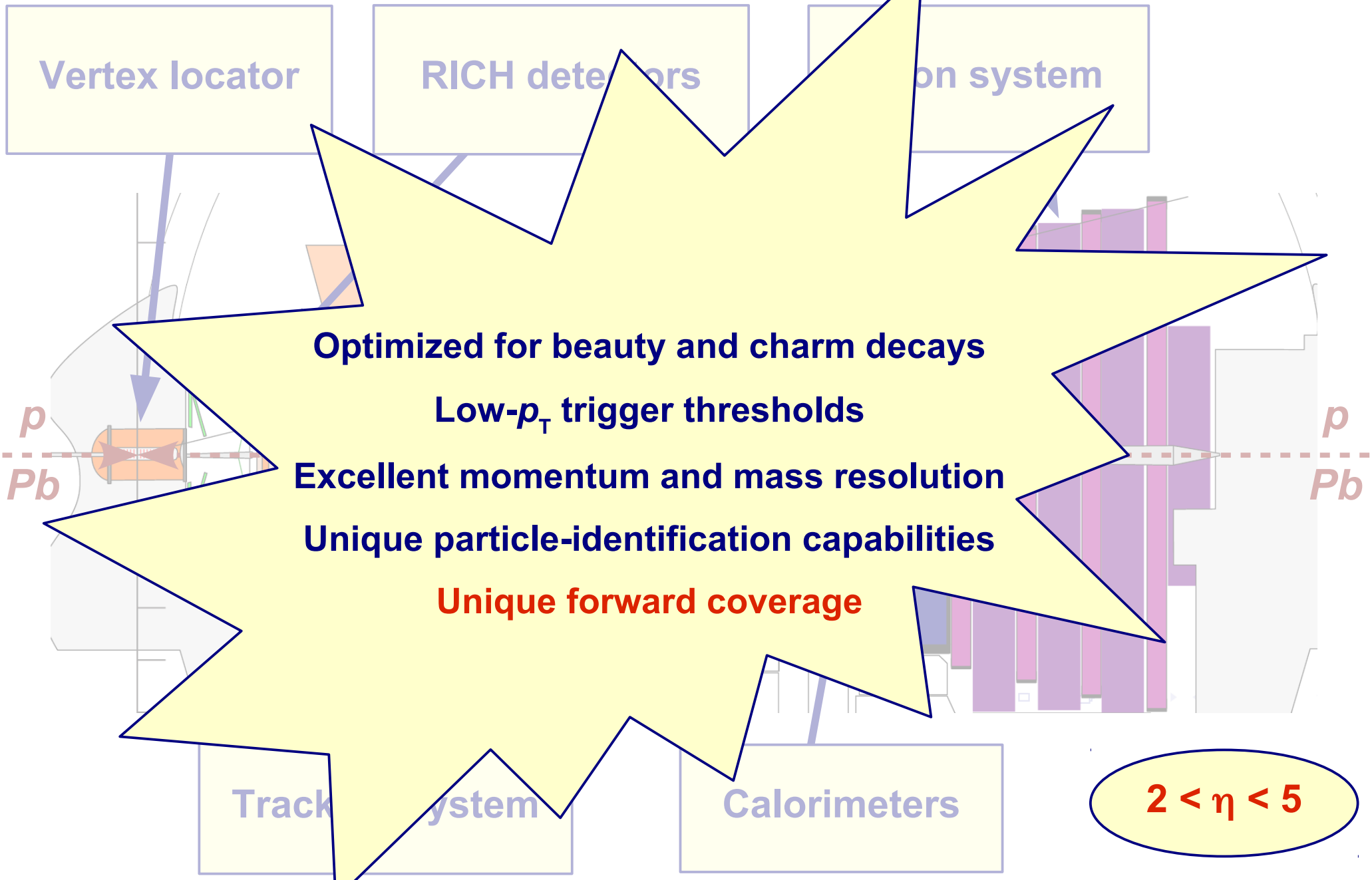
LHCb

[JINST 3(2008)S08005]



LHCb

[JINST 3(2008)S08005]



Optimized for beauty and charm decays

Low-p_T trigger thresholds

Excellent momentum and mass resolution

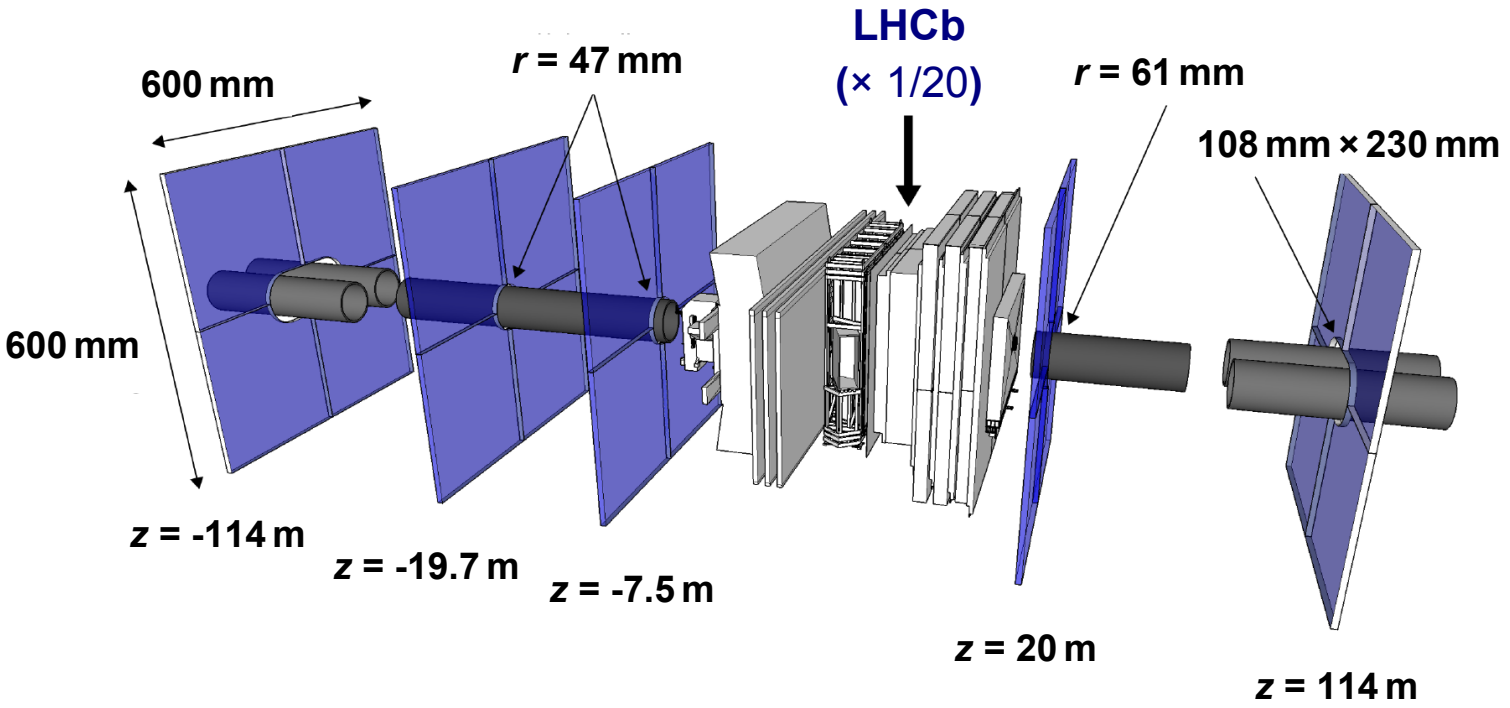
Unique particle-identification capabilities

Unique forward coverage

$2 < \eta < 5$

HeRSCheL

[JINST 13(2018)04017]



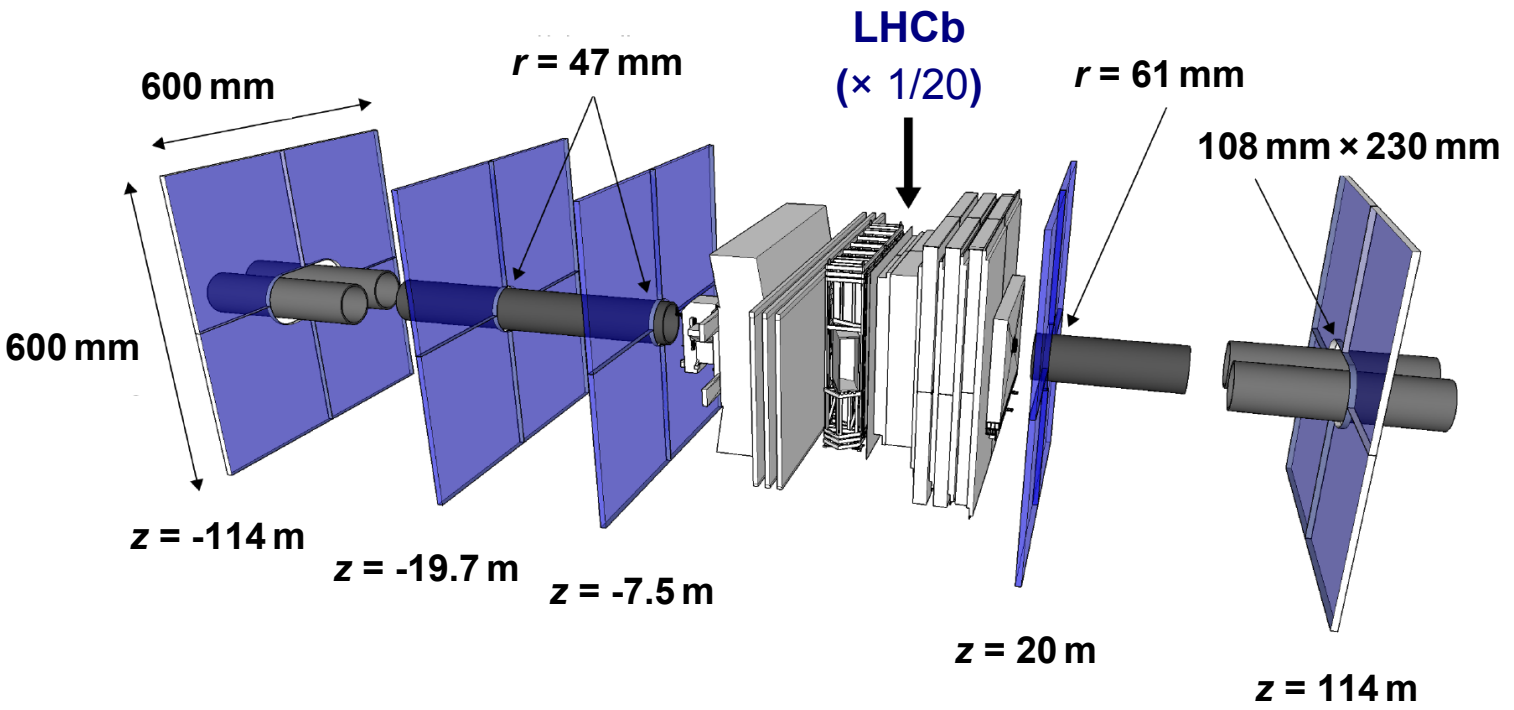
New for Run II: High-Rapidity Scintillation Counters for LHCb

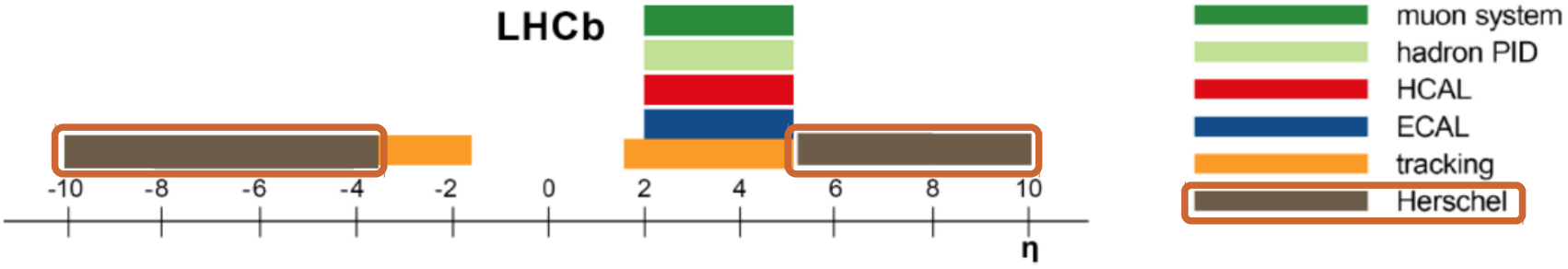
Five stations of planar scintillators at distances of up to 114 m upstream and downstream of the LHCb detector

Main purpose: improve acceptance at high $|\eta|$ for studies of Central Exclusive Production

HeRSCheL

[arXiv:1801.04281]

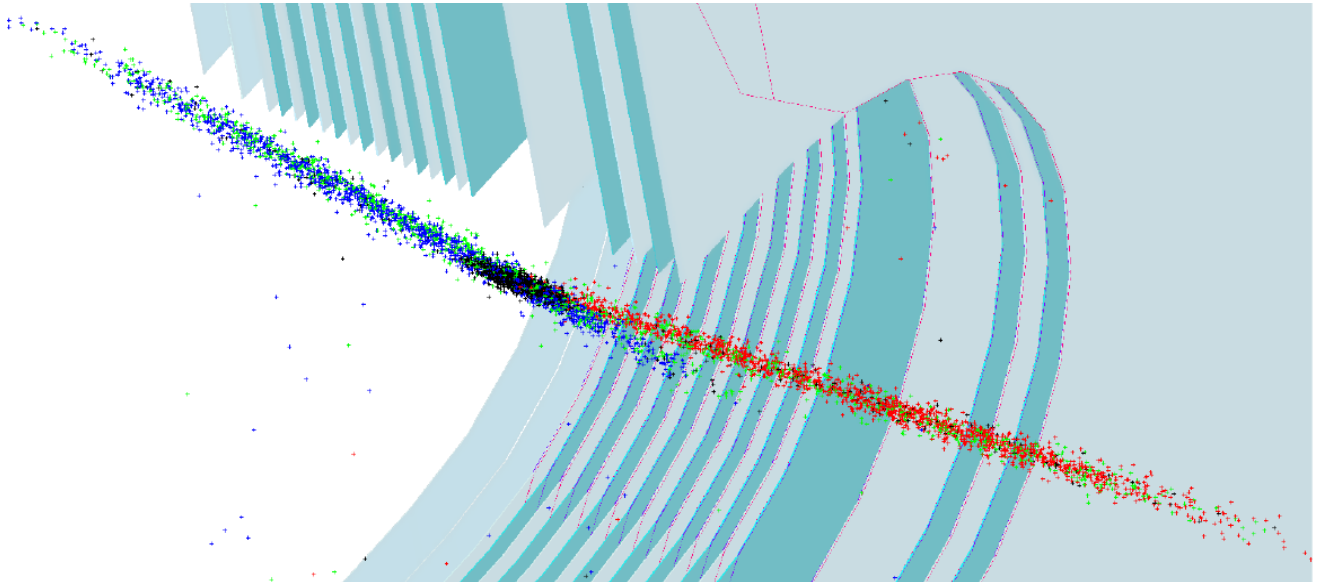




Main purpose: improve acceptance at high $|\eta|$ for studies of Central Exclusive Production

SMOG

[JINST 9(2014)12005]

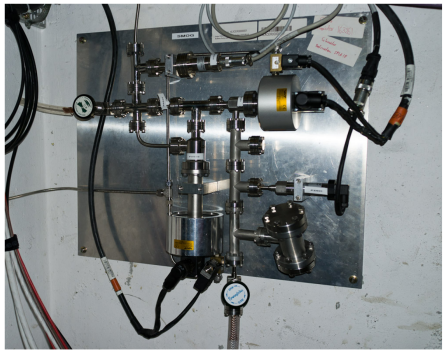


System for Measuring the Overlap with Gas:

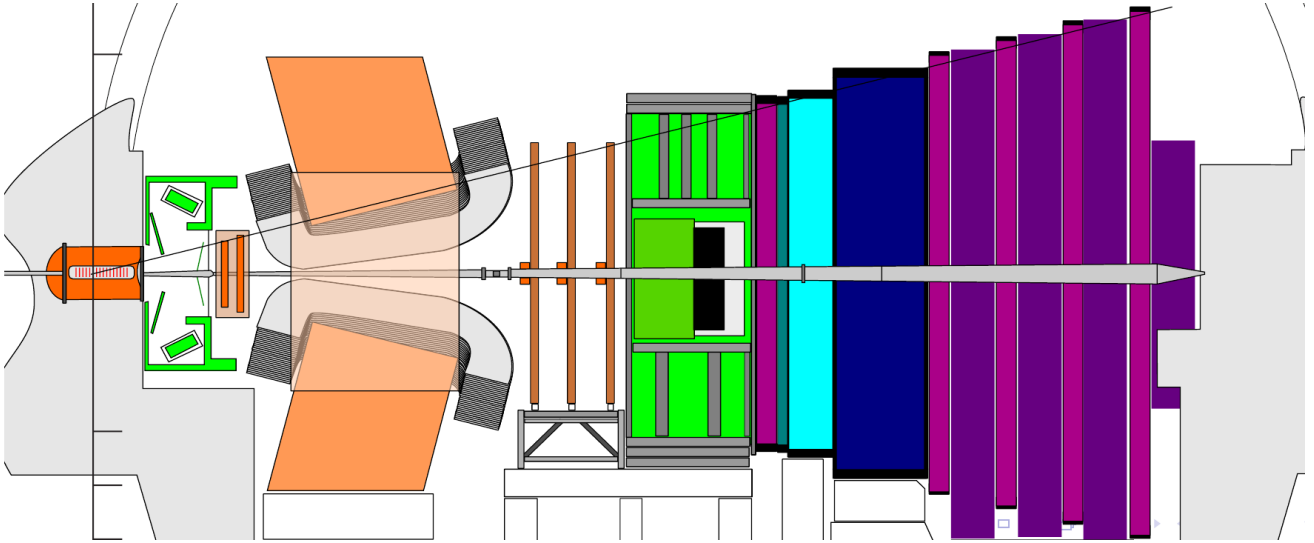
Inject small amounts of noble gas into the LHC vacuum
(increase pressure from 10^{-9} to 10^{-7} mbar)

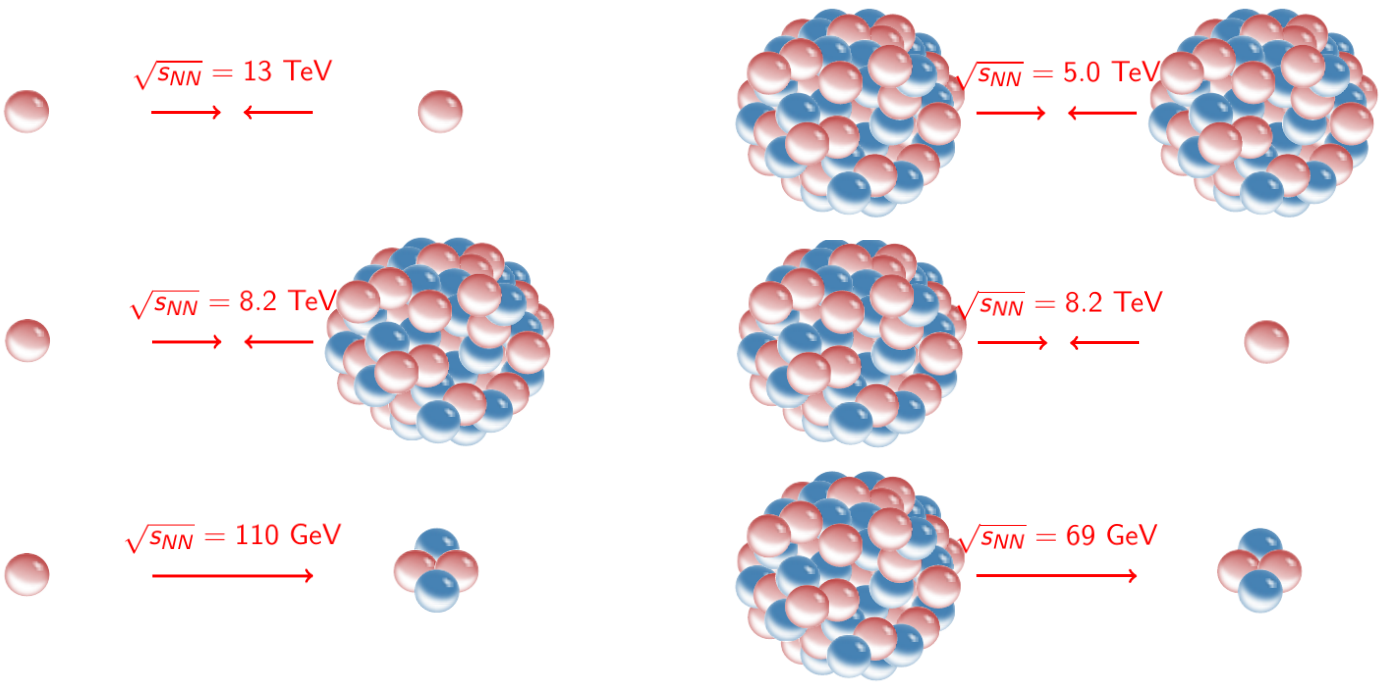
Main purpose: precise measurement of beam profiles for determination of instantaneous luminosity

Allows to study fixed-target collisions of proton or ion beam on gas atoms

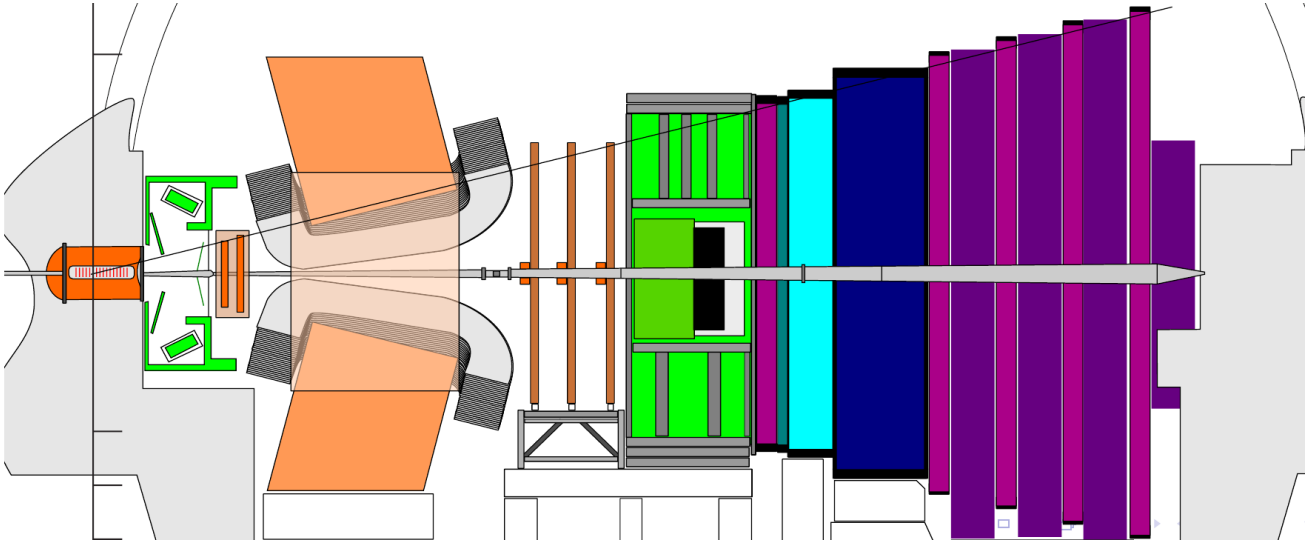


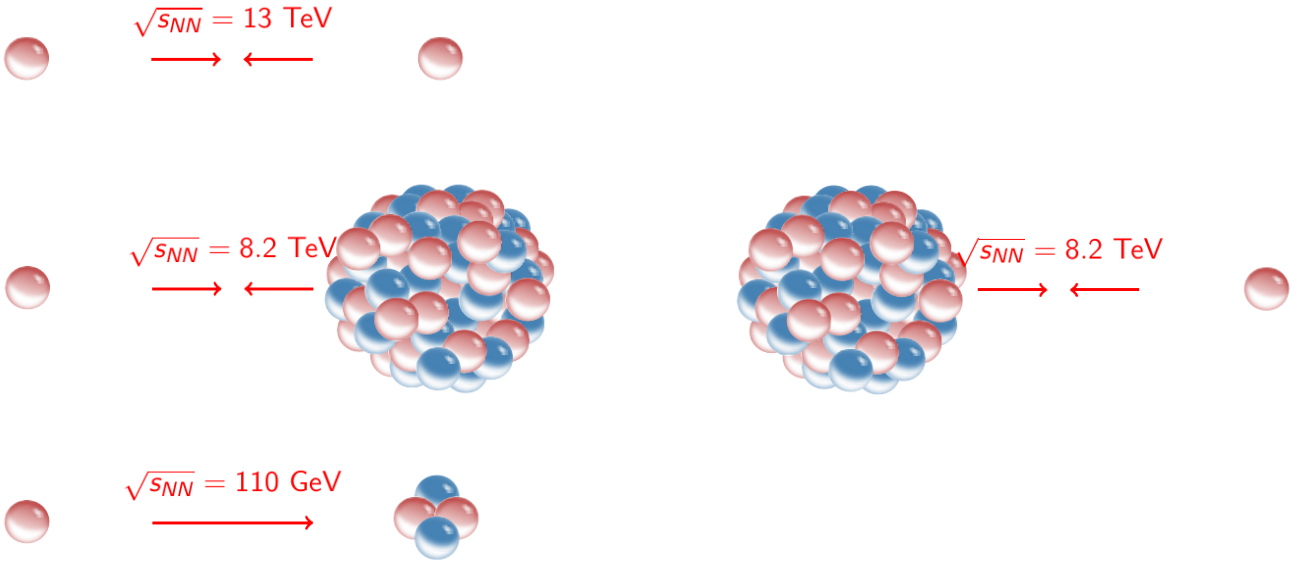
Data sets




$\sqrt{s_{NN}} = 13$ TeV
$\sqrt{s_{NN}} = 5.0$ TeV
$\sqrt{s_{NN}} = 8.2$ TeV
$\sqrt{s_{NN}} = 8.2$ TeV
$\sqrt{s_{NN}} = 110$ GeV
$\sqrt{s_{NN}} = 69$ GeV

