Recent results with heavy ion and fixed target collisions at LHCb

9th International Workshop on Multiple Partonic Interactions at the LHC
Shimla, India, December 11th - 15th

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Universität Zürich
on behalf of the LHCb collaboration

December 14th, 2017

Outline

Introduction

Proton-lead: 5 and 8 TeV

- D^0 production
- J/Ψ production

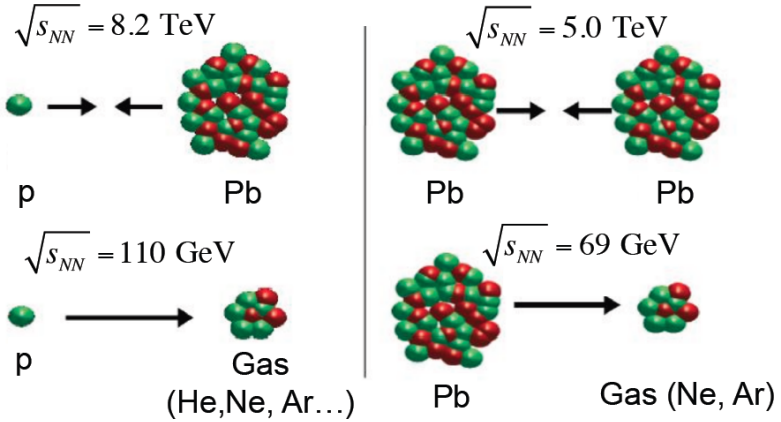
Lead-lead: 5 TeV

- First signals

Fixed target: pAr and pHe

- D^0 and J/Ψ production
- Anti-protons production

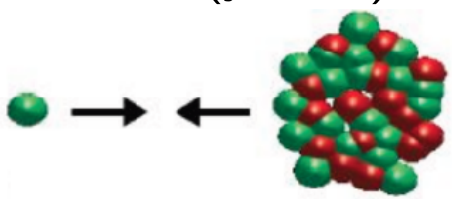
Conclusions



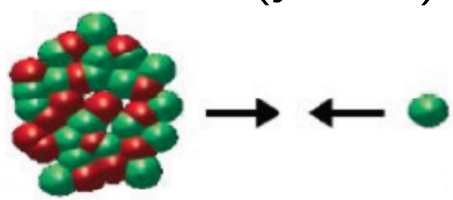
LHCb detector