Data sets





Outline

pp collisions @ 13 TeV

→ Inelastic cross section

→ Top-pair production

→ $B^{\pm}$ production cross section and asymmetries

→ Charmonium in CEP

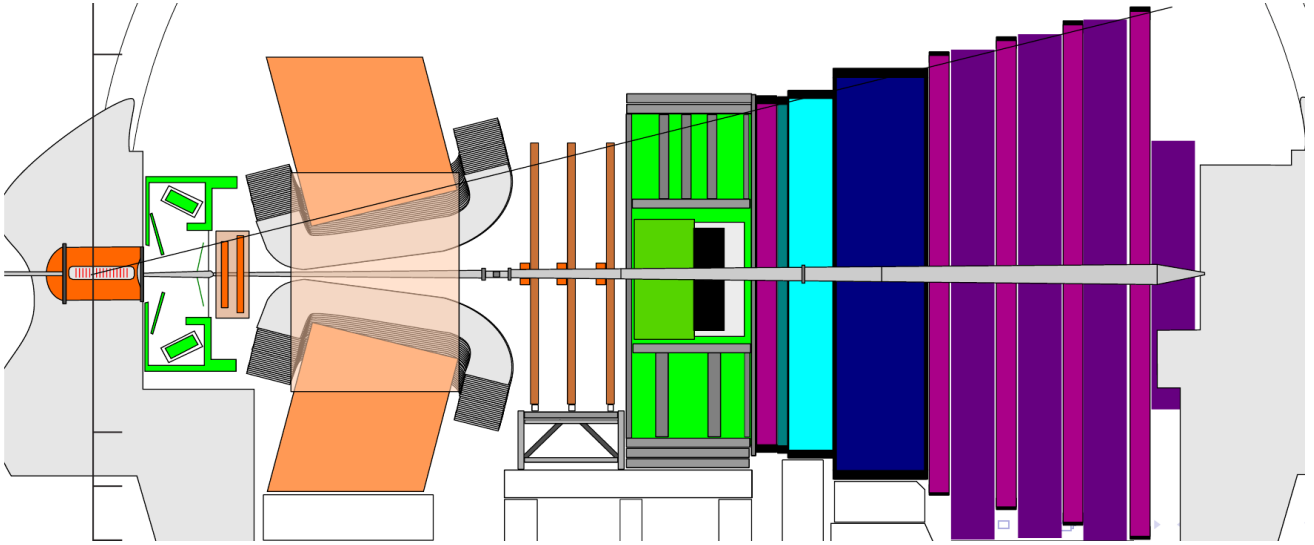
pPb and Pbp collisions

→ Open charm and charmonium production

p fixed target

→ Open charm and charmonium production

→ Anti-proton production



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

Inelastic *pp* cross section

[arXiv:1803.10974]

691 million events from 10.7 nb^{-1} collected in Summer 2015

Require at least one prompt long-lived charged particle
$p > 2$ GeV/c | $2 < \eta < 5$ | $\Delta t > 30$ ps

→ Measure fraction p_0 of empty events

(correcting for detector inefficiency and wrongly reconstructed tracks)

→ Determine average number μ of interactions per event assuming Poisson statistics

→ Determine fiducial cross section as

$$\sigma_{\text{acc}} \equiv \frac{(\mu - \mu_{\text{bkg}}) \cdot N_{\text{evt}}}{\int L\,dt}$$

$$\sigma_{\text{acc}} = 62.2 \pm 0.2\,(\text{stat}) \pm 2.5\,(\text{syst})\ \text{mb}$$

Systematic uncertainty dominated by luminosity measurement

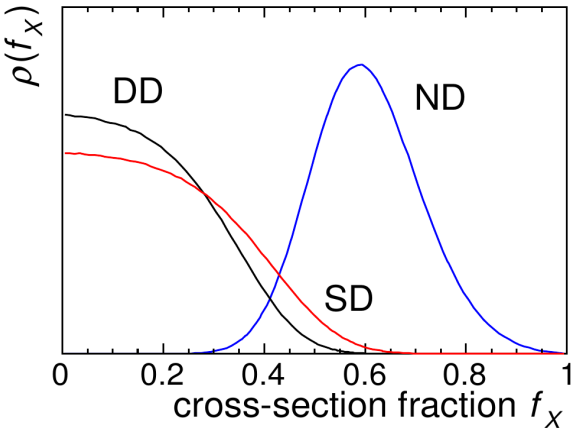
Inelastic *pp* cross section

[arXiv:1803.10974]

Extrapolate to full phase space using simulation

→ Assume incoherent sum of Non-Diffractive, Single-Diffractive and Double Diffractive scattering

→ Allow ND, SD, DD fractions to vary to estimate uncertainty on the extrapolation



$$\sigma_{\text{inel}}\left(\sqrt{s}=13\,\text{TeV}\right) = 75.4 \pm 3.0\,(\text{exp}) \pm 4.5\,(\text{extr})\ \text{mb}$$

Also: update of inelastic cross section at 7 TeV, using improved luminosity calibration:

$$\sigma_{\text{inel}}\left(\sqrt{s}=7\,\text{TeV}\right) = 68.7 \pm 2.1\,(\text{exp}) \pm 4.5\,(\text{extr})\ \text{mb}$$

Top-pair production

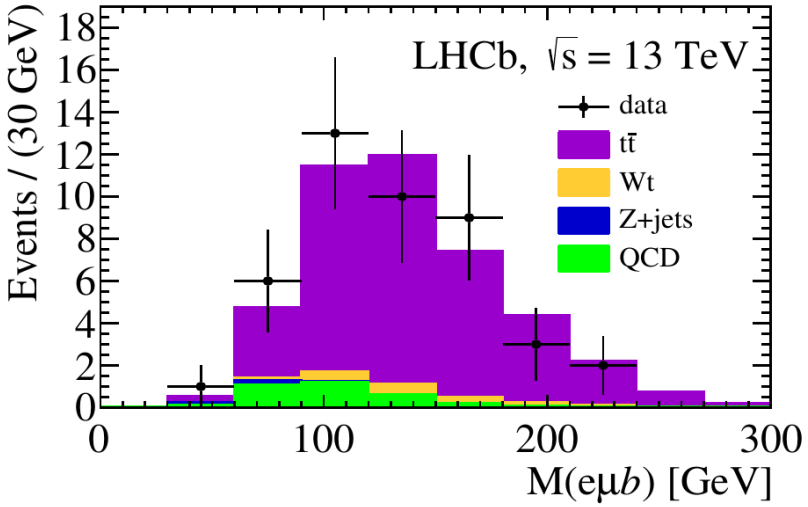
[arXiv:1803.05188]

electron + muon + *b*-jet with:

$p_T(\ell) > 20\,\text{GeV}/c$ $\quad p_T(\text{jet}) > 20\,\text{GeV}/c$

$2 < \eta(\ell) < 4.5$ $\quad 2.2 < \eta(\text{jet}) < 4.2$

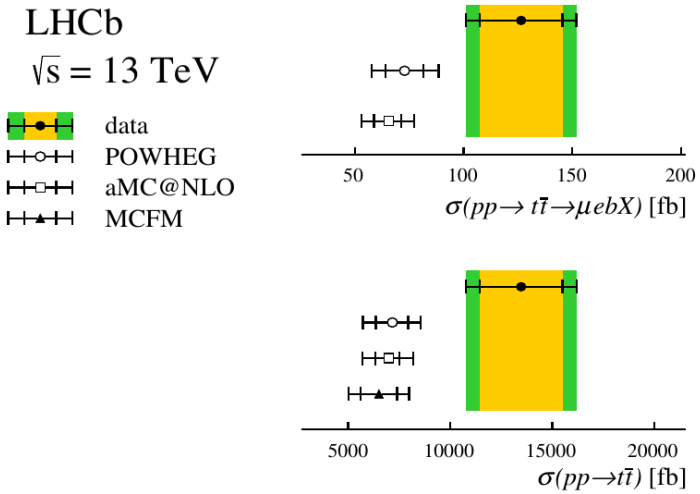
$\Delta R(\ell,\ell) > 0.1$ $\quad \Delta R(\ell,\text{jet}) > 0.5$



Find 44 candidates with signal purity of 87 %

Cross section inside fiducial volume:

$$\sigma_{t\bar{t}} = 126 \pm 19\,(\text{stat}) \pm 16\,(\text{syst}) \pm 5\,(\text{lumi})\ \text{fb}$$



→ **For details, see Patrick Robbe's talk from Tuesday morning, WG1**

$B^{\pm}$ production cross section

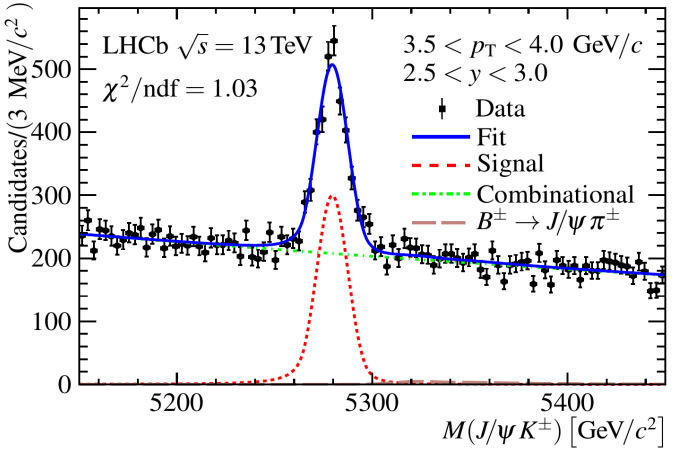
[JHEP 12(2017)026]

Reconstruct $B^{\pm} \to J/\psi K^{\pm}$ with $J/\psi \to \mu^+ \mu^-$

Measure double-differential cross sections

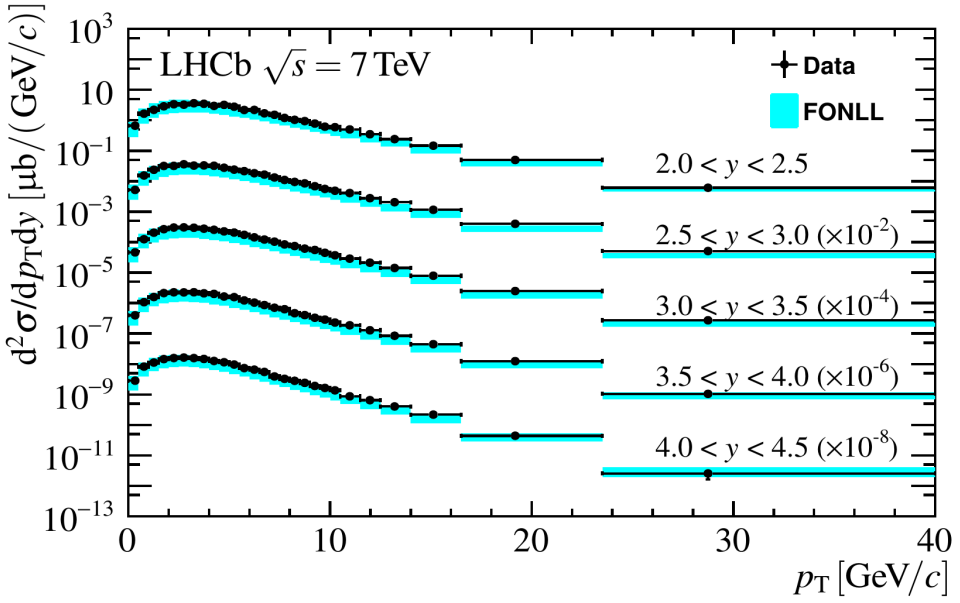
→ at 7 TeV (1.0 fb^{-1}) and 13 TeV (0.3 fb^{-1})

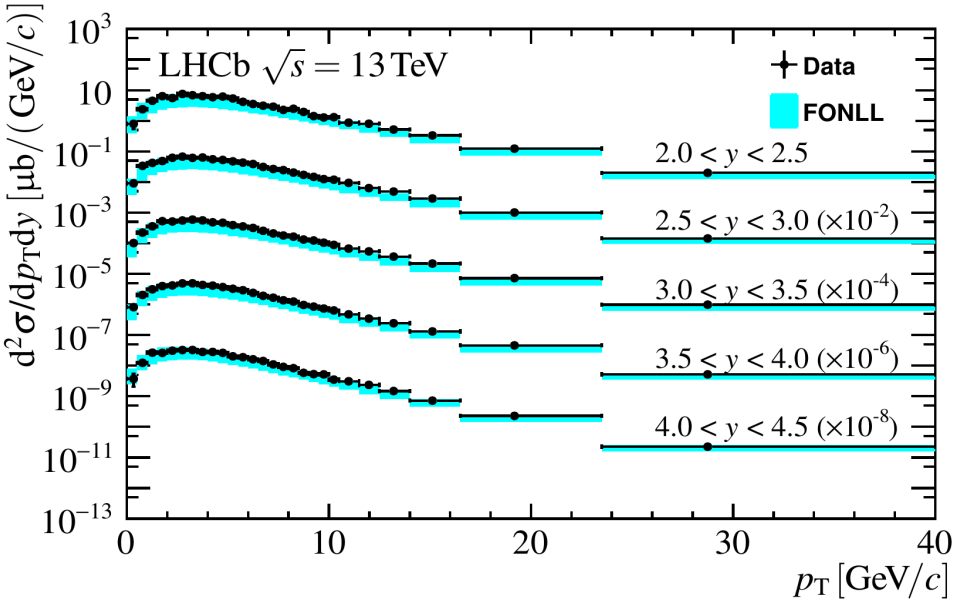
→ for p_T < 40 GeV/c and 2.5 < y < 4.0



Find good agreement with FONLL predictions

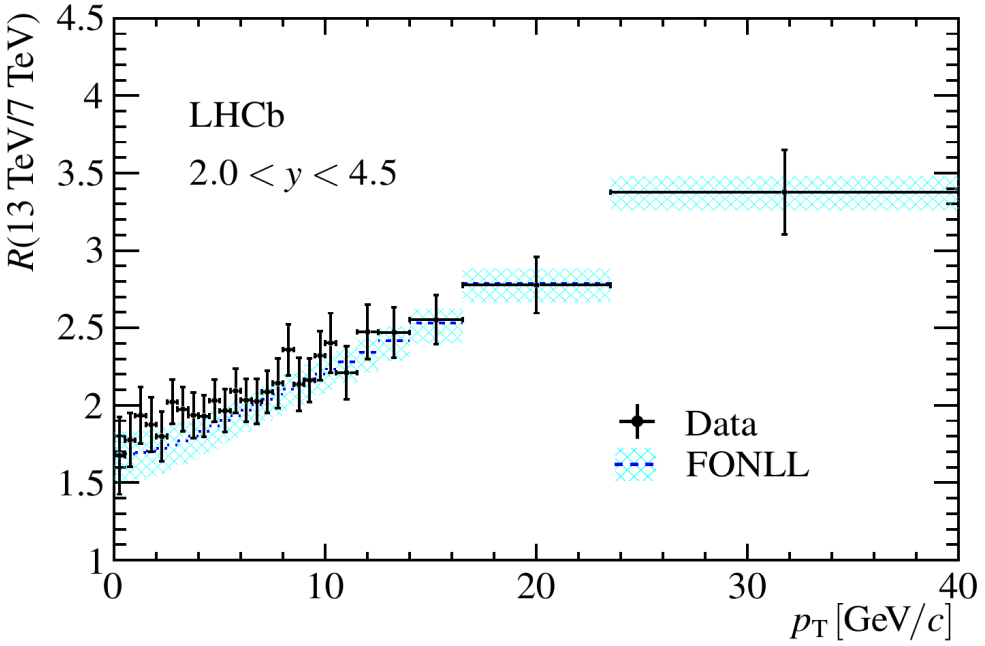
Cacciari et al. [EPJC 75(2015)610]

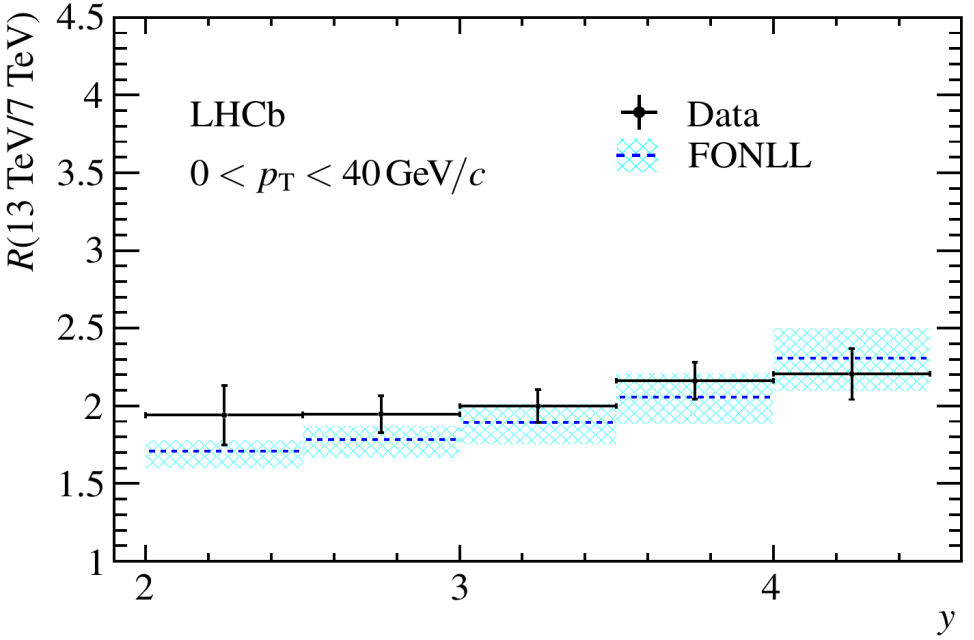




$B^{\pm}$ production cross section

[JHEP 12(2017)026]





$$\sigma_{7\,\text{TeV}}(pp \to B^{\pm} X) = 43.0 \pm 0.2\,(\text{stat}) \pm 2.5\,(\text{syst}) \pm 1.7\,(\text{ext})\ \mu\text{b}$$

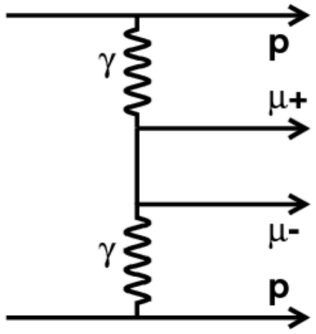
$$\sigma_{13\,\text{TeV}}(pp \to B^{\pm} X) = 86.6 \pm 0.5\,(\text{stat}) \pm 5.4\,(\text{syst}) \pm 3.4\,(\text{ext})\ \mu\text{b}$$

$$\sigma_{13\,\text{TeV}}/\sigma_{7\,\text{TeV}} = 2.02 \pm 0.02\,(\text{stat}) \pm 0.12\,(\text{syst})$$

Central Exclusive Production

[LHCb-CONF-2016-007]

Goal: study hadronic interactions with no net colour exchange



photon fusion:
e.g. non-resonant $\mu^+\mu^-$

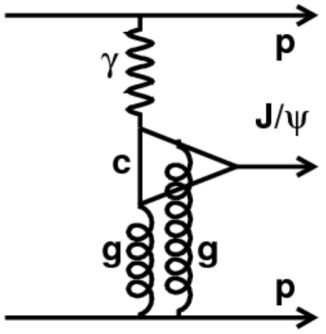
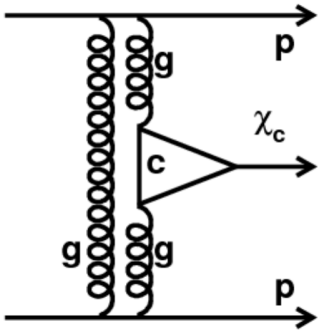


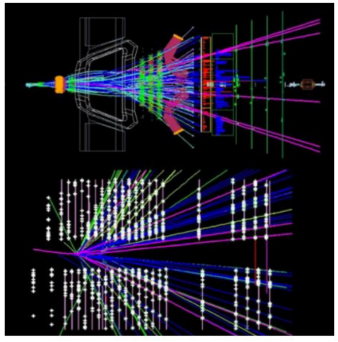
photo-production:
e.g. *J*/ψ

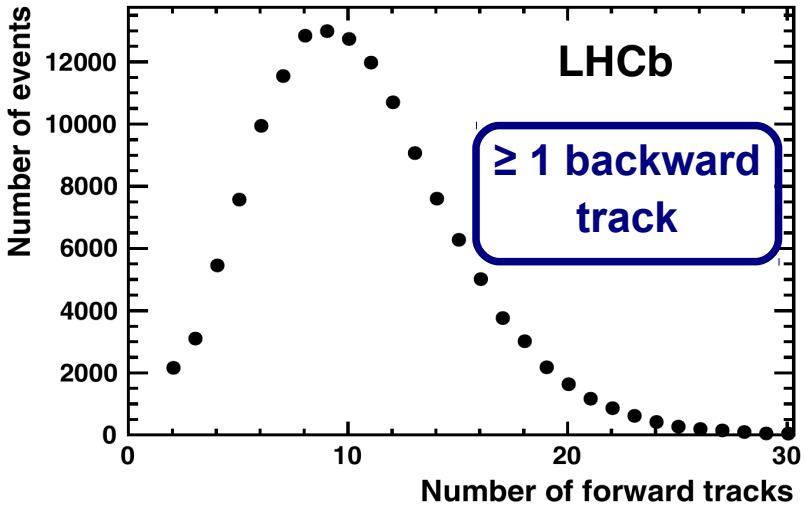


double Pomeron exchange:
e.g. χ_c ($\rightarrow$ *J*/ψ γ)

Selection of candidates :

→ No tracks in backward hemisphere

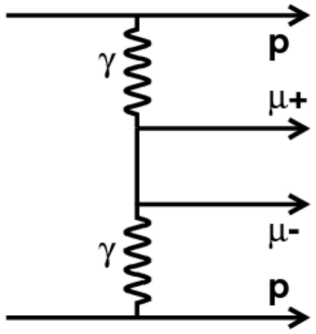




[JPG40 (2013) 045001]

Central Exclusive Production

Goal: study hadronic interactions with no net colour exchange



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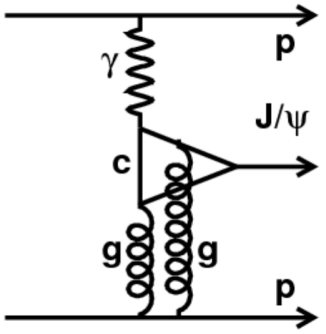
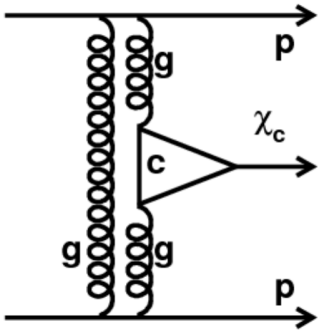


photo-production:
e.g. *J*/ψ



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e.g. χ_c ($\rightarrow$ *J*/ψ γ)

Selection of candidates :

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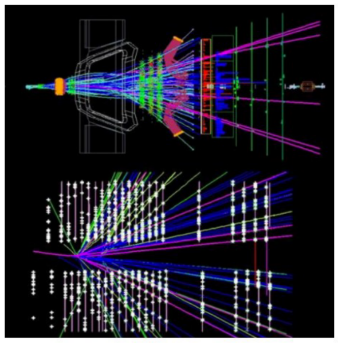
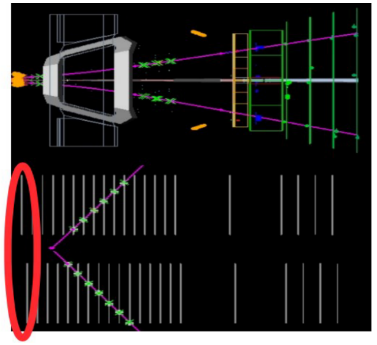
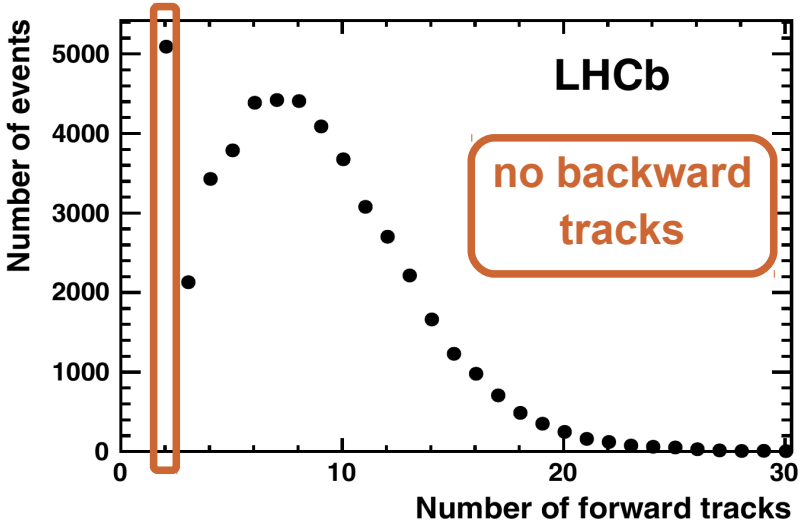


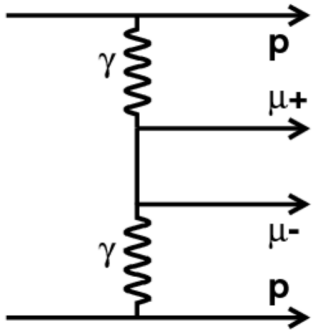




[JPG40 (2013) 045001]

Central Exclusive Production

Goal: study hadronic interactions with no net colour exchange



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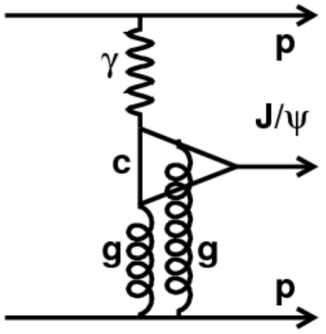

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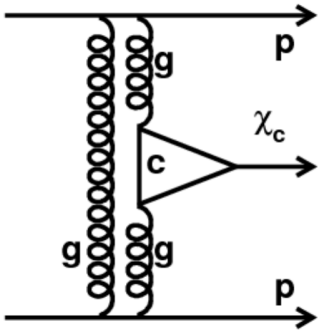
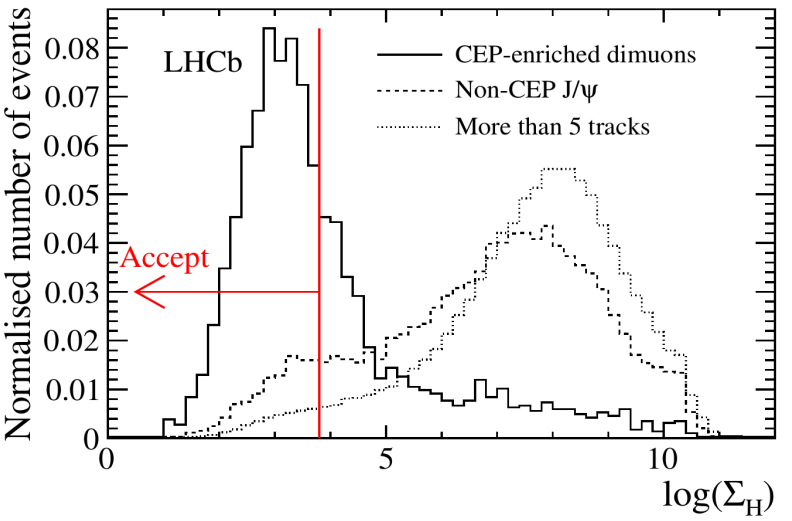


double Pomeron exchange:
e.g. χ_c ($\rightarrow$ *J*/ψ γ)

Selection of candidates :

→ **No tracks in backward hemisphere**

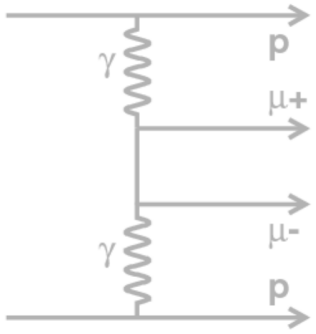
→ **Low activity in HeRSCheL counters**



[LHCb-CONF-2016-007]

Central Exclusive Production

Goal: study hadronic interactions with no net colour exchange



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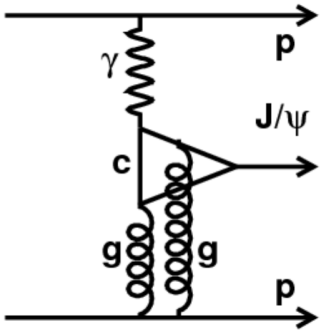

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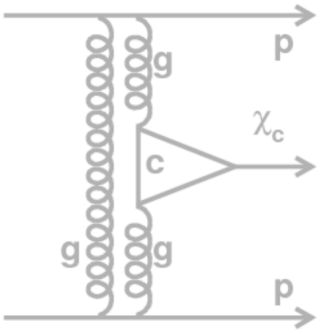


double Pomeron exchange:
e.g. χ_c ($\rightarrow$ *J*/ψ γ)

Proportional to square of the gluon PDF

Related to photo-production cross section

$$\sigma_{pp\to p\psi p} = \underbrace{r(W_+)}_{\text{gap survival probability}} \underbrace{k_+ \frac{dn}{dk_+}}_{\text{photon energy spectrum}} \underbrace{\sigma_{\gamma p\to\psi p}(W_+)}_{\text{cross section}} + \underbrace{r(W_-)k_- \frac{dn}{dk_-}\sigma_{\gamma p\to\psi p}(W_-)}_{\text{same, with the roles of the two protons swapped}}$$

Charmonium in CEP

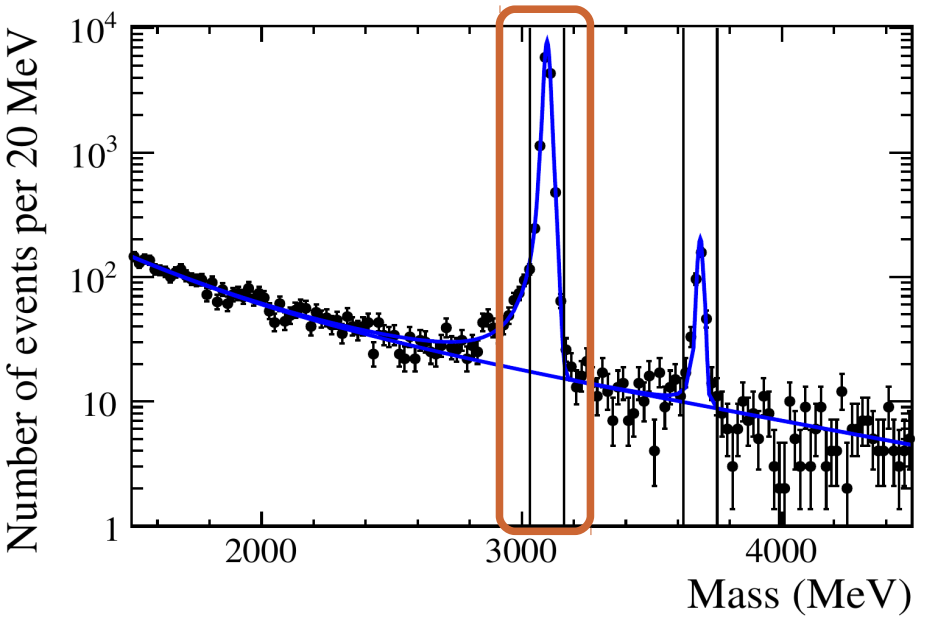
[LHCb-CONF-2016-007]

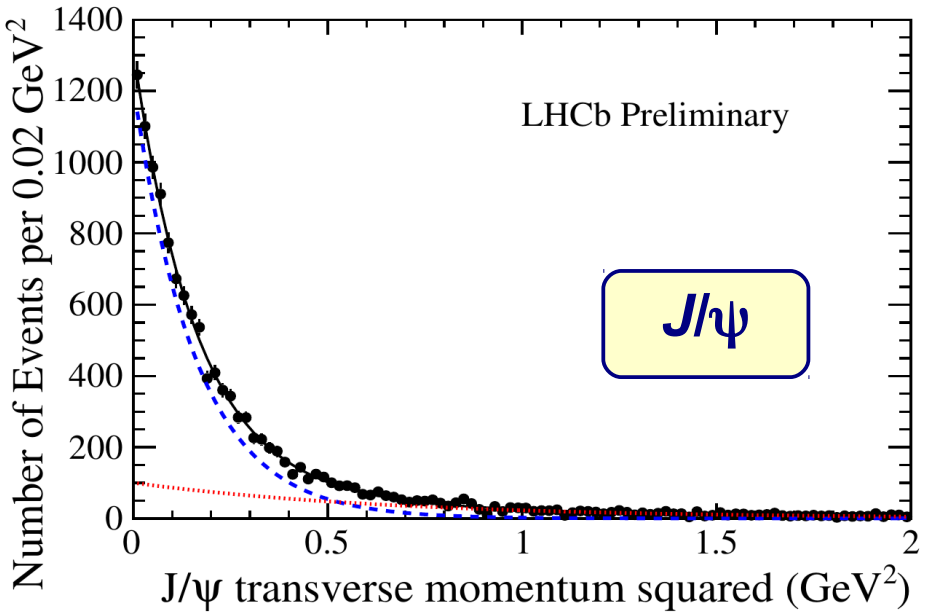
Study 0.2 fb^{-1} collected at low pile-up

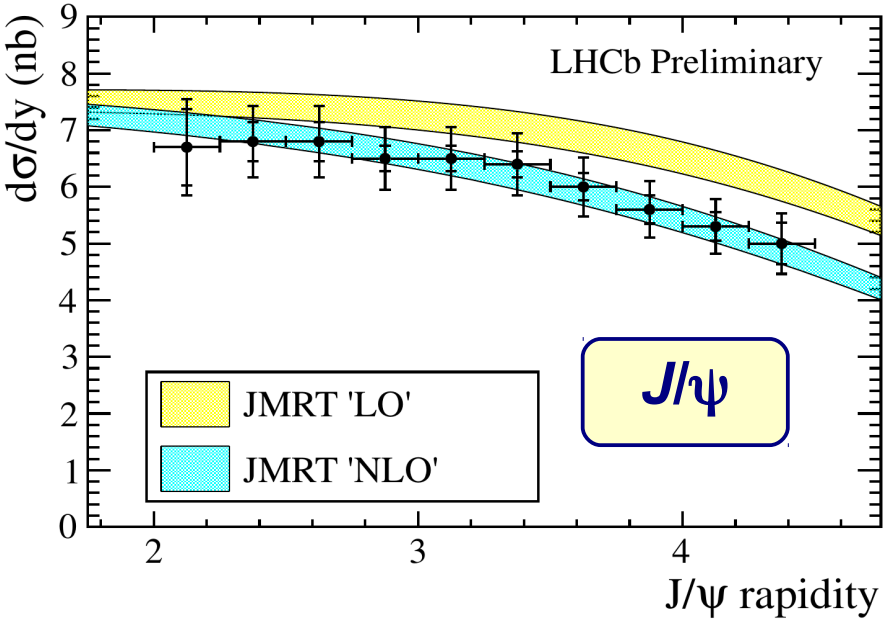
Measure J/ψ production as a function of p_T and y

Find good agreement with NLO prediction by

Jones et al. [JHEP 11(2013)085]





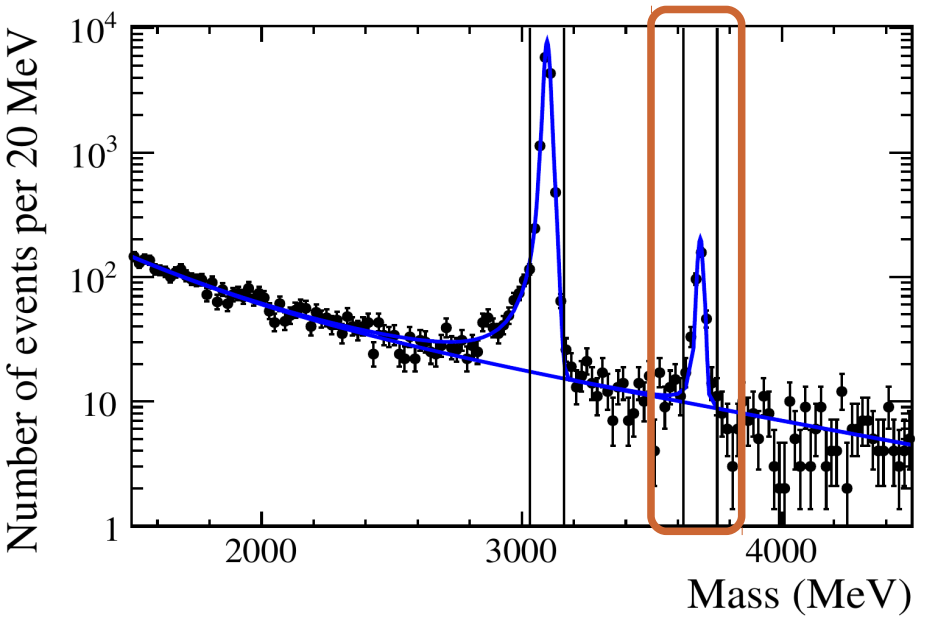


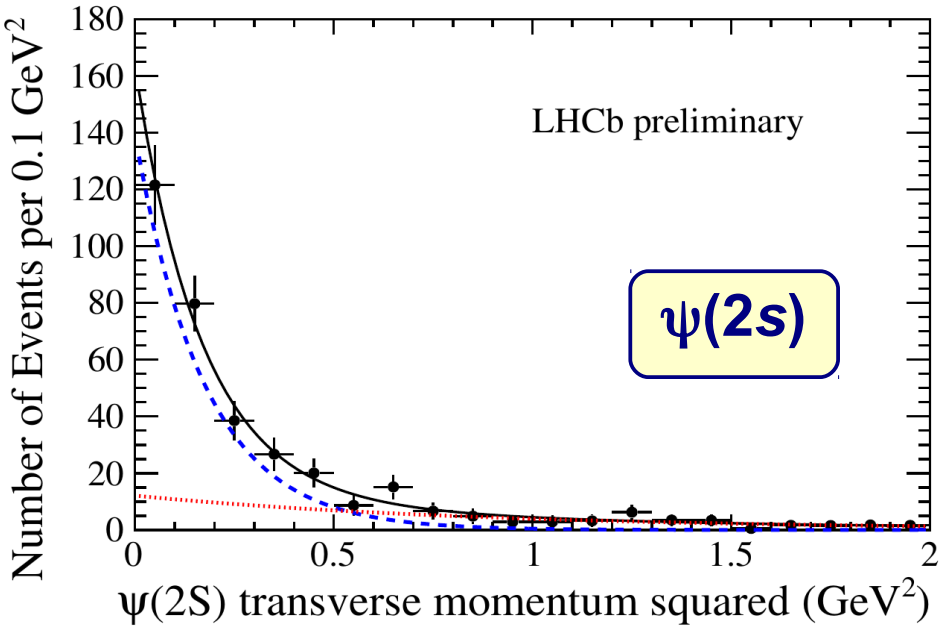
Charmonium in CEP

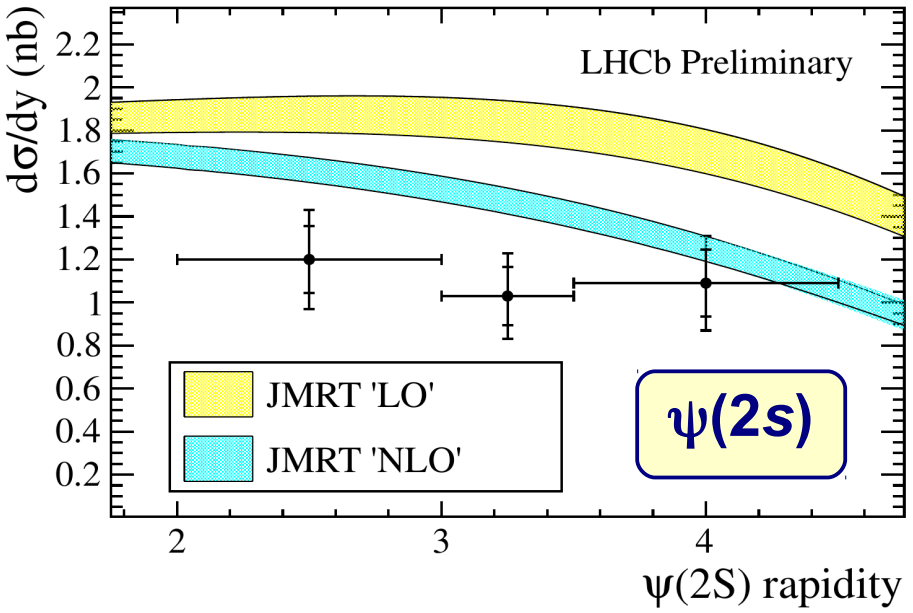
[LHCb-CONF-2016-007]

Same for ψ(2s)

Reasonable agreement with NLO prediction







Charmonium in CEP

[LHCb-CONF-2016-007]

Photo-production cross section

$$\sigma_{pp\to p\psi p} = r(W_+)k_+\frac{dn}{dk_+}\sigma_{\gamma p\to\psi p}(W_+) + r(W_-)k_-\frac{dn}{dk_-}\sigma_{\gamma p\to\psi p}(W_-)$$

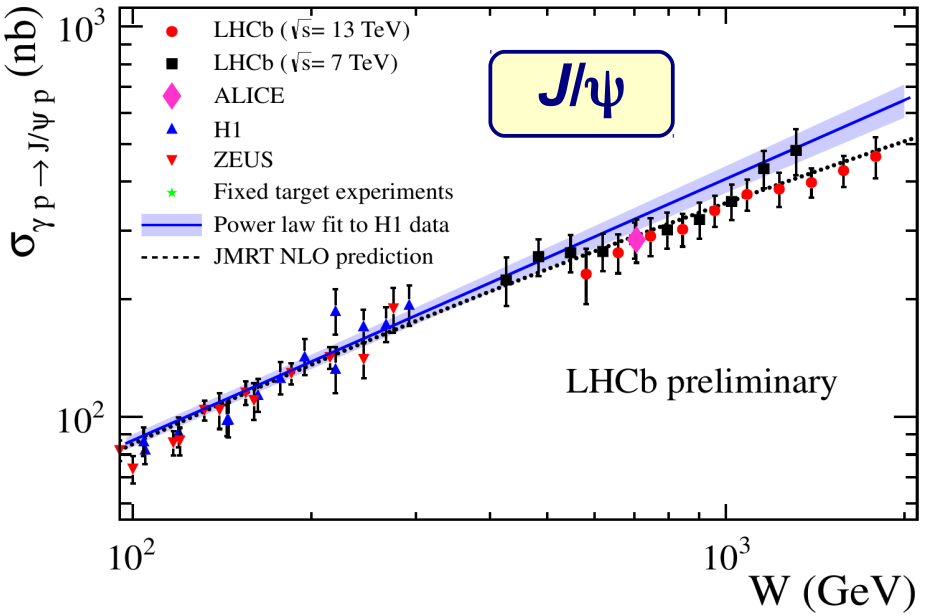
→ **Gap-survival probabilities from updates of**

[JHEP 11(2013)085] [JPG 41(2014)055009]

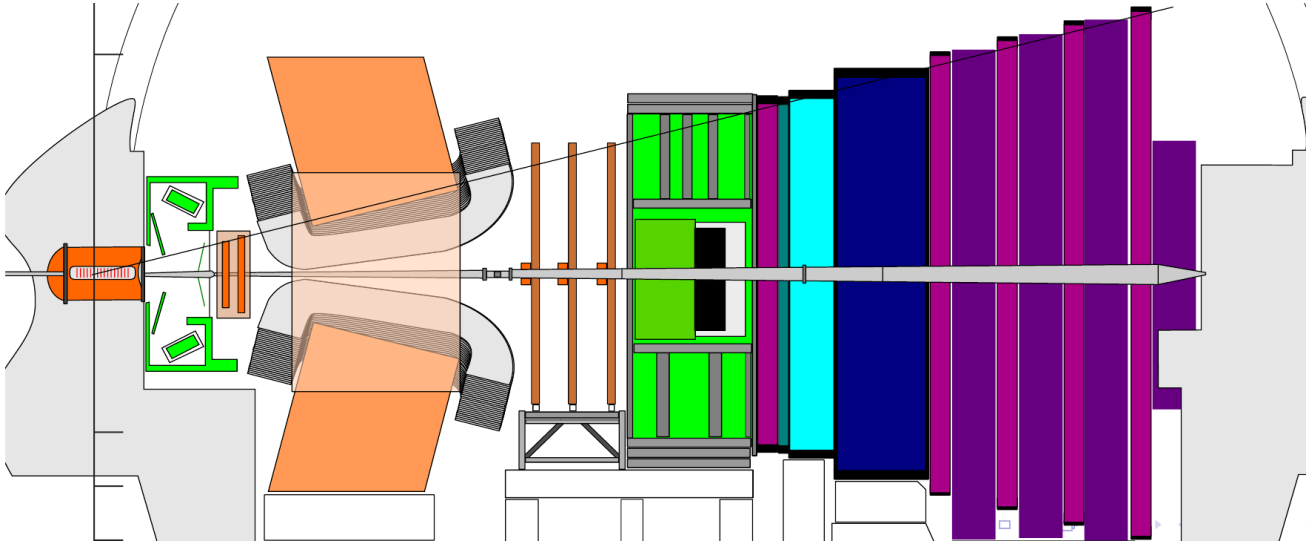
→ **Photon fluxes from**

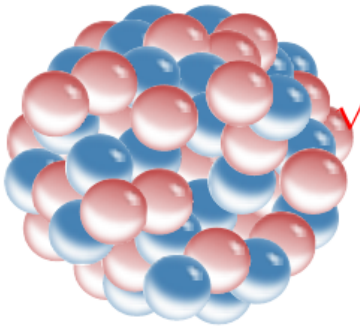
Kepka, [PhD thesis,Orsay,2009]

→ **Fix $\sigma(W_-)$ to HERA measurements and extract $\sigma(W_+)$**



→ **Find deviation from simple power law, in agreement with NLO prediction**





$\sqrt{s_{NN}} = 8.2$ TeV

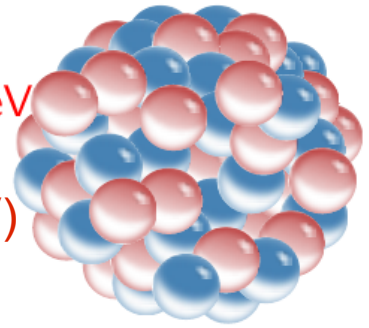
$\longrightarrow \quad \longleftarrow$

$(\sqrt{s}_{NN} = 5\,\text{TeV})$

$\sqrt{s_{NN}} = 8.2$ TeV

$\longrightarrow \quad \longleftarrow$

$(\sqrt{s}_{NN} = 5\,\text{TeV})$



“backward”

“forward”

Open charm production

Open charm production in *AA* collisions provides sensitive probe for properties of Quark Gluon Plasma

→ Charm produced in the early stage of the collisions

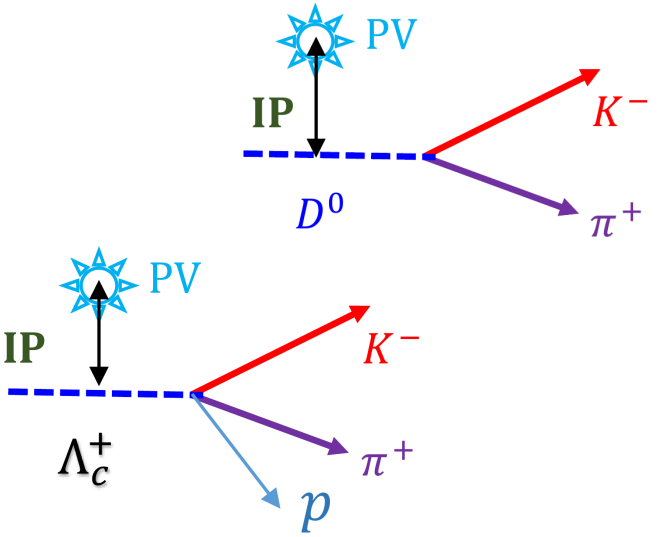
→ Significant D^0 suppression observed in central PbPb collisions

Open charm production in *pA* collisions provide baseline measurements to disentangle cold nuclear matter effects from effects of hot and dense medium

LHCb well suited for such measurements:

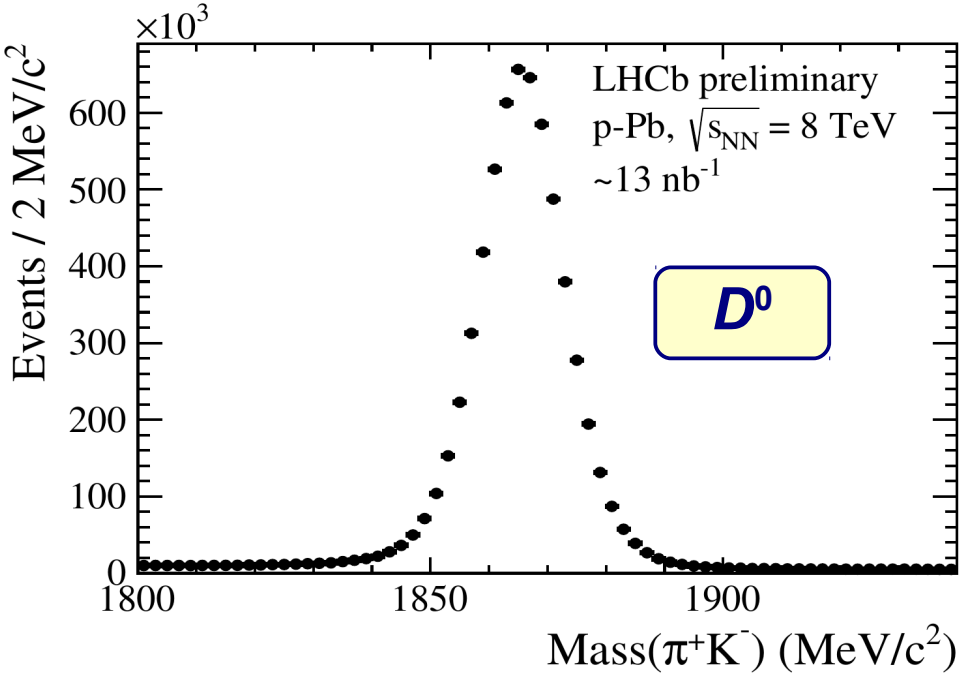
→ Measurement down to p_T close to 0

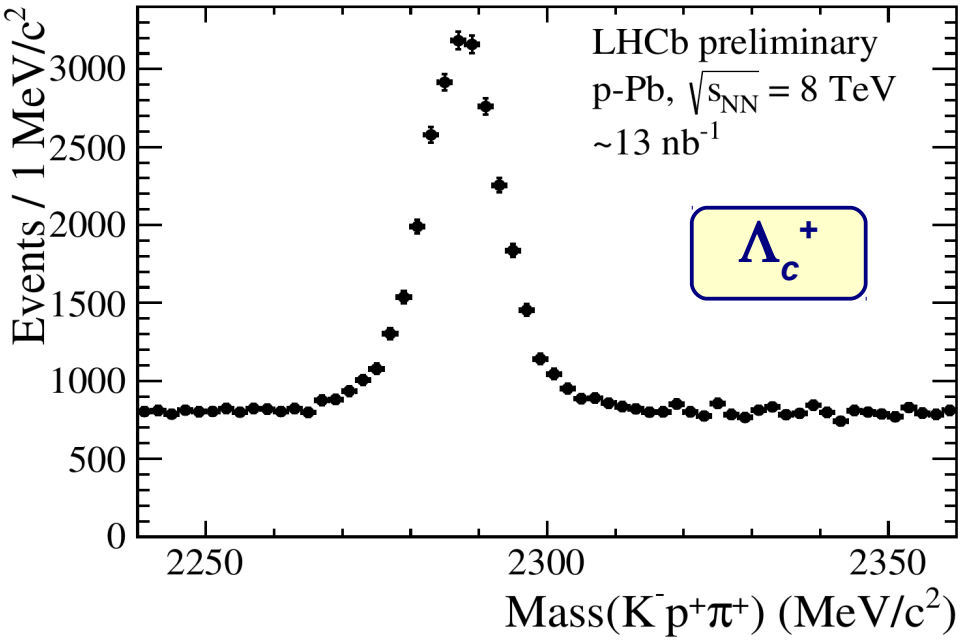
→ Separation of prompt charm from $b \to c X$



D^0 and Λ_c^+ at $\sqrt{s_{NN}} = 8.16$ TeV

Analysis of data taken in 2016 at $\sqrt{s_{NN}} = 8.16$ TeV still underway …





[https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2016]

D^0 production at $\sqrt{s_{NN}} = 5$ TeV

[JHEP 10(2017)90]

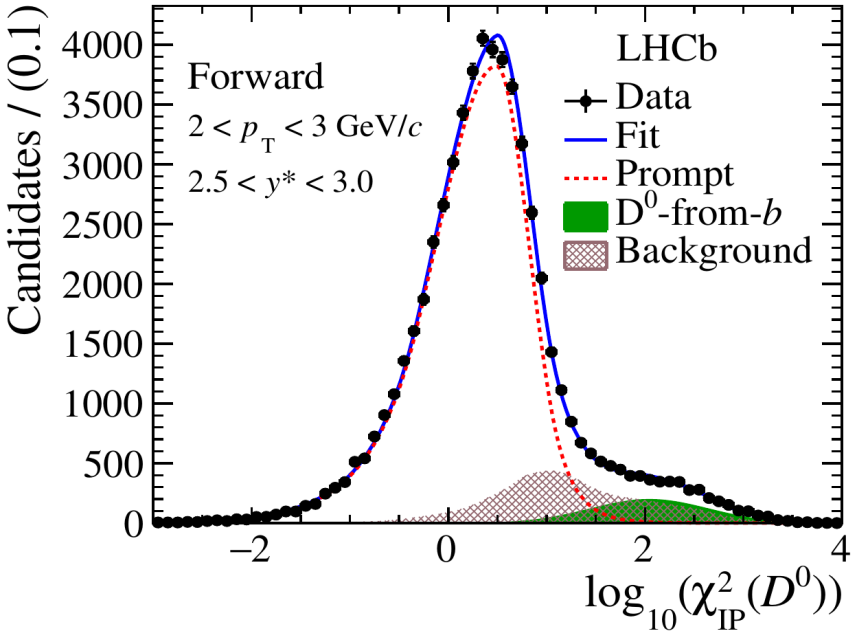
Reconstruct $D^0 \to K^-\pi^+$

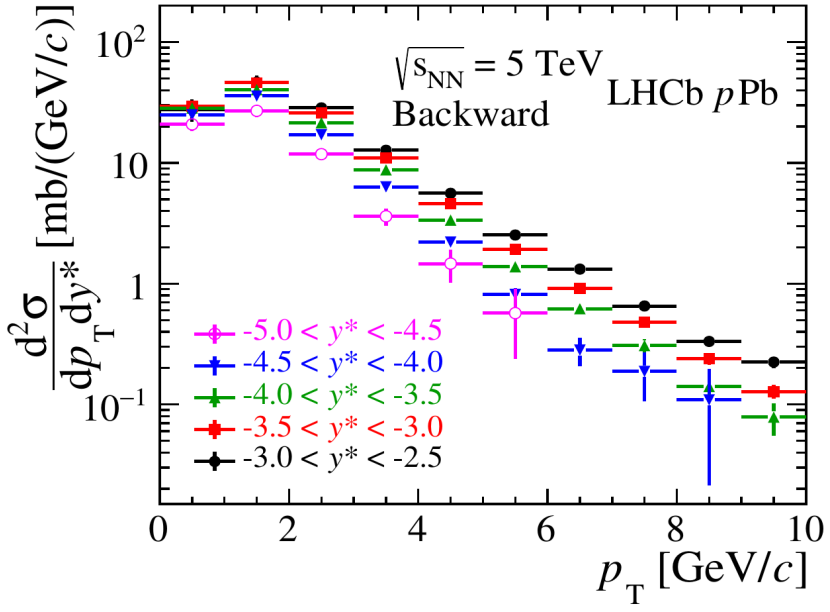
Separate prompt D^0 from $b \to D^0 X$ using impact parameter significance

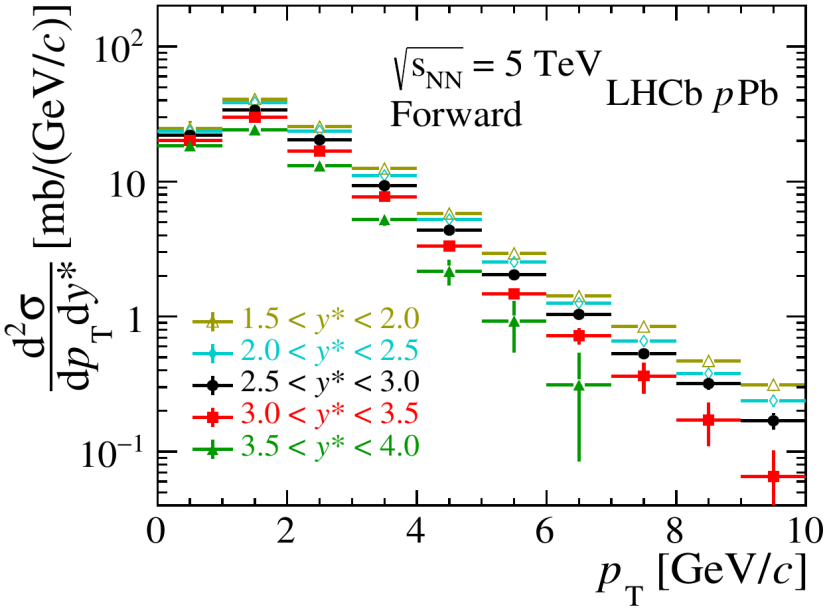
Measure double-differential prompt cross section for $p_T < 10$ GeV/c and

-5.0 < y* < -2.5 ("backward")

1.5 < y^* < 4.0 ("forward")





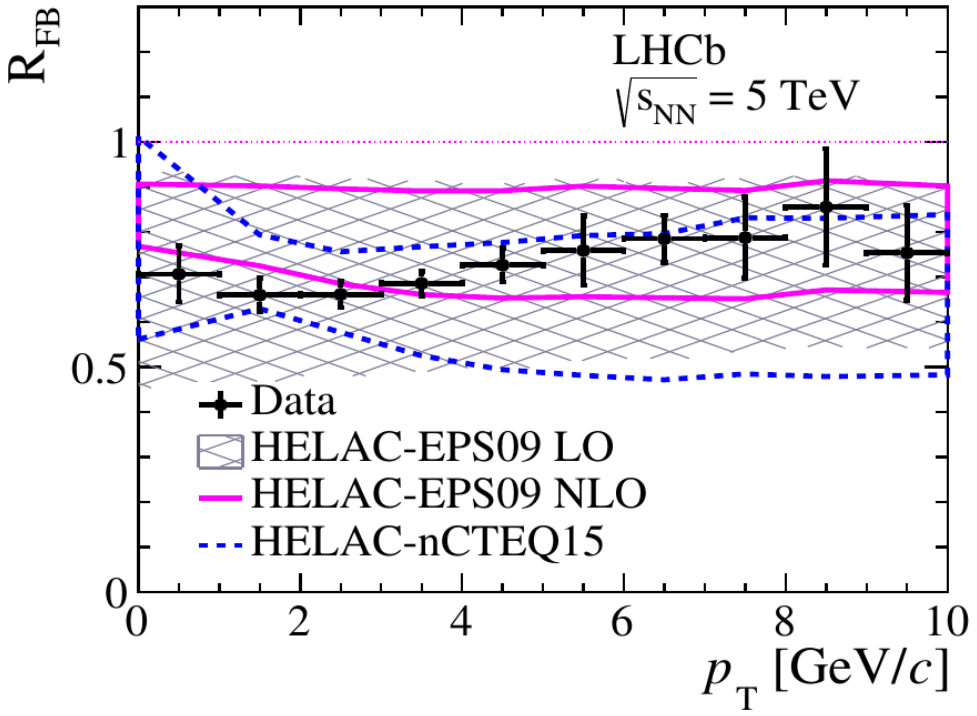


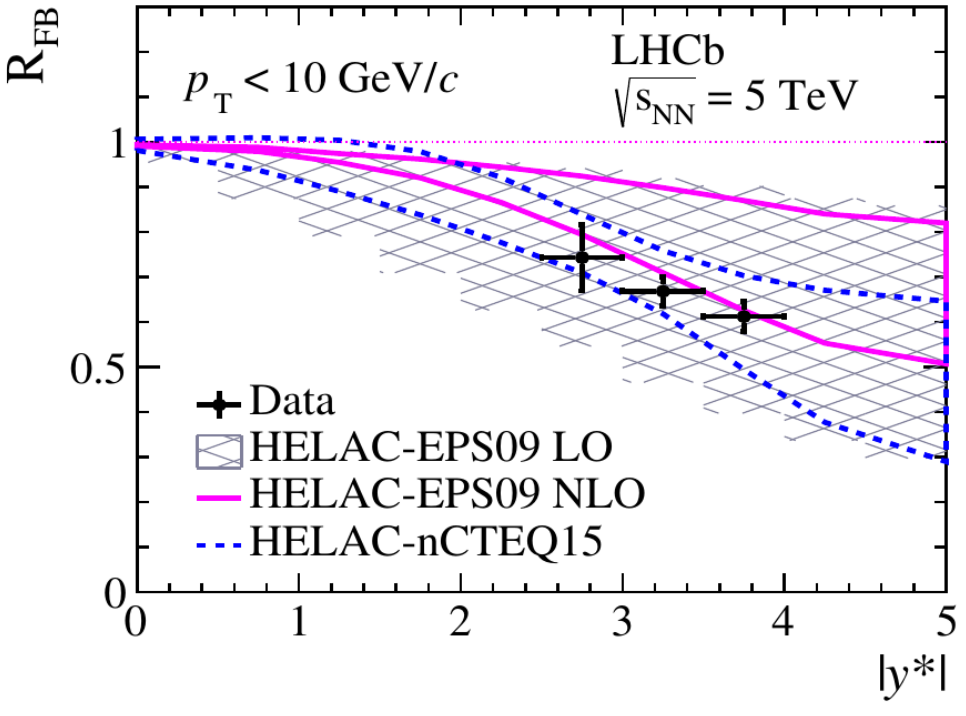
D^0 production at $\sqrt{s_{NN}} = 5$ TeV

[JHEP 10(2017)90]

Calculate forward/backward production asymmetries in overlap region $2.5 < |y^*| < 4.0$

→ Find good agreement with predictions





HELAC: Shao [Comp Phys Comm 198(2016)238]

EPS09: Eskola et al. [JHEP 04(2009)065]

nCTEQ15: Kovarik et al. [PRD 93(2016)085037]

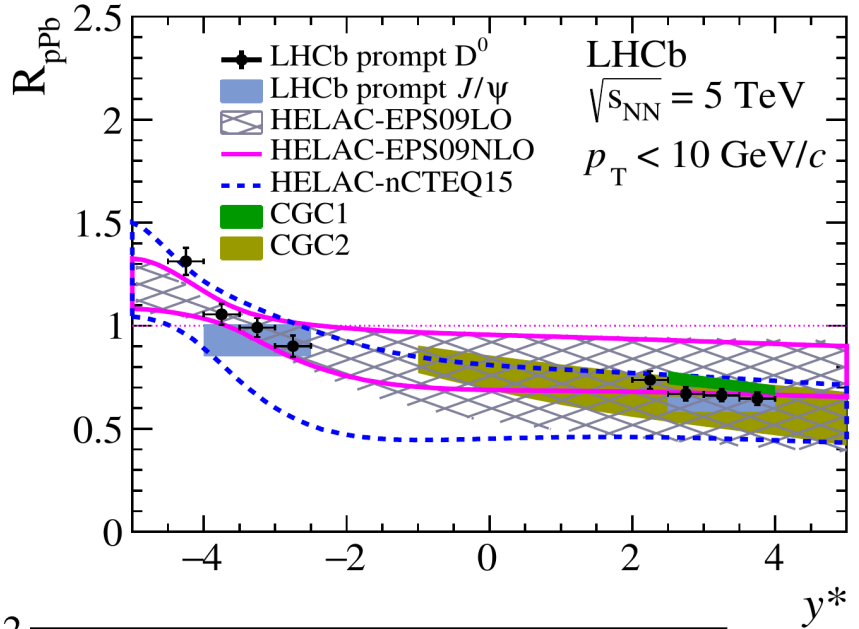
D^0 production at $\sqrt{s_{NN}} = 5$ TeV

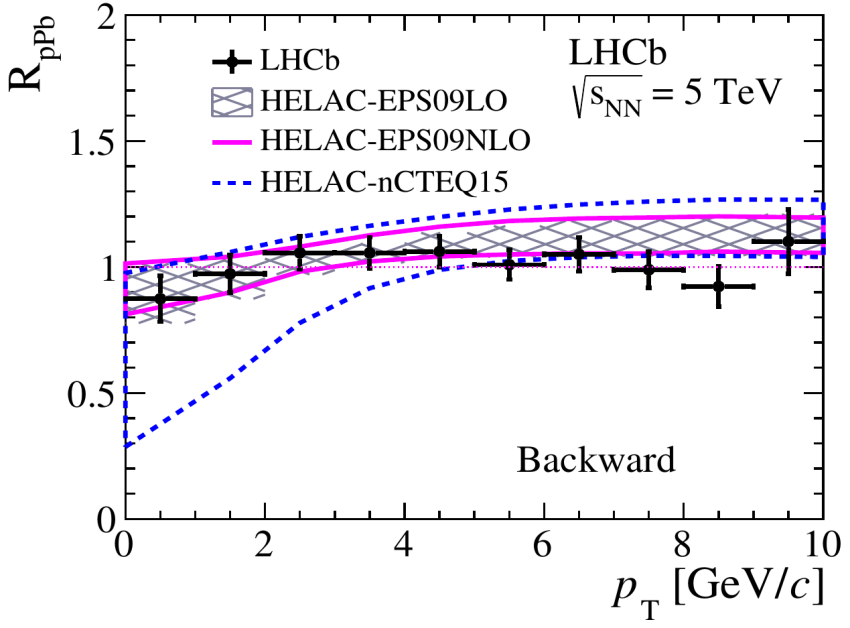
[JHEP 10(2017)90]

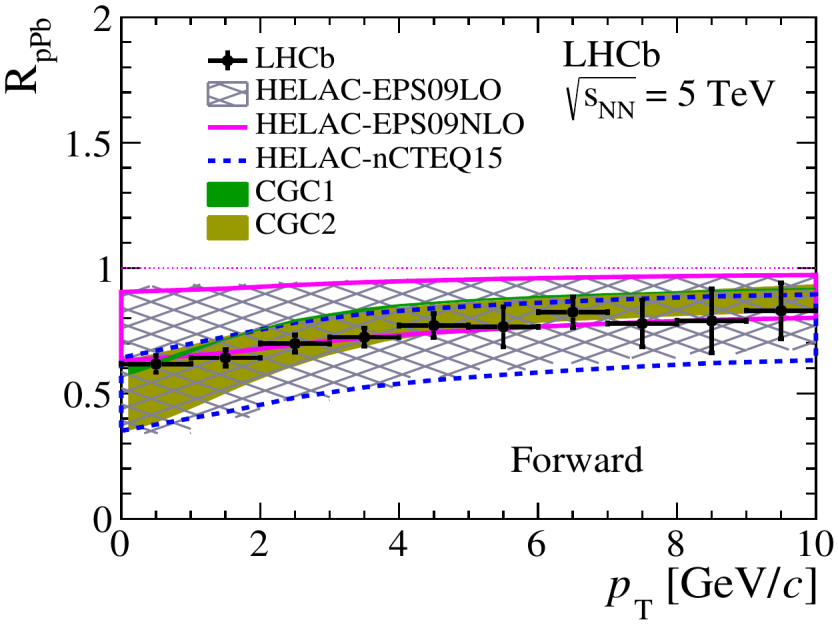
Determine nuclear modification factor

→ **Compare to LHCb measurement of D^0 production in *pp* collisions**

→ **As expected, nuclear suppression seen in "forward" collisions**







CGC1: Ducloué et al. [PRD 91(2015)114005] CGC2: Fujii et al. [arXiv:1706.06728]

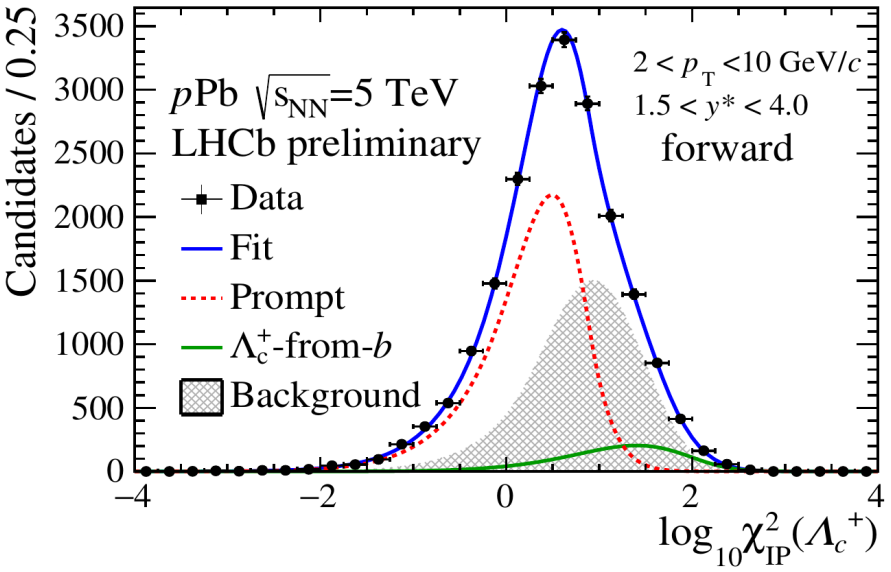
Λ_c^+ production at $\sqrt{s_{NN}} = 5$ TeV

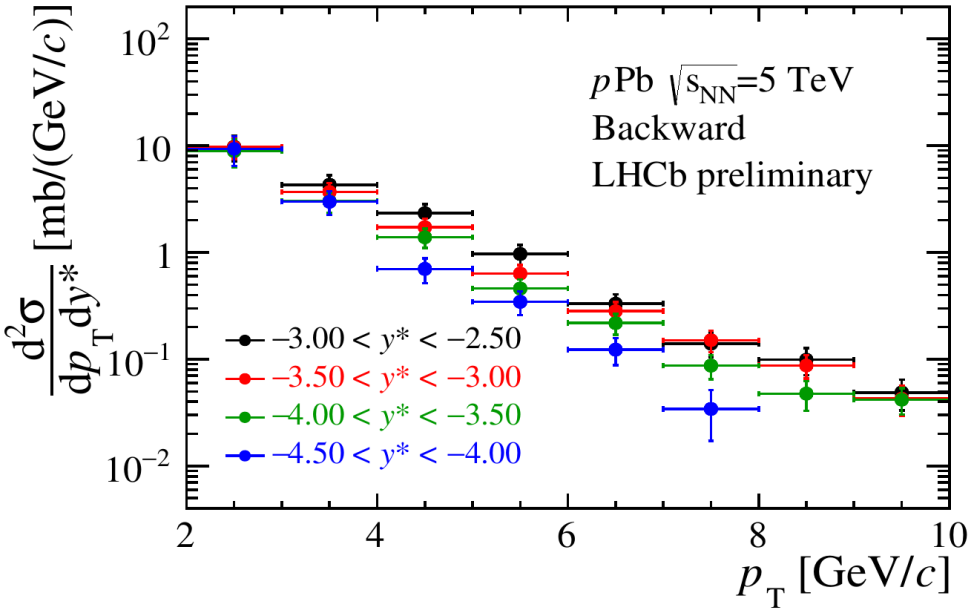
[LHCb-CONF-2017-005]

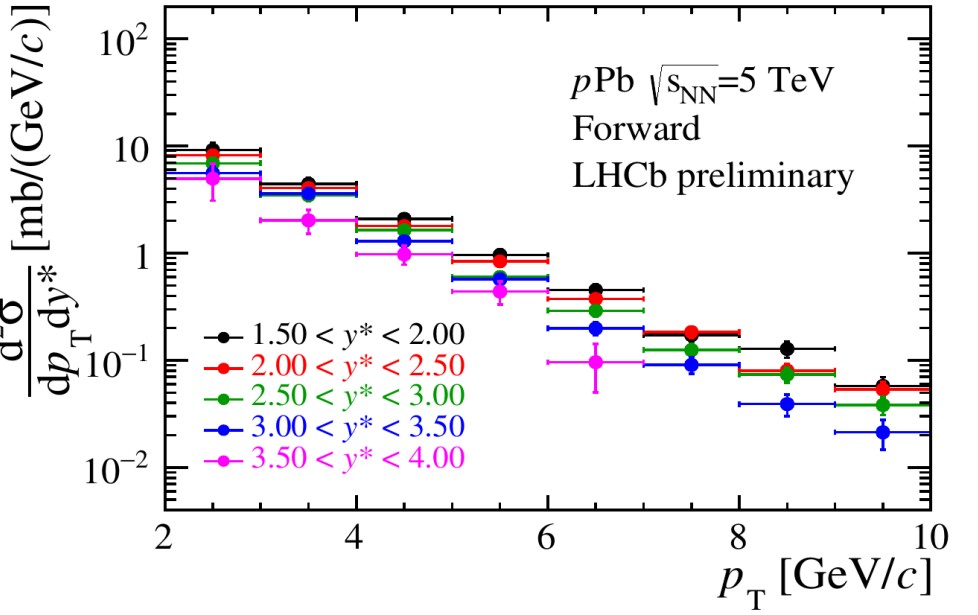
Similar for $\Lambda_c^+ \to p K^- \pi^+$:

Separate prompt Λ_c^+ from $b \to \Lambda_c^+ X$ using impact parameter significance

Measure prompt double-differential cross section



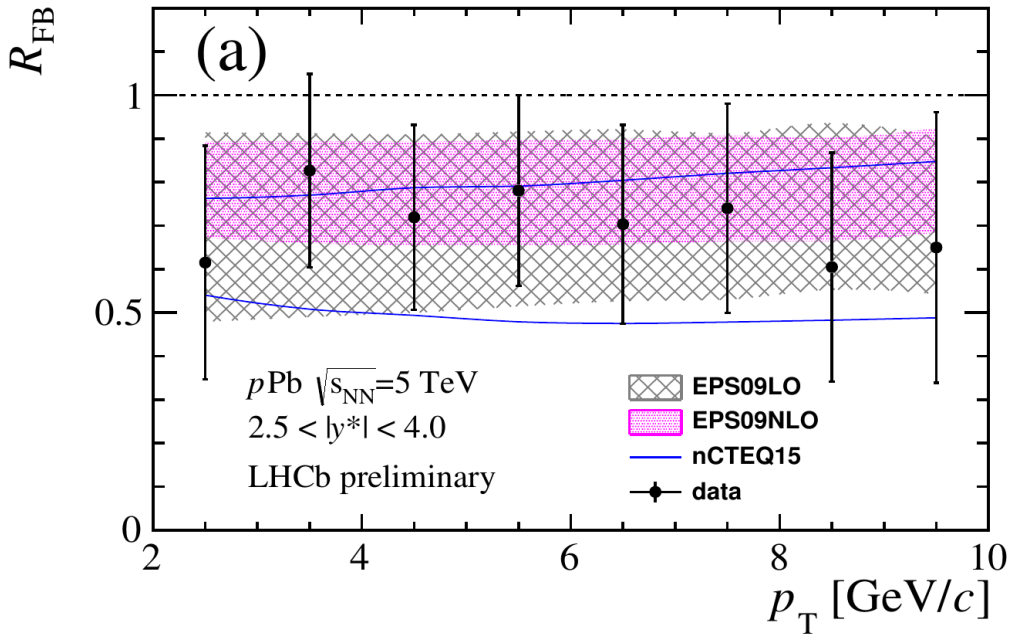


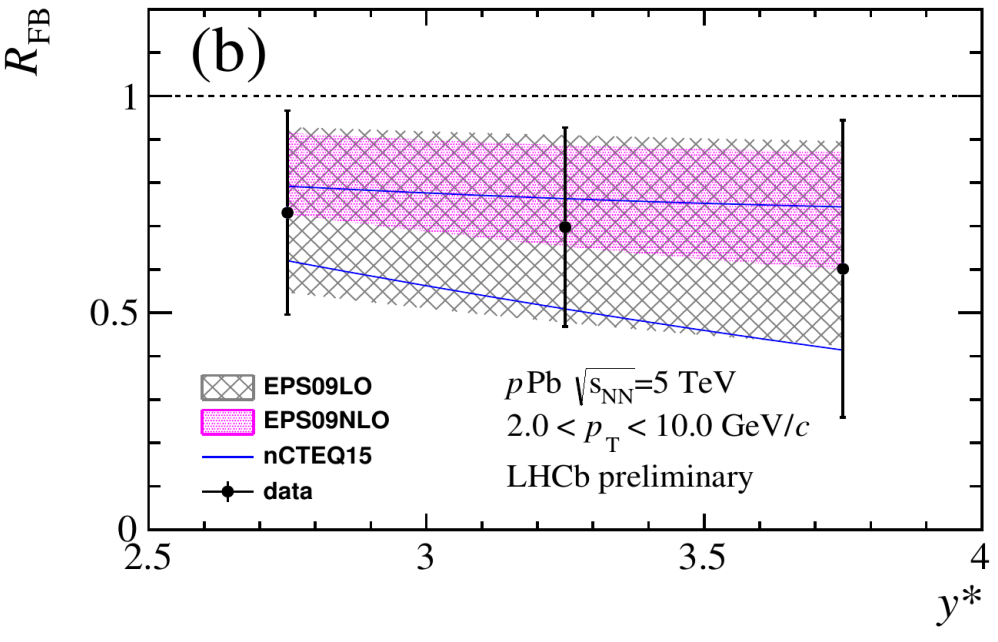


Λ_c^+ production at $\sqrt{s_{NN}} = 5$ TeV

[LHCb-CONF-2017-005]

Forward/backward production asymmetries



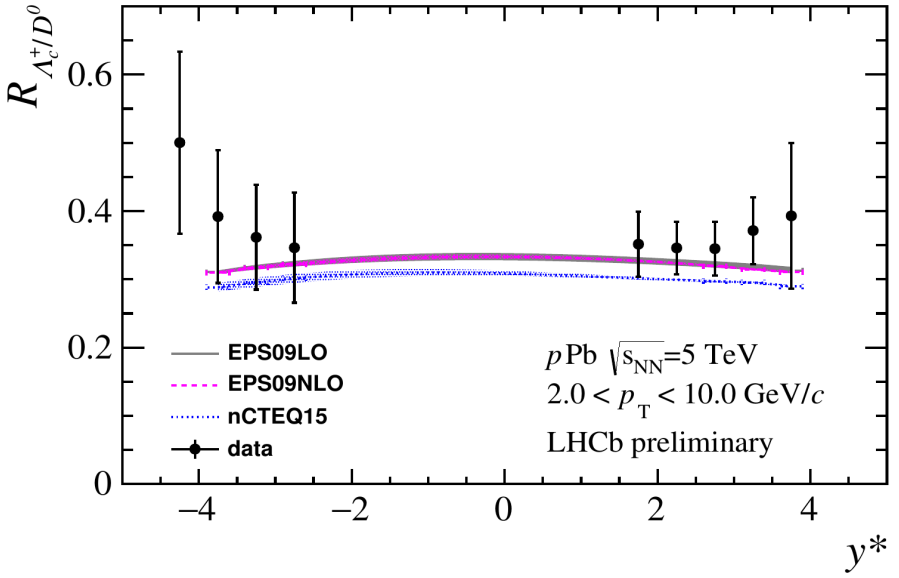


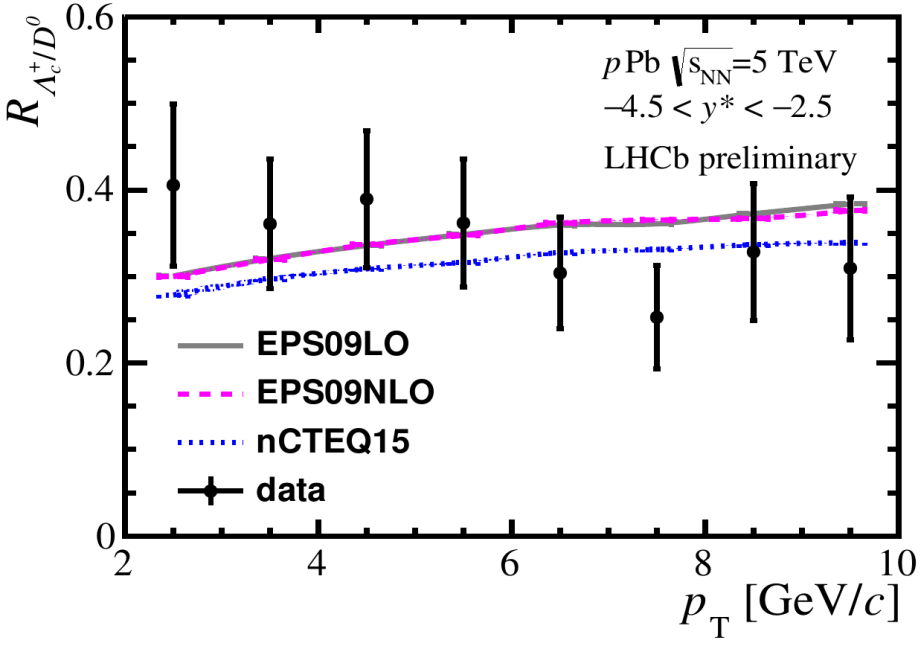
EPS09: Eskola et al. [JHEP 04(2009)065] nCTEQ15: Kovarik et al. [PRD 93(2016)085037]

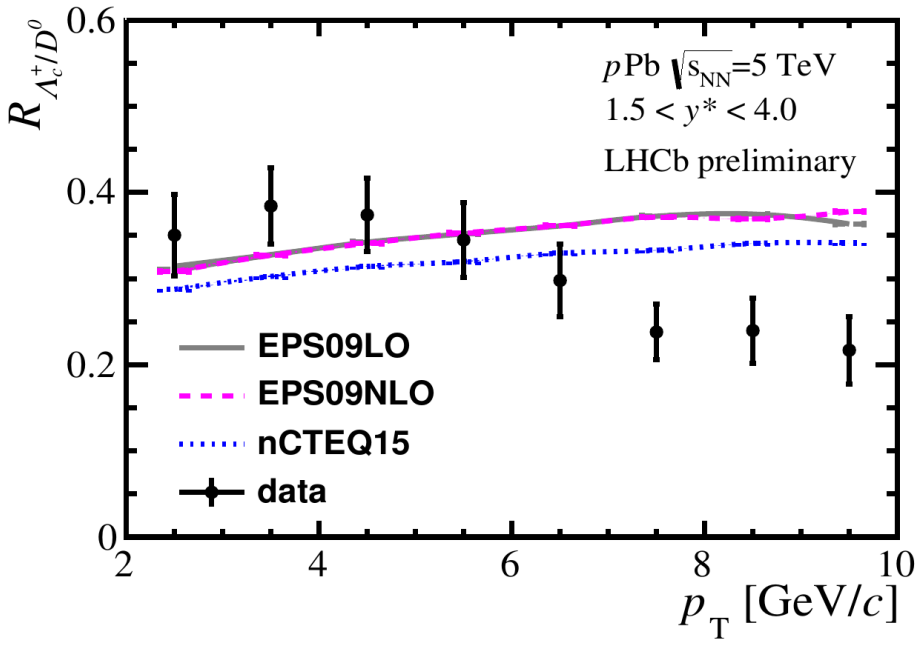
Λ_c^+ production at $\sqrt{s_{NN}} = 5$ TeV

[LHCb-CONF-2017-005]

Λ_c^+ / D^0 production ratio







EPS09: Eskola et al. [JHEP 04(2009)065] nCTEQ15: Kovarik et al. [PRD 93(2016)085037]

J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

[PLB 774(2017)159]

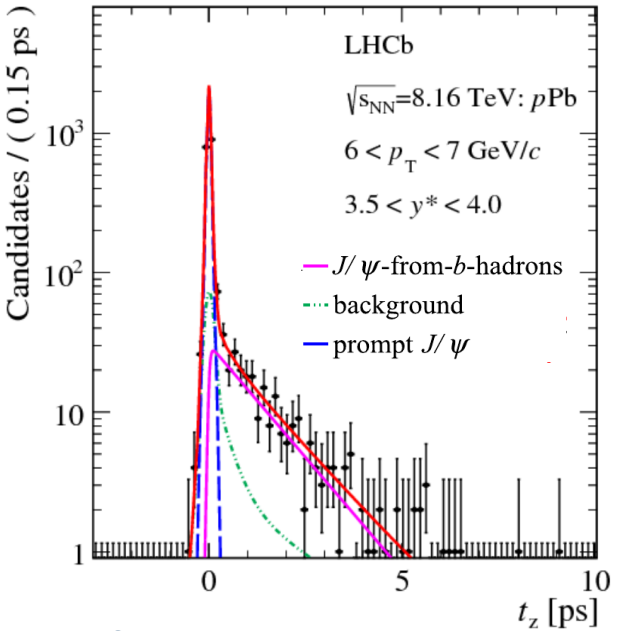
Reconstruct $J/\psi \to \mu^+ \mu^-$

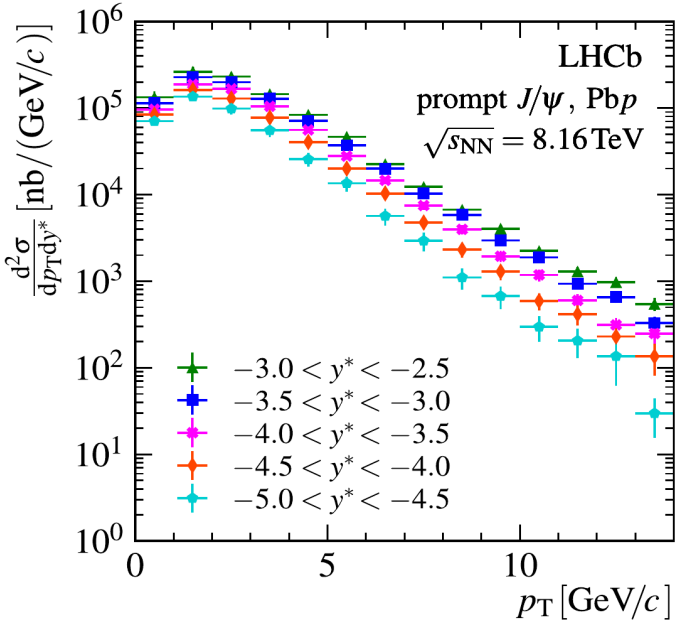
Separate prompt J/ψ from $b \to J/\psi X$ using decay-time estimate

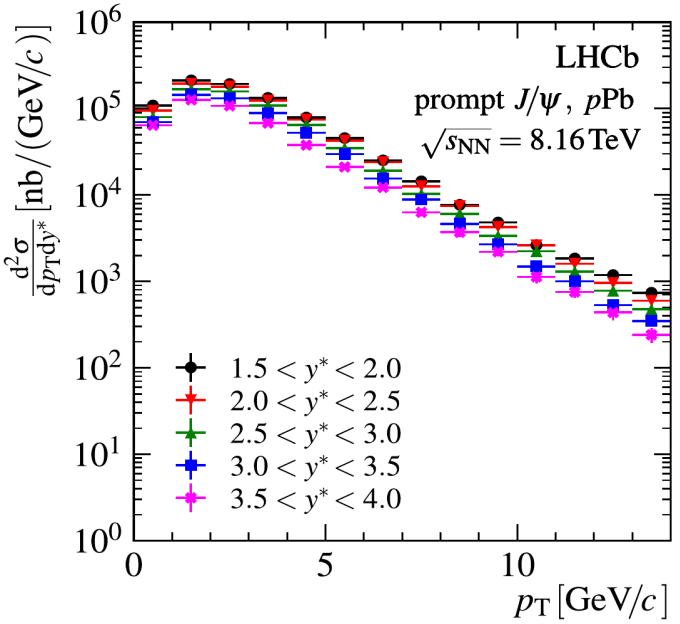
Measure double-differential prompt cross sections for $p_T < 14$ GeV/c and

$-5.0 < y^* < -2.5$ ("backward")

$1.5 < y^* < 4.0$ ("forward")





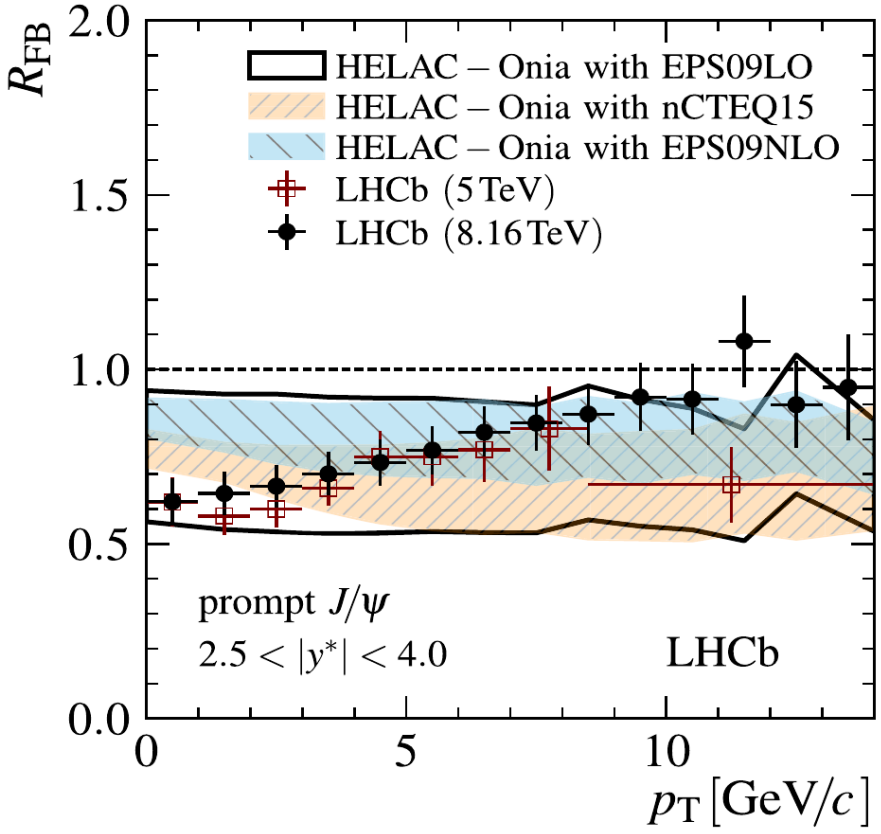


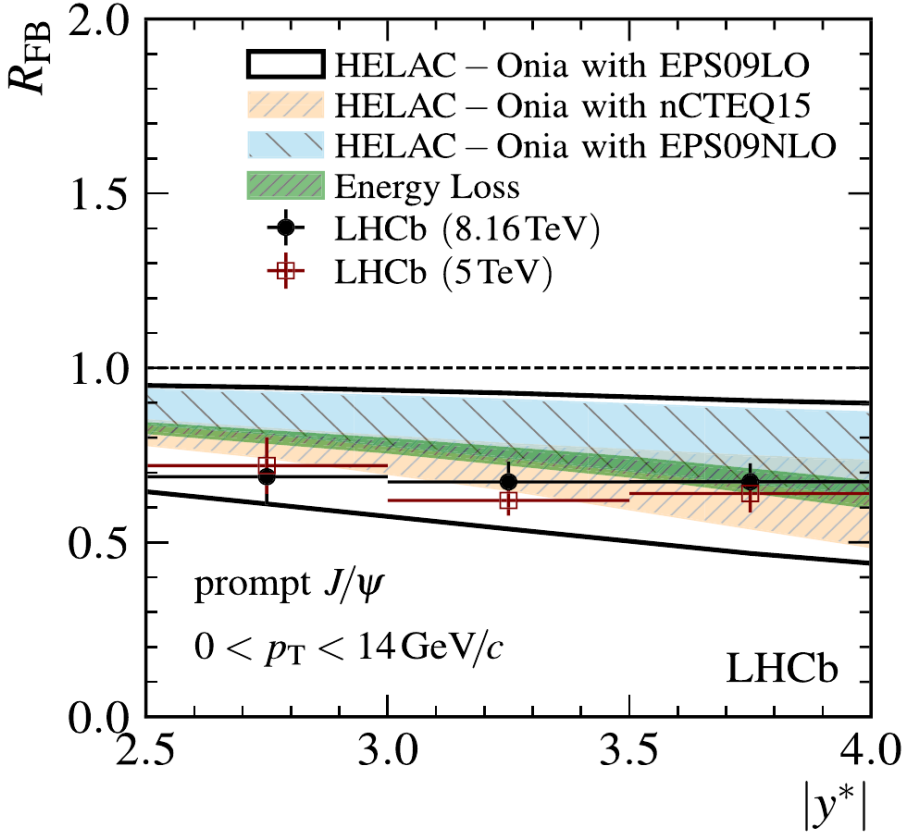
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

[PLB 774(2017)159]

Forward-backward asymmetry for prompt J/ψ production

→ Good agreement with predictions





Energy loss: Arleo et al. [JHEP 03(2013)122]

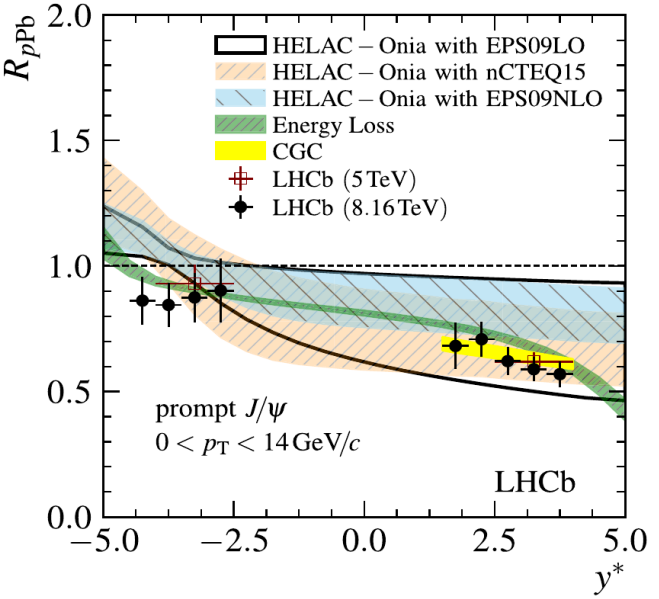
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

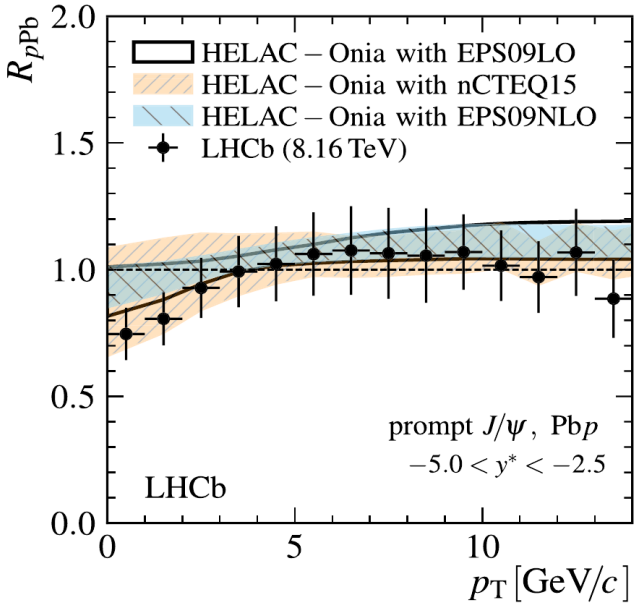
[PLB 774(2017)159]

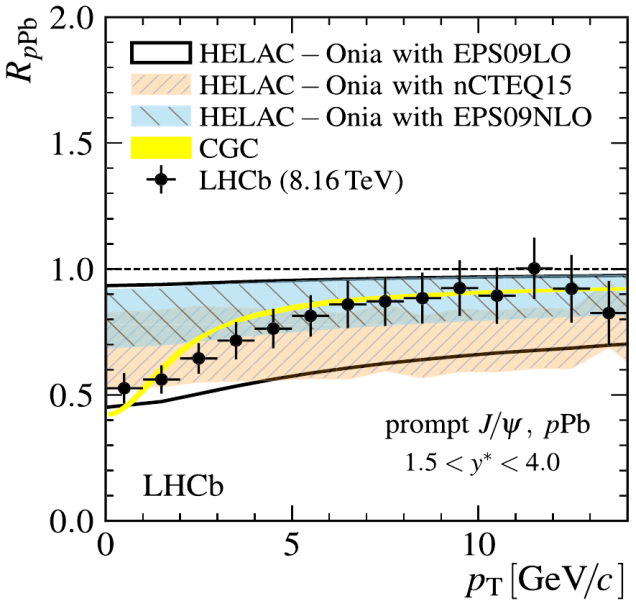
→ Nuclear modification factor for prompt J/ψ production

→ As expected, find suppression in "forward" configuration

→ Good agreement with earlier LHCb measurement at 5 TeV





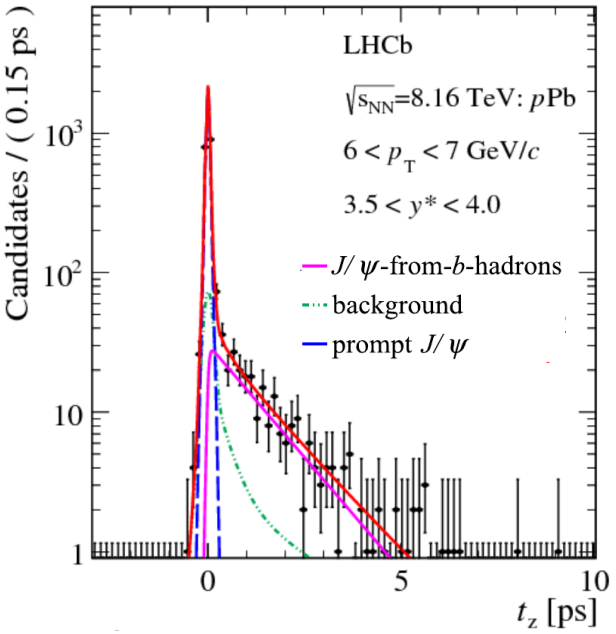


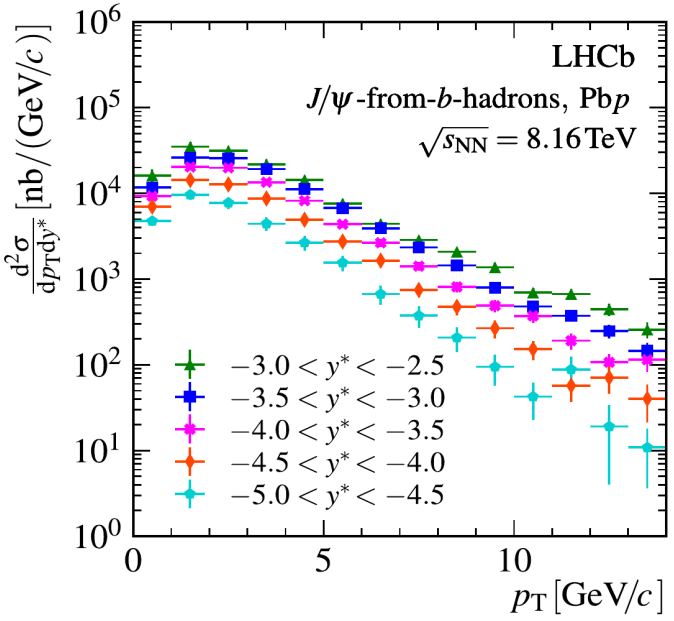
CGC: Ducloué et al. [PRD 94(2016)074031]

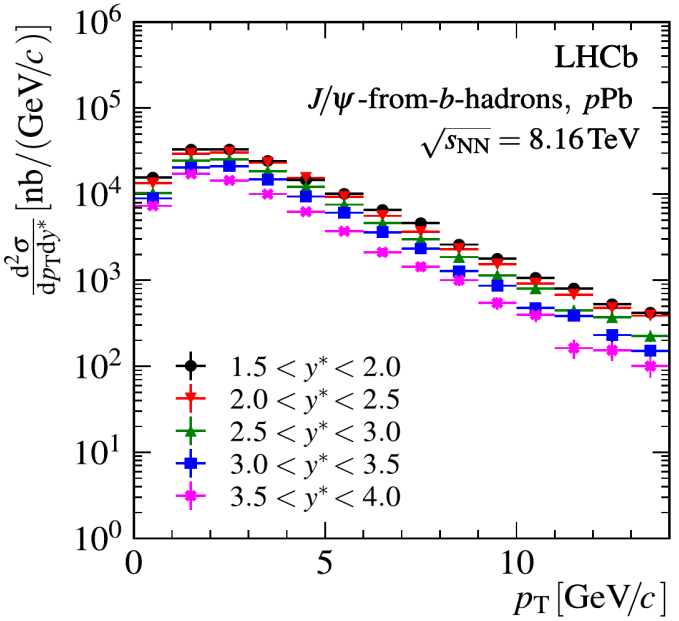
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

[PLB 774(2017)159]

… same for $b \to J/\psi X$





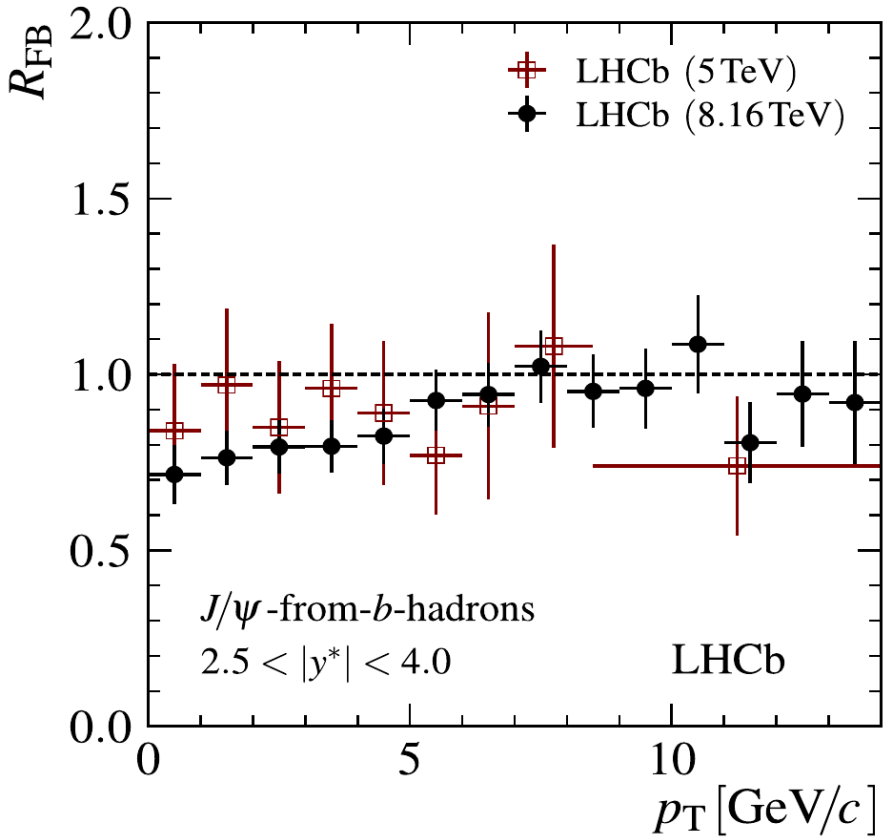


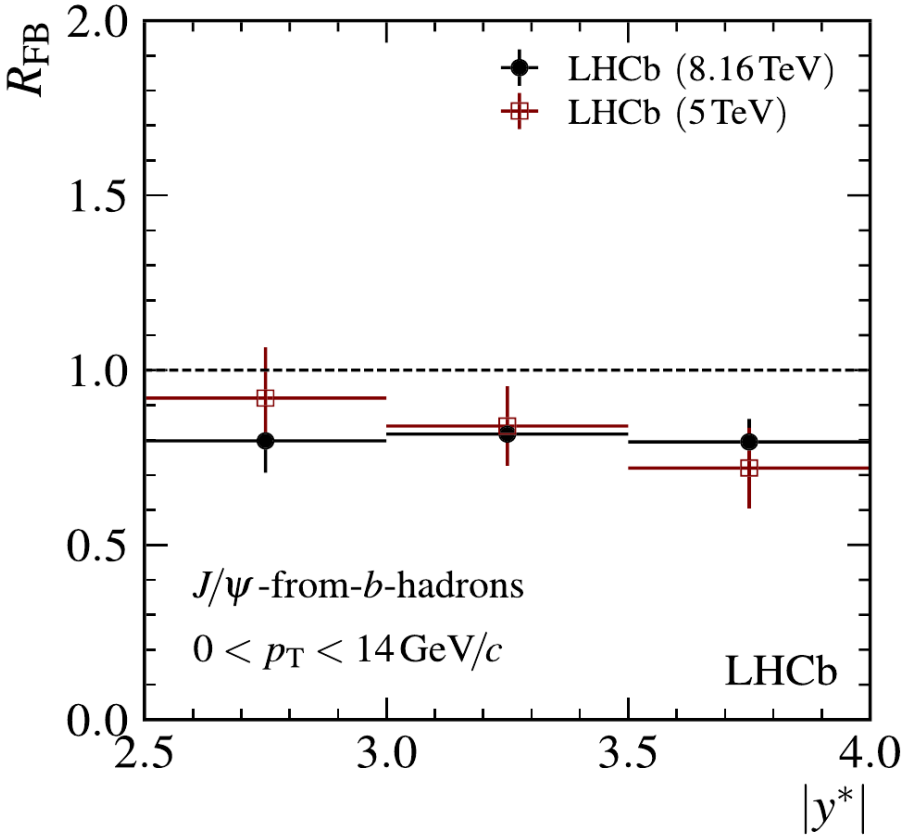
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

[PLB 774(2017)159]

Forward-backward asymmetry for $b \to J/\psi X$

$\to$ Good agreement with earlier measurement at $\sqrt{s_{NN}} = 5$ TeV





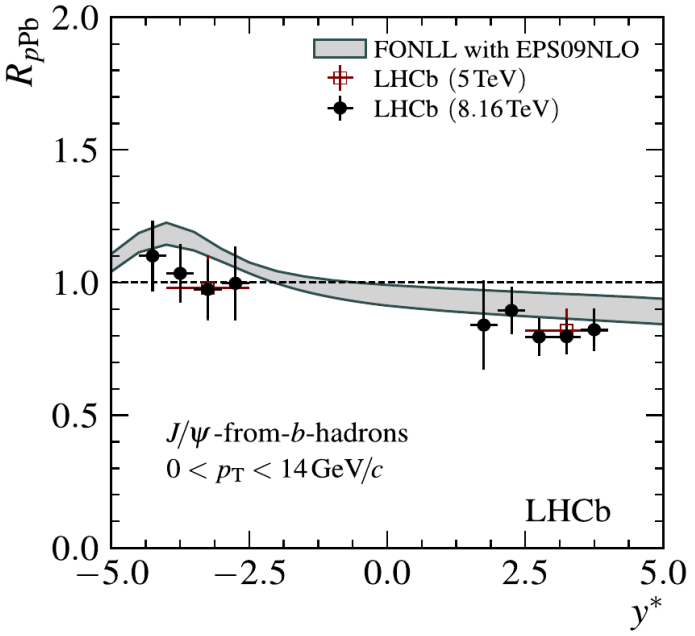
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

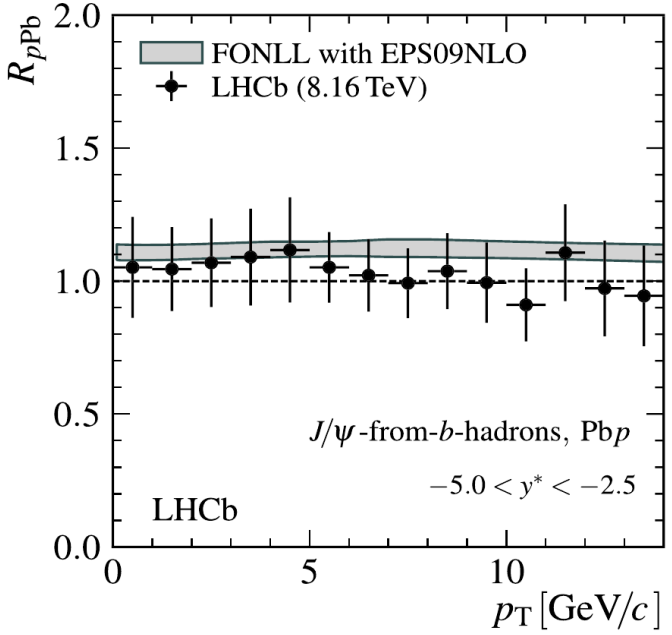
[PLB 774(2017)159]

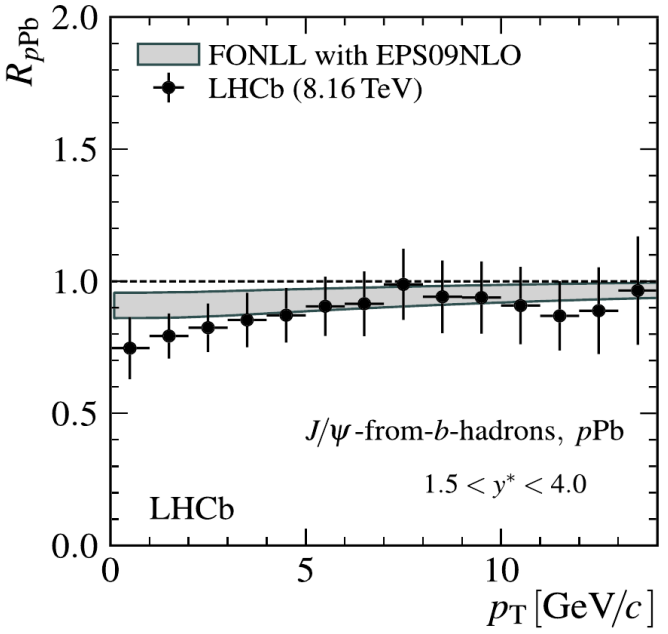
→ Nuclear modification factor for $b \to J/\psi X$

→ As expected, less suppression in "forward" configuration

→ Again, good agreement with earlier LHCb measurement at 5 TeV



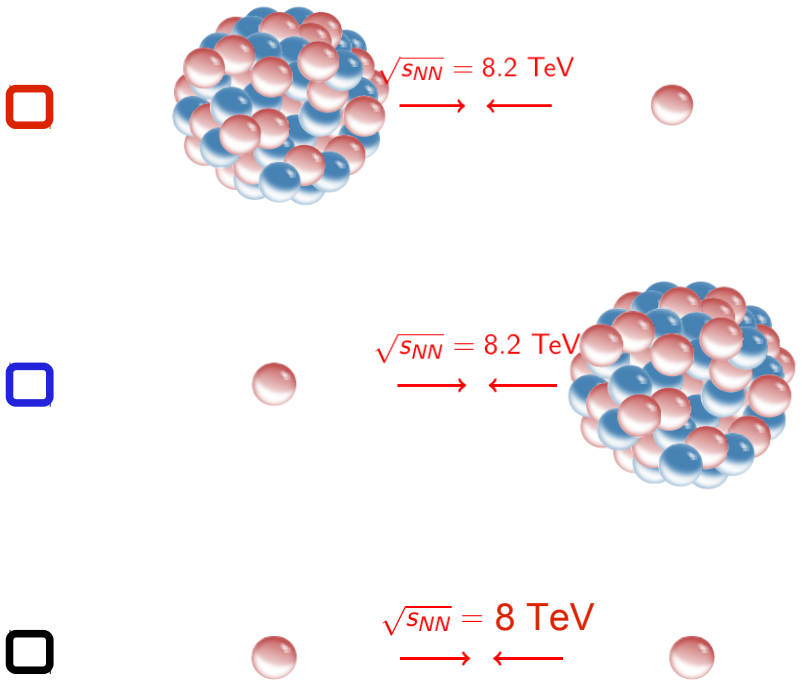


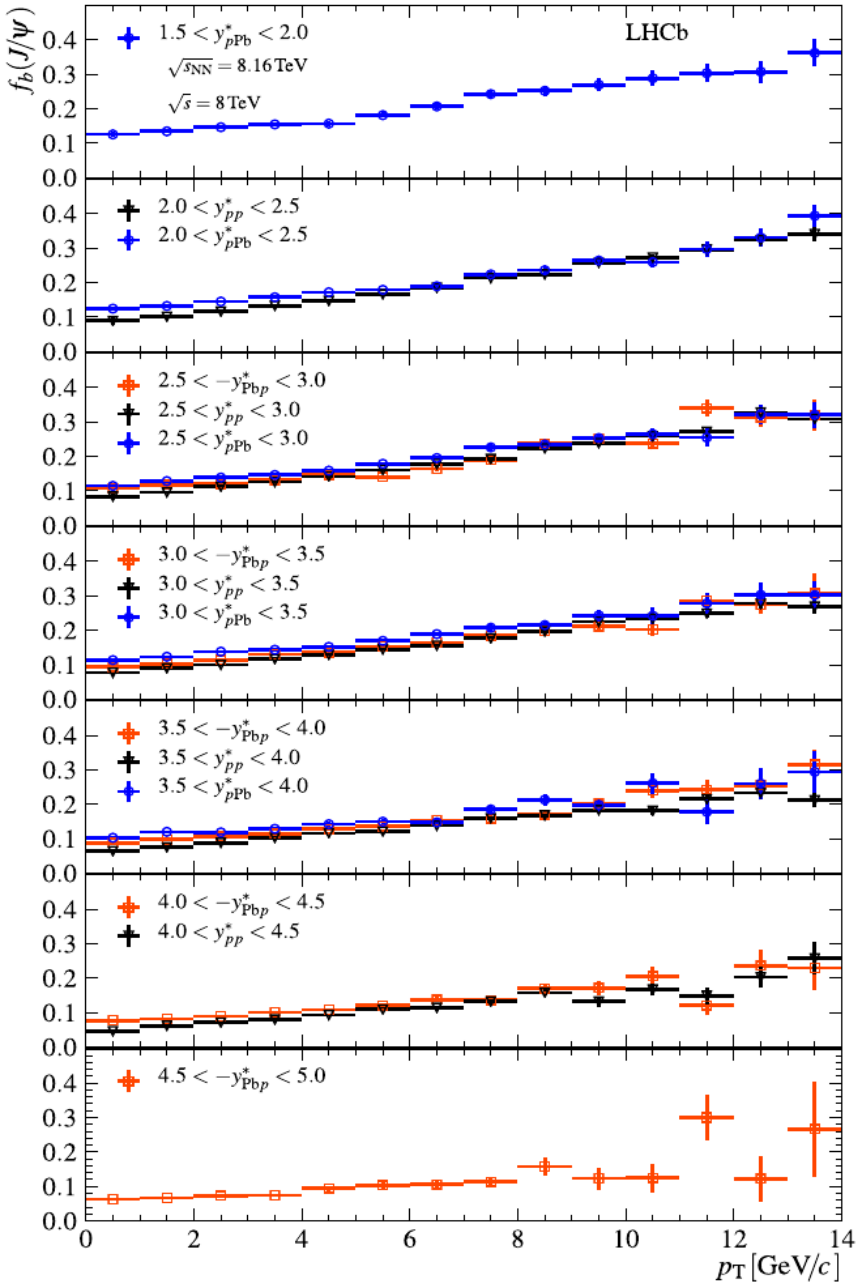


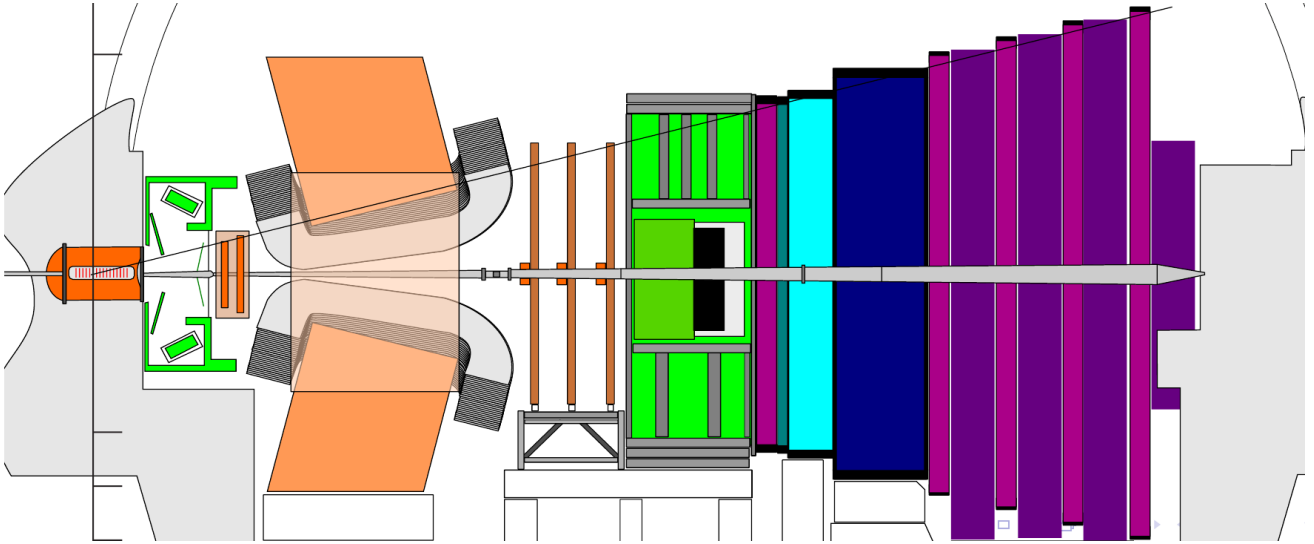
J/ψ production at $\sqrt{s_{NN}} = 8.16$ TeV

[PLB 774(2017)159]

Fraction of J/ψ from $b \to J/\psi X$





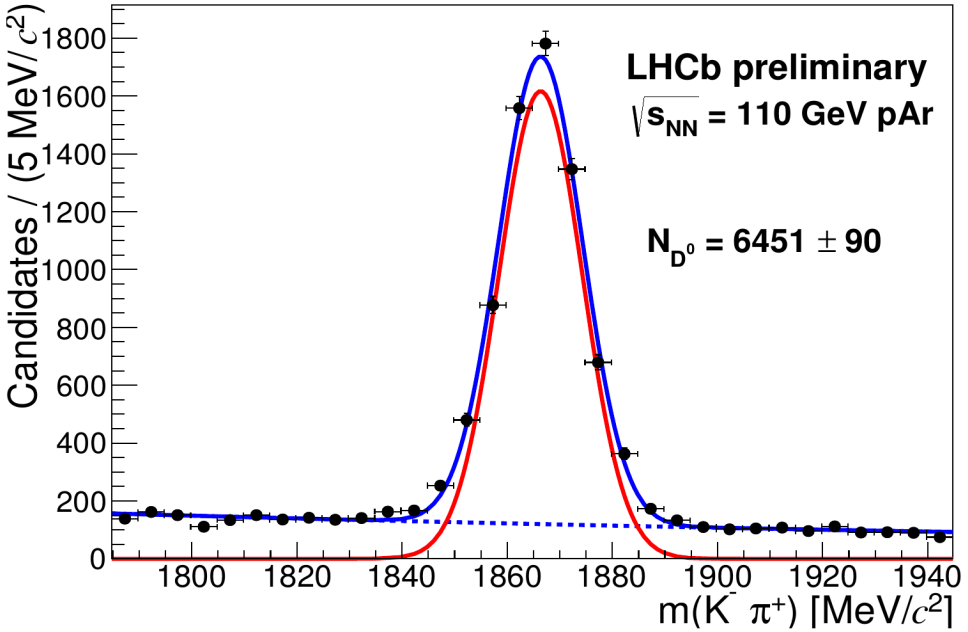


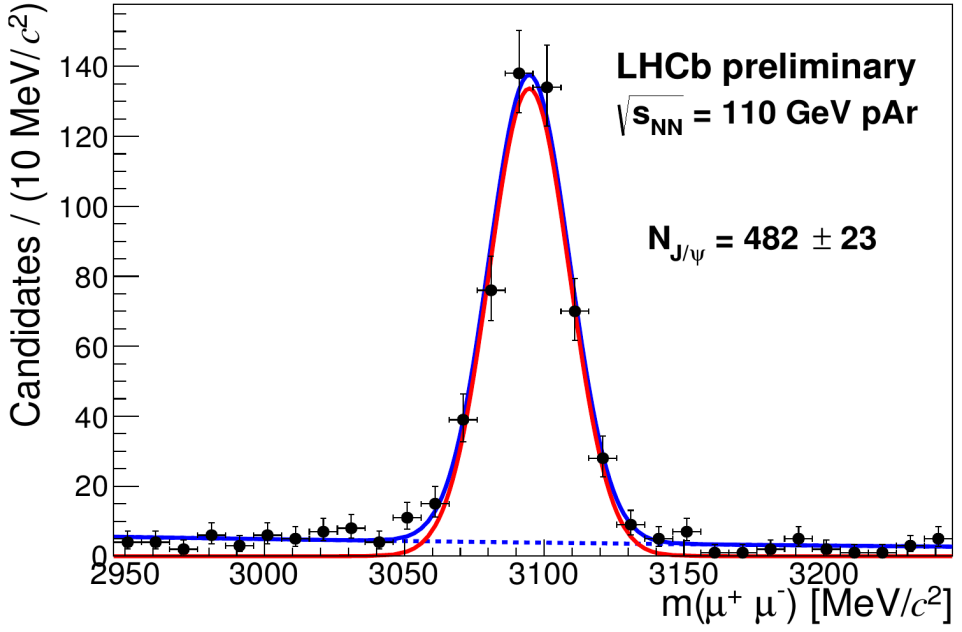
$\sqrt{s_{NN}} = 110$ GeV

Open charm and charmonium production

[LHCb-CONF-2017-001]

From about 18 hours of data taking with Argon target:



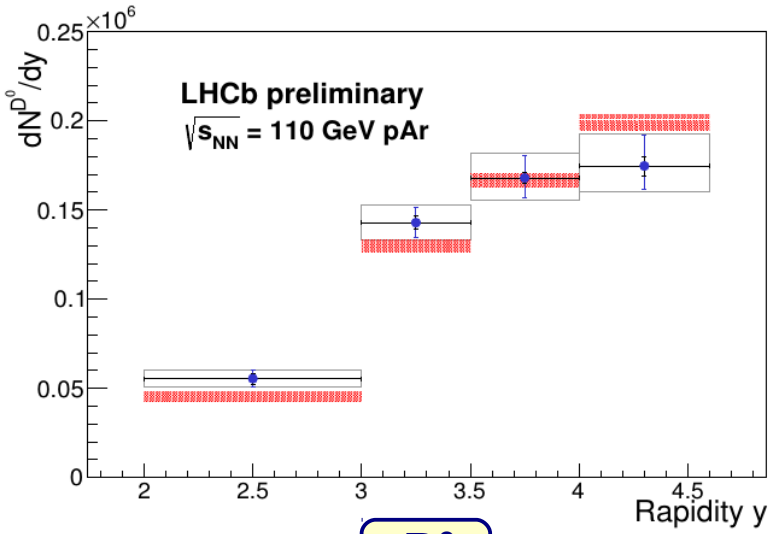


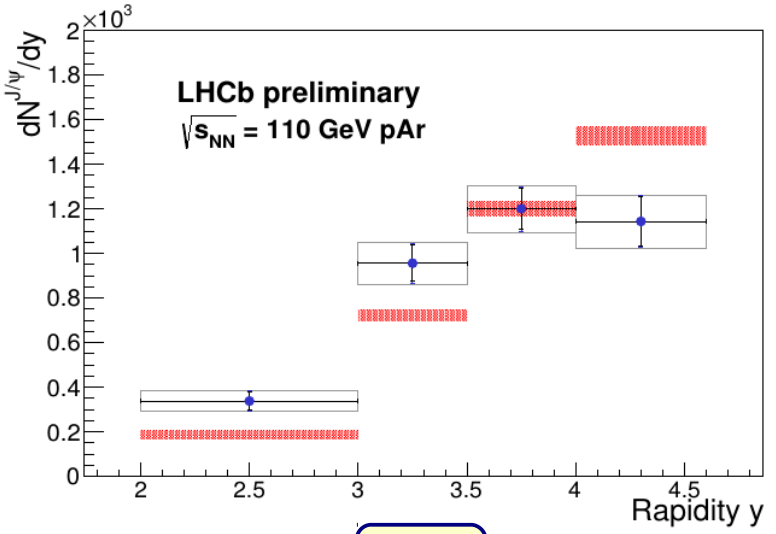
$D^0 \to K^-\pi^+$

$J/\psi \to \mu^+\mu^-$

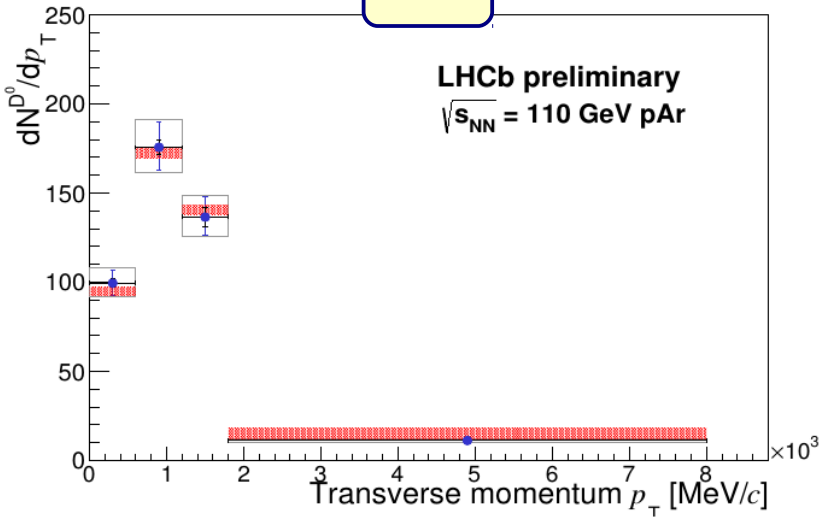
Open charm and charmonium production

[LHCb-CONF-2017-001]

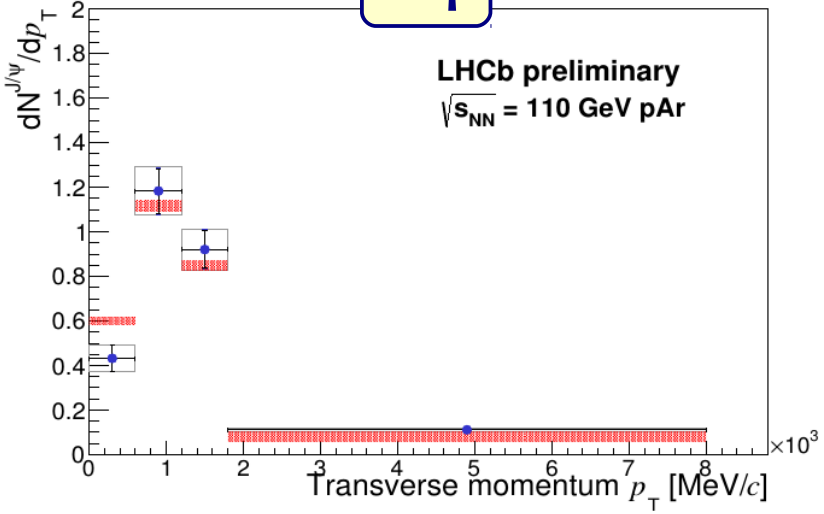




D^0



J/ψ

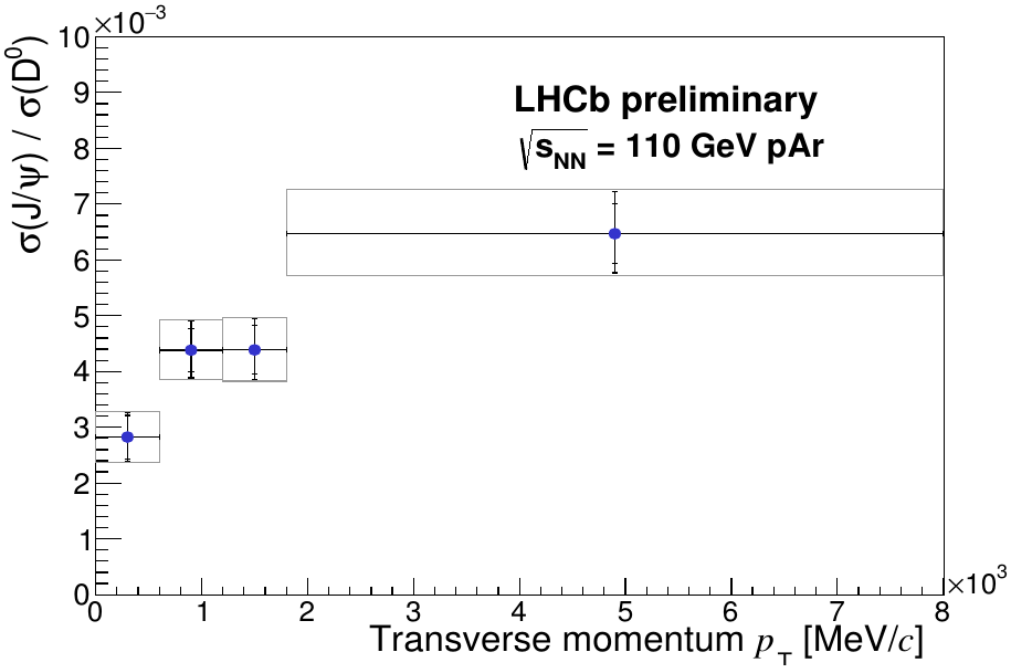


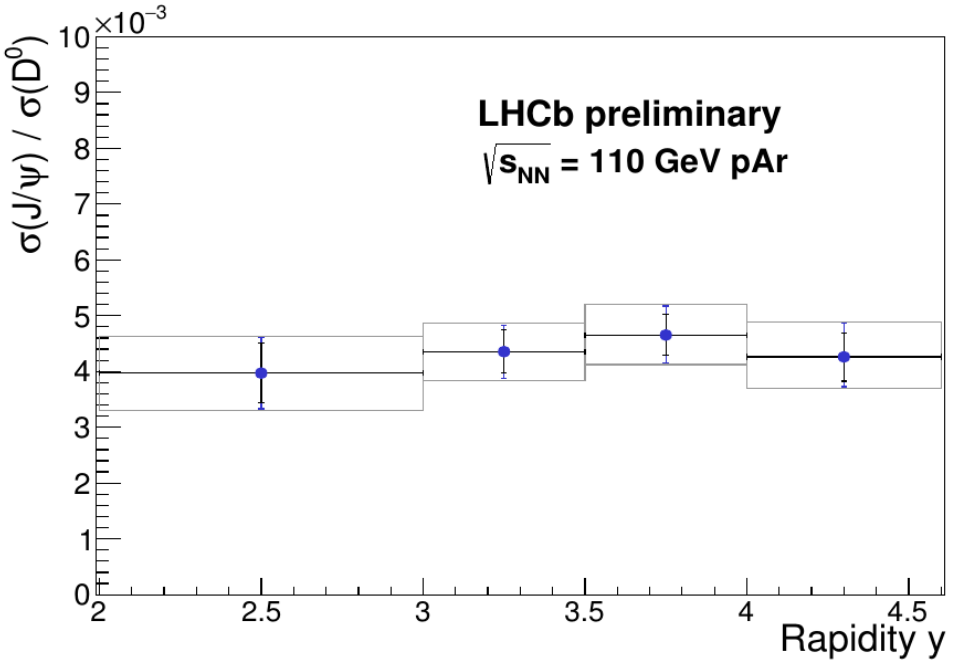
Differential distributions compared to PYTHIA8 prediction

Sjostrand et al. [Comp Phys Comm 178(2008)852]

Open charm and charmonium production

[LHCb-CONF-2017-001]

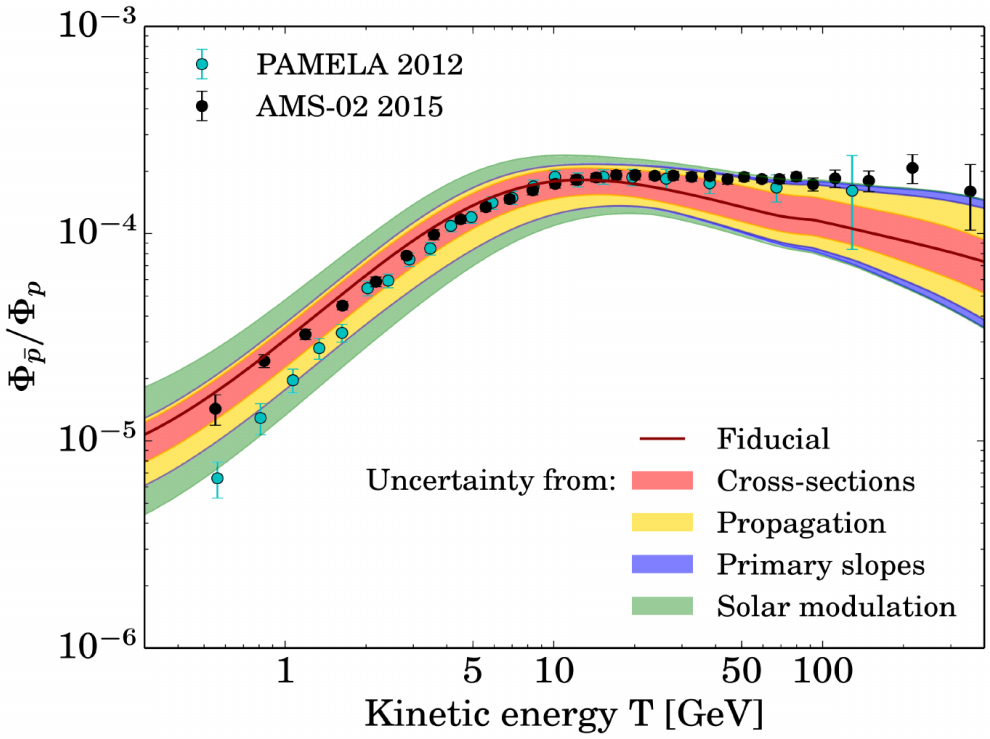




J/ψ to D^0 production ratio

Antiproton production

Antiproton cross sections of interest our colleagues in astro-particle physics



Giesen et al. [JCAP 1509(2015)023]

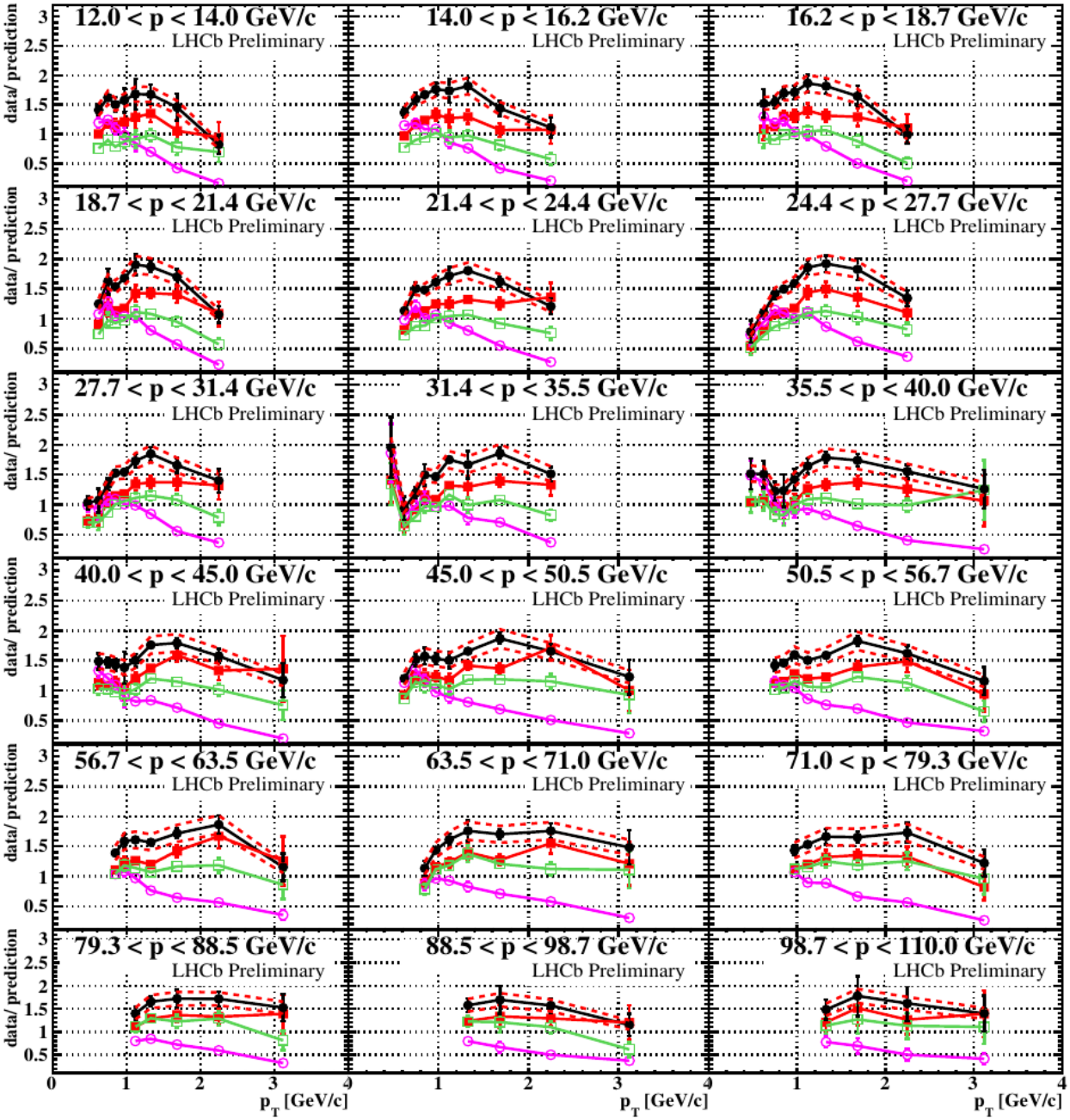
Antiproton production

[LHCb-CONF-2017-002]

→ **Measure double differential cross-section as a function of p and p_T**

→ **Compare with predictions from various models**

- EPOS LHC
- EPOS 1.99
- QGSJETII-04
- HIJING 1.38



Pierog et al. [PRC 92(2015)034906]
Pierog et al. [NPPS 196(2009)102]
Ostapchenko [PRD 83(2011)014018]
Gyulassy et al. [CPC 83(1994)307]

Summary

LHCb provides unique opportunities
to probe particle production
in *pp*, *p*Pb, PbPb and *p*A fixed-target collisions
in so-far unexplored kinematic regions

Results provide input for
pdf fits and tuning of QCD models

More results to come …

Summary

See also related LHCb talks in other sessions:

"*W*, *Z* and top production measurements at LHCb"

Patrick Robbe, Tuesday morning, WG1

"Heavy-flavour hadron production at LHCb"

Patrick Robbe, yesterday afternoon, WG1/5 joint session

Outline

pp collisions @ 13 TeV

→ **Inelastic cross section**
[arXiv:1803.10974]

→ **Top-pair production**
[arXiv:1803.05188]

→ **$B^{\pm}$ production cross section and asymmetries**
[JHEP 12(2017)026] [PLB 774(2017)139]

→ **Charmonium in CEP**
[LHCb-CONF-2016-007]

pPb collisions

→ **Open charm and charmonium production**
[JHEP 10(2017)90] [LHCb-CONF-2017-005] [PLB 774(2017)159]

p fixed target

→ **Open charm and charmonium production**
[LHCb-CONF-2017-001]

→ **Anti-proton production**
[LHCb-CONF-2017-002]

Backup

Data Sets

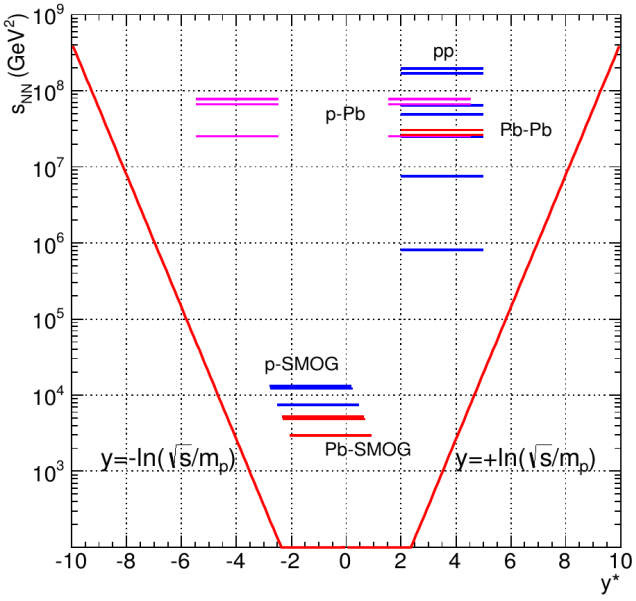
E_{beam}(p)	pp	p-Gas	p-Pb/Pb-p	Pb-Gas	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV$^{(1)}$			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV$^{(2)}$	5 TeV	54 GeV$^{(2)}$	
6.5 TeV	13 TeV	110 GeV$^{(3)}$	8.2 TeV	69 GeV$^{(1)}$	5 TeV

(1) SMOG with ^{40}Ar

(2) SMOG with ^{20}Ne

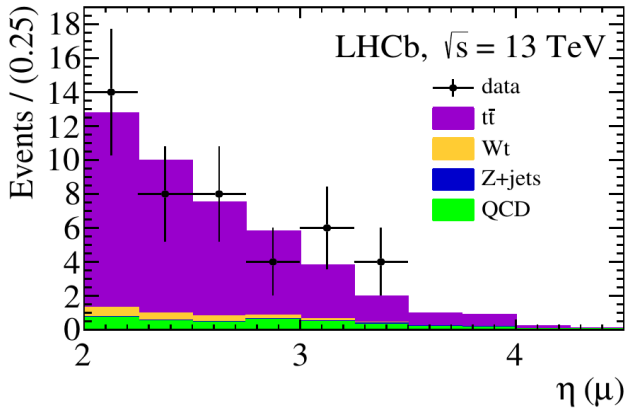
(3) SMOG with ^{4}He, ^{20}Ne, ^{40}Ar

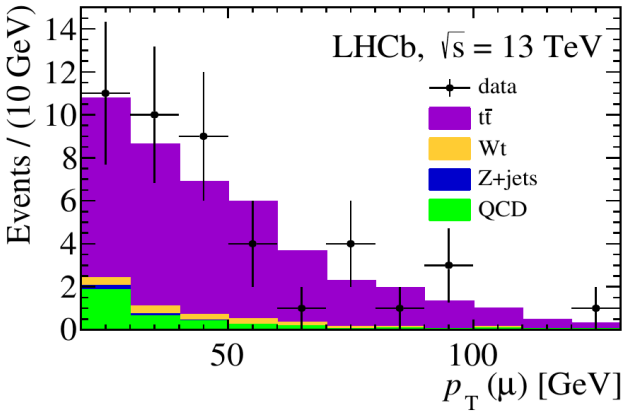
Caveat: granularity of tracking system not optimized for central Pb-Pb collisions

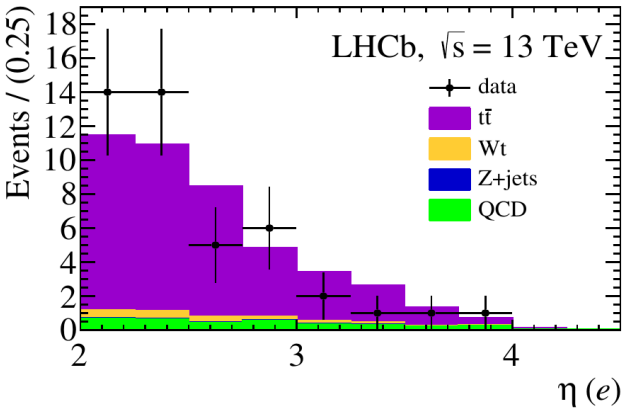


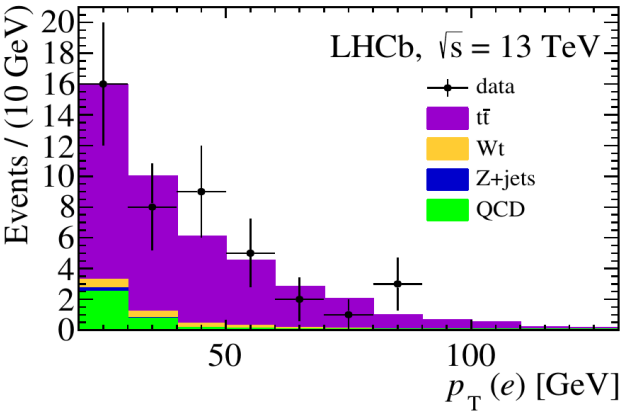
Top-pair production

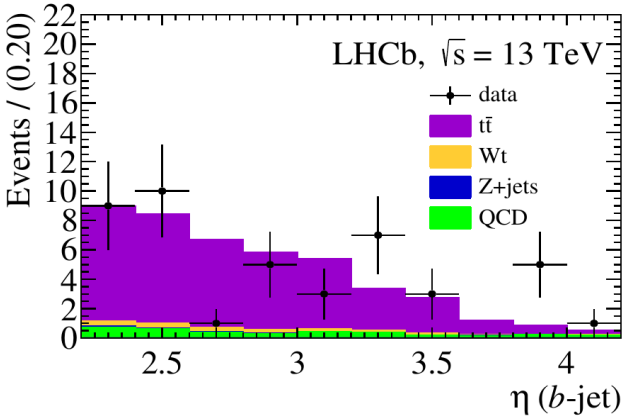
[arXiv:1803.05188]

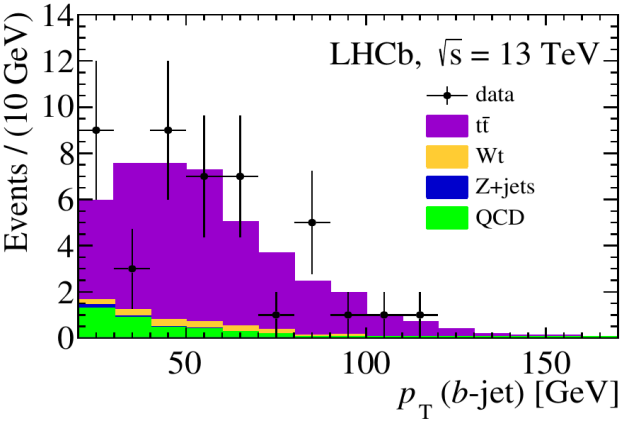












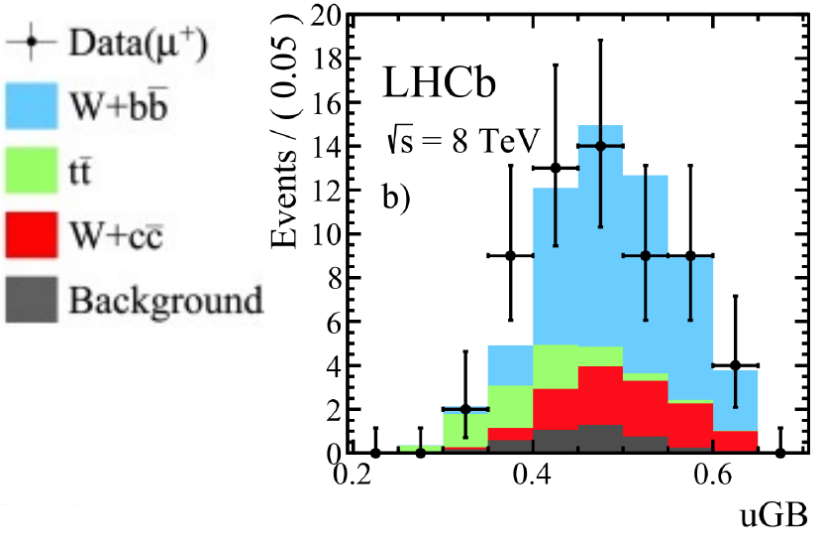
Top-pair production at $\sqrt{s} = 8$ TeV

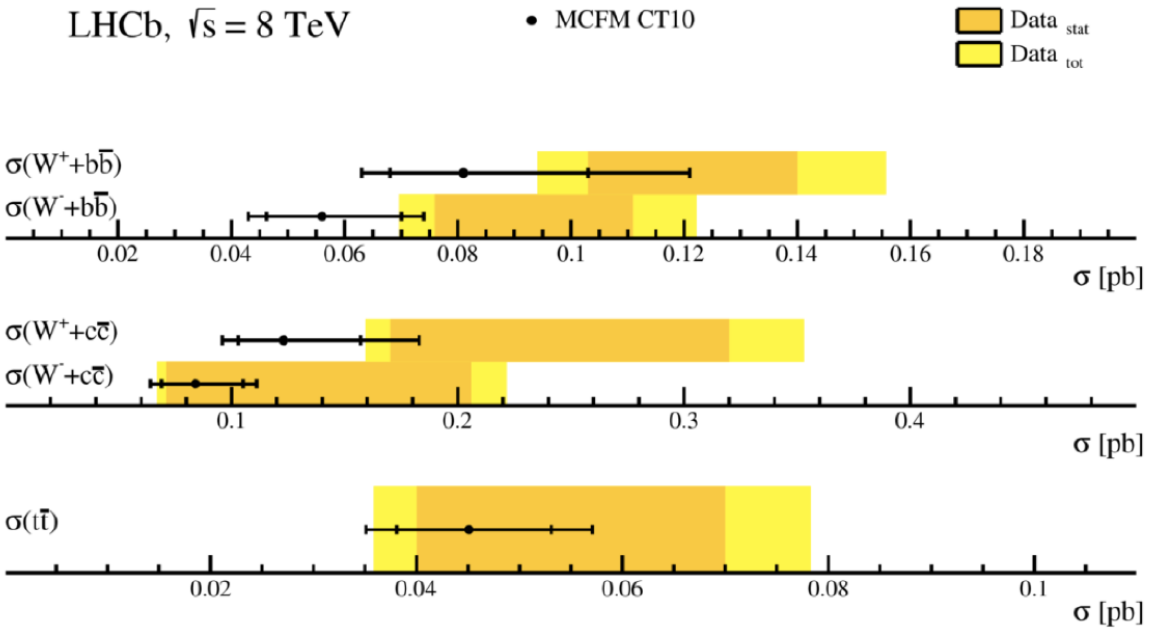
[PLB 767(2017)110]

$W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ production cross sections

→ 1 lepton + 2 *b*/*c* jets

→ $2.2 < \eta_{jet} < 4.2$

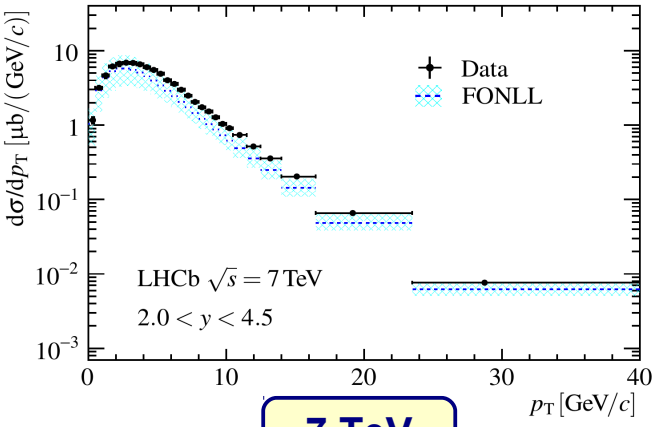




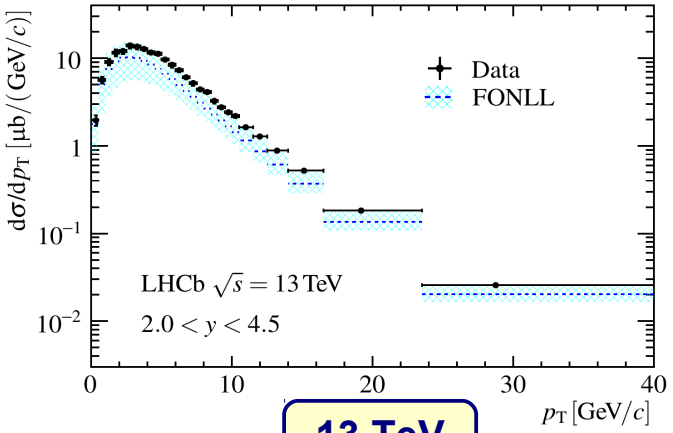
Sample	Significance
$t\bar{t}$	4.9σ
$W^+ + b\bar{b}$	7.1σ
$W^- + b\bar{b}$	5.6σ
$W^+ + c\bar{c}$	4.7σ
$W^- + c\bar{c}$	2.5σ

$B^{\pm}$ production cross section

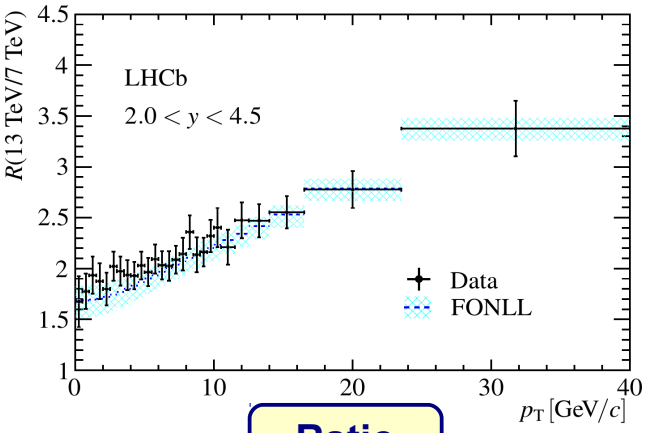
[JHEP 12(2017)026]



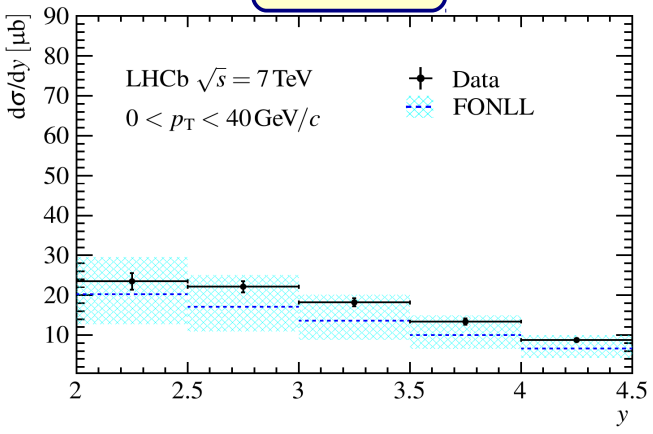
7 TeV

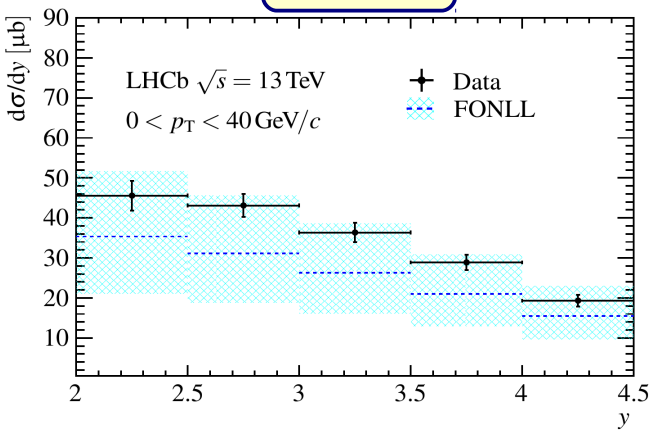


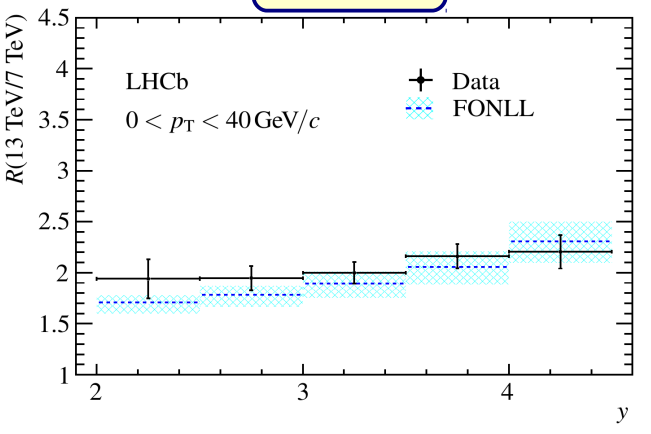
13 TeV



Ratio







$$\sigma_{7\,\mathrm{TeV}}(pp \to B^{\pm} X) = 43.0 \pm 0.2\,(\mathrm{stat}) \pm 2.5\,(\mathrm{syst}) \pm 1.7\,(\mathrm{ext})\ \mu\mathrm{b}$$

$$\sigma_{13\,\mathrm{TeV}}(pp \to B^{\pm} X) = 86.6 \pm 0.5\,(\mathrm{stat}) \pm 5.4\,(\mathrm{syst}) \pm 3.4\,(\mathrm{ext})\ \mu\mathrm{b}$$

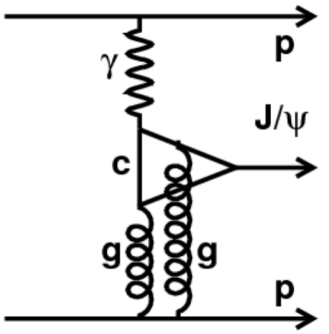
$$\sigma_{13\,\mathrm{TeV}}/\sigma_{7\,\mathrm{TeV}} = 2.02 \pm 0.02\,(\mathrm{stat}) \pm 0.12\,(\mathrm{syst})$$

Charmonium in CEP

[LHCb-CONF-2016-007]

Relation to photo-production cross section

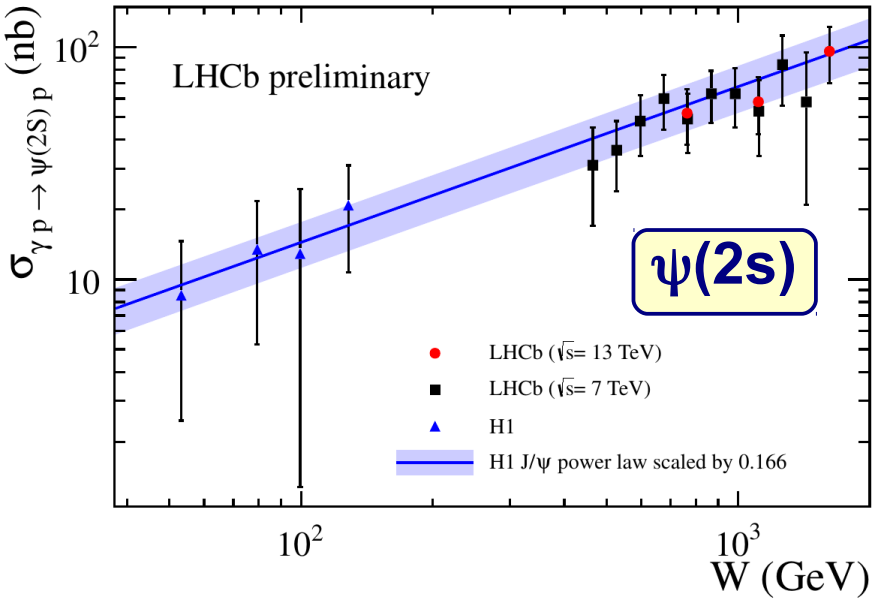
$$\sigma_{pp\to p\psi p} = \underbrace{r(W_+)}_{\text{gap survival probability}} \underbrace{k_+ \frac{dn}{dk_+}}_{\text{photon energy spectrum}} \underbrace{\sigma_{\gamma p\to\psi p}(W_+)}_{\text{cross section}} + \underbrace{r(W_-)k_- \frac{dn}{dk_-}\sigma_{\gamma p\to\psi p}(W_-)}_{\text{same, with the roles of the two protons swapped}}$$



→ Take gap-survival probability from updates of

[JHEP 11(2013)085] [JPG 41(2014)055009]

→ Fix $\sigma(W_-)$ to HERA measurements to extract $\sigma(W_+)$



→ Agreement with simple power law for ψ(2s)

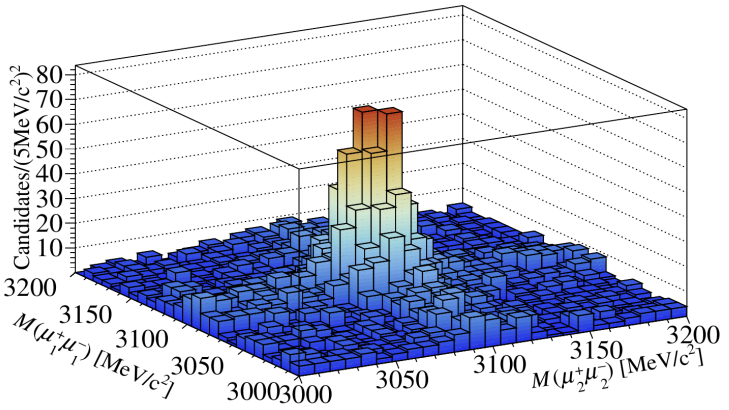
Double-J/ψ production

[JHEP 06(2017)047;JHEP 10(2017)068]

Reconstruct pairs of $J/\psi \to \mu^+\mu^-$, each with $p_T < 10$ GeV/c and $2.0 < y < 4.5$

Find ≈1000 signal candidates in 0.3 fb^{-1}

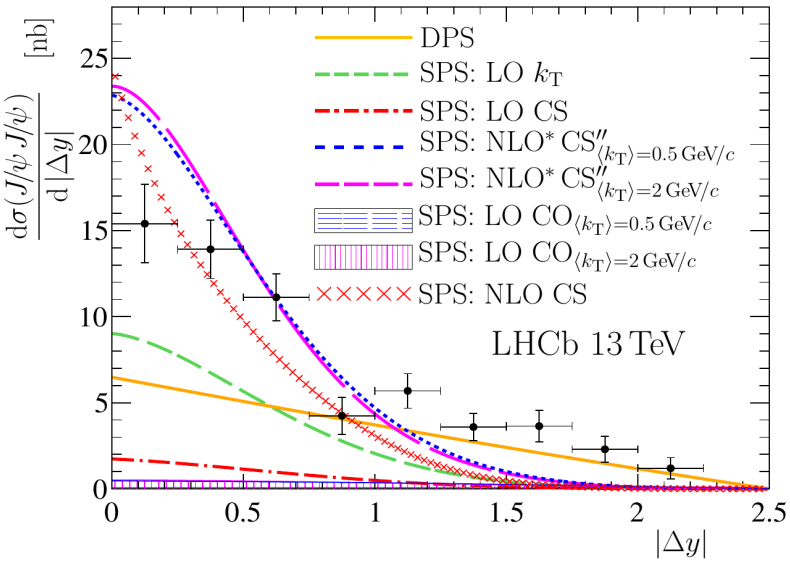
$$\sigma_{J/\psi\, J/\psi} = 15.2 \pm 1.0\,(\text{stat}) \pm 0.9\,(\text{syst})\ \text{nb}$$



Determine differential cross sections as functions of various kinematic variables

$p_T(J/\psi)$, $y(J/\psi)$, $p_T(J/\psi\ J/\psi)$, $y(J/\psi\ J/\psi)$, $m(J/\psi\ J/\psi)$, A_T, $|\Delta y|$, $|\Delta\phi|$

Find need for significant contribution from Double Parton Scattering



J/ψ production in jets

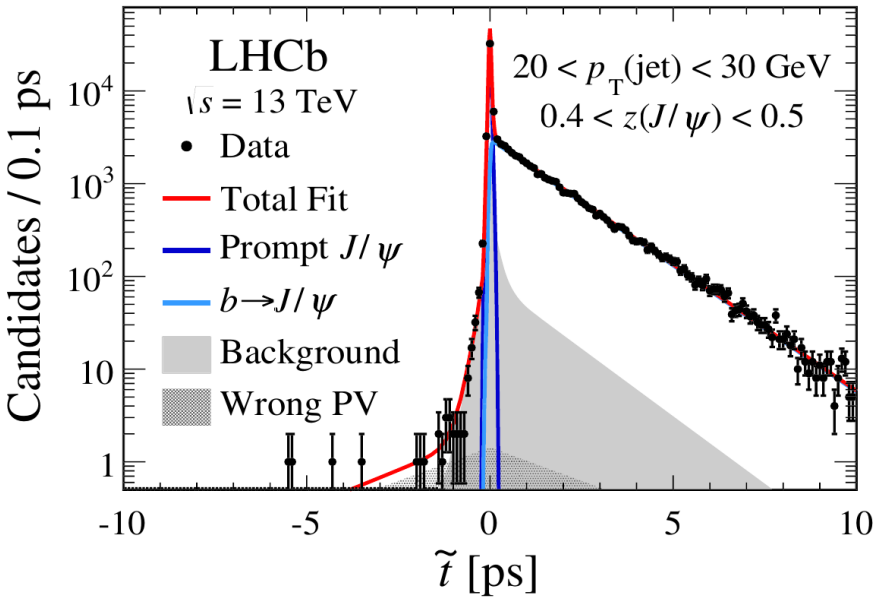
[PRL 118(2017)192001]

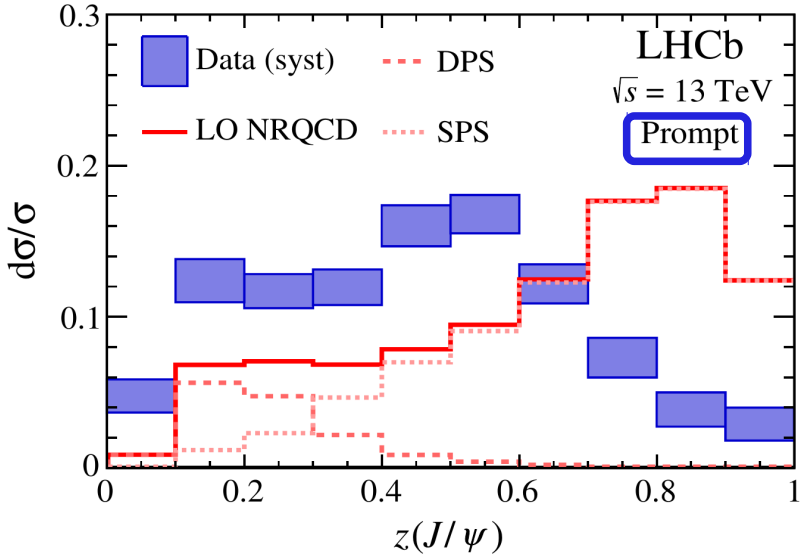
Search for $J/\psi \to \mu^+\mu^-$ in jets with
p_T (jet) > 20 GeV/c and 2.5 < η (jet) < 4.0

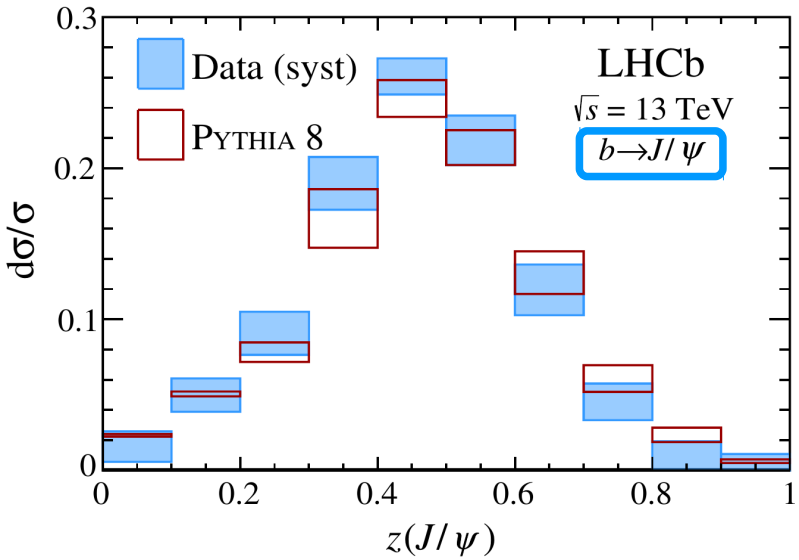
Separate prompt J/ψ and $b \to J/\psi$ using estimate of decay time

Measure fraction of jet-p_T carried by J/ψ

Find good agreement with Pythia 8 prediction for $b \to J/\psi$, but not for prompt







J/ψ production in jets

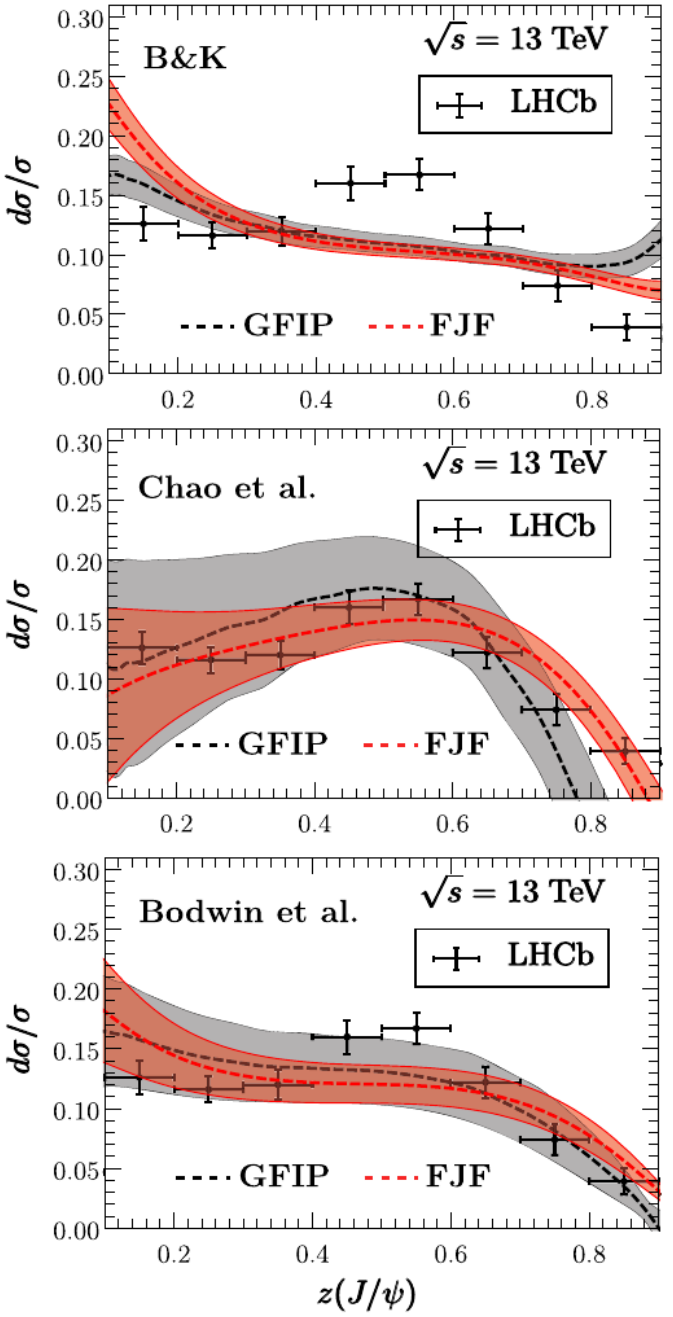
Bain, Makris, Mehen, Dai, Leibovic

[PRL 119(2017)032002]

achieve better description of LHCb data using

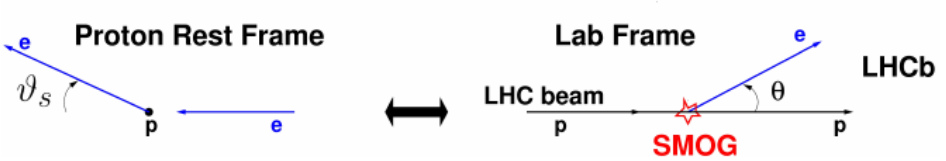
→ Fragmenting Jet Functions (FJF)

→ Gluon Fragmentation Improved Pythia (GFIP)



Antiprotons in *p*Ar

Normalization

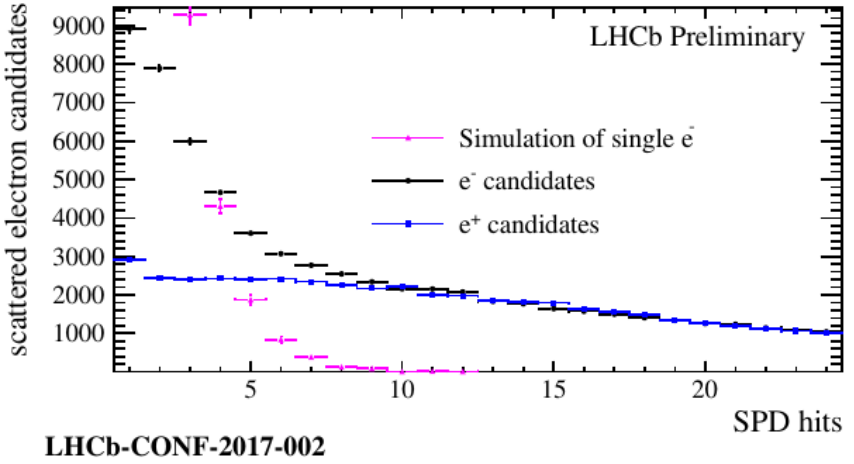


Gas target density not precisely known, using **p-e$^-$ elastic scattering**

Pro:

- LHCb sees the purely elastic regime: $\theta > 10$mrad ➡ $\vartheta_s < 29$ mrad, $Q^2 < 0.01$ GeV^2
  ➡ cross-section very well known

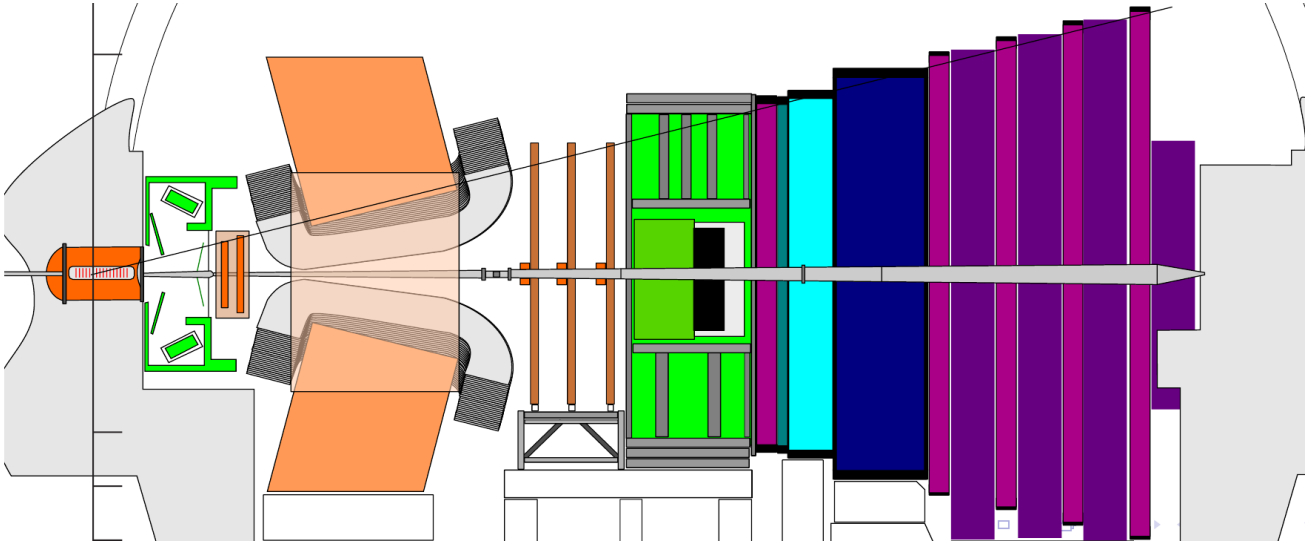
- distinct signature with single low-p and very low p_T electron track, and nothing else
- background events mostly expected from very soft collisions, where candidate comes from γ conversion or pion from central exclusive production event ➡ **background expected to be charge symmetric**, can use "single positrons" to model it in data

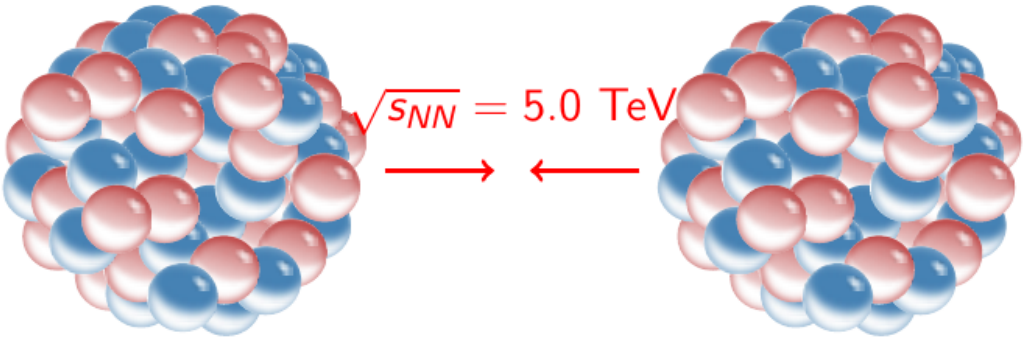


LHCb-CONF-2017-002

Cons:

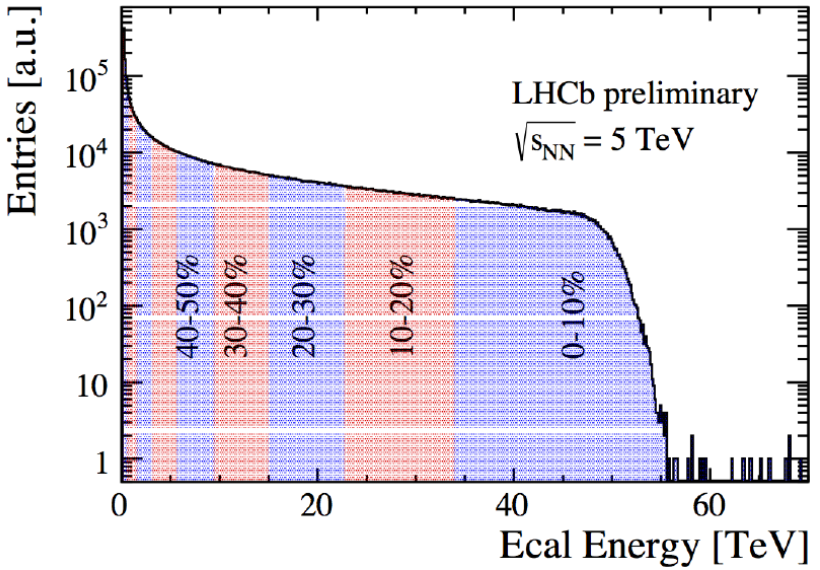
- cross-section is small (order 100 μb, 3 orders of magnitude below hadronic cross section)
- electron has very low momentum and showers through beam pipe/detectors
  ➡ low acceptance and reconstruction efficiency



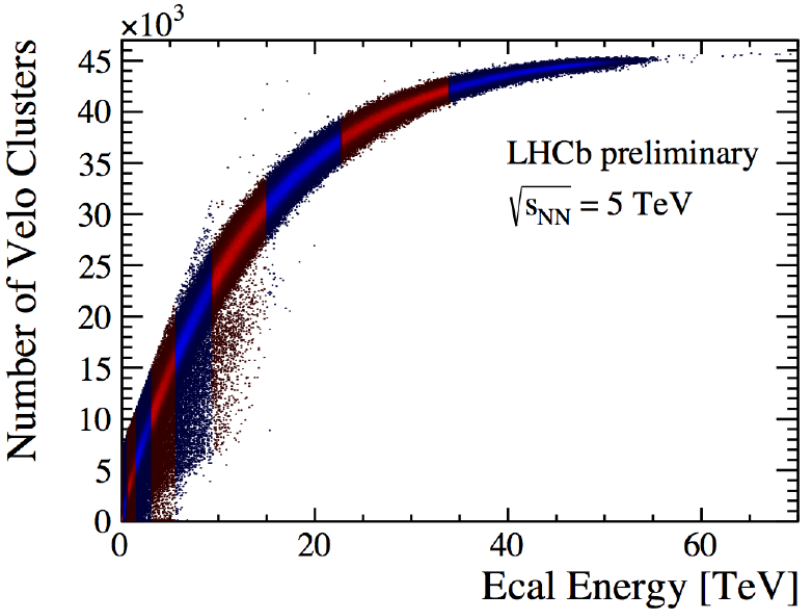

$\sqrt{s_{NN}} = 5.0$ TeV

Proof of principle

Characterize centrality of collision by total energy deposit in ECAL



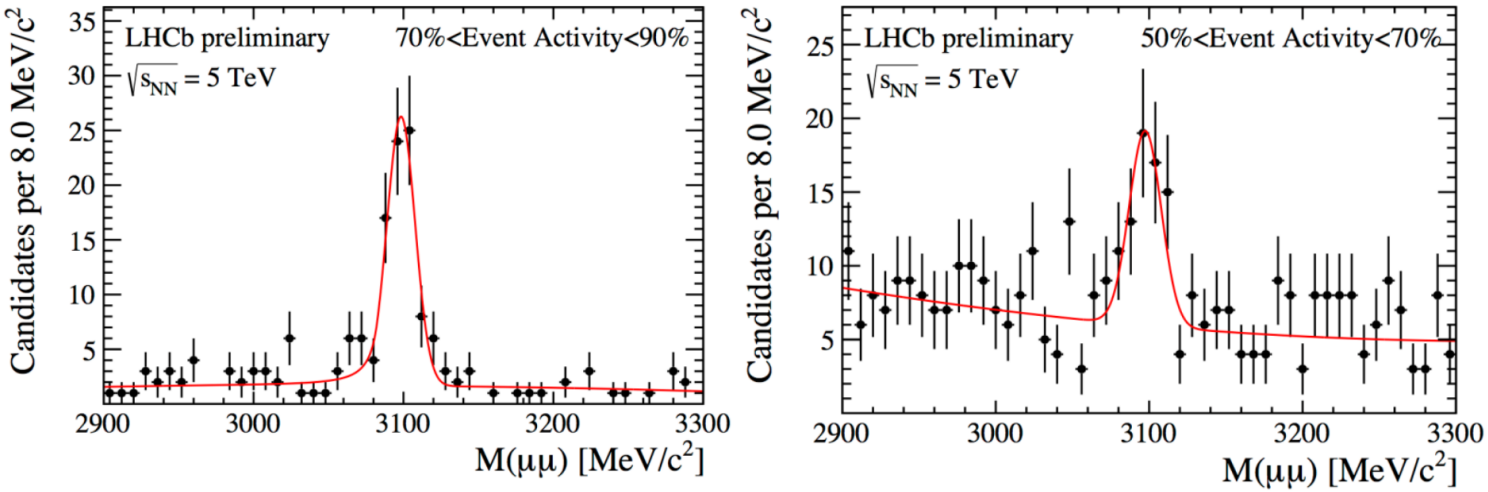
Saturation of VELO activity for very central collisions (high ECAL energy deposit)



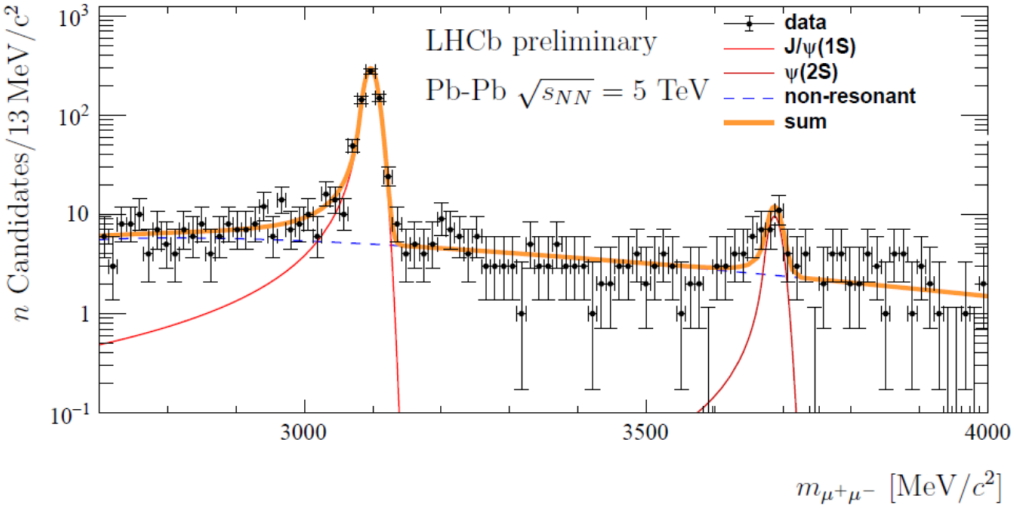
[https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015]

Proof of principle

J/ψ signals in two categories of event activity



Charmonium photo-production in very peripheral collisions



[https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015]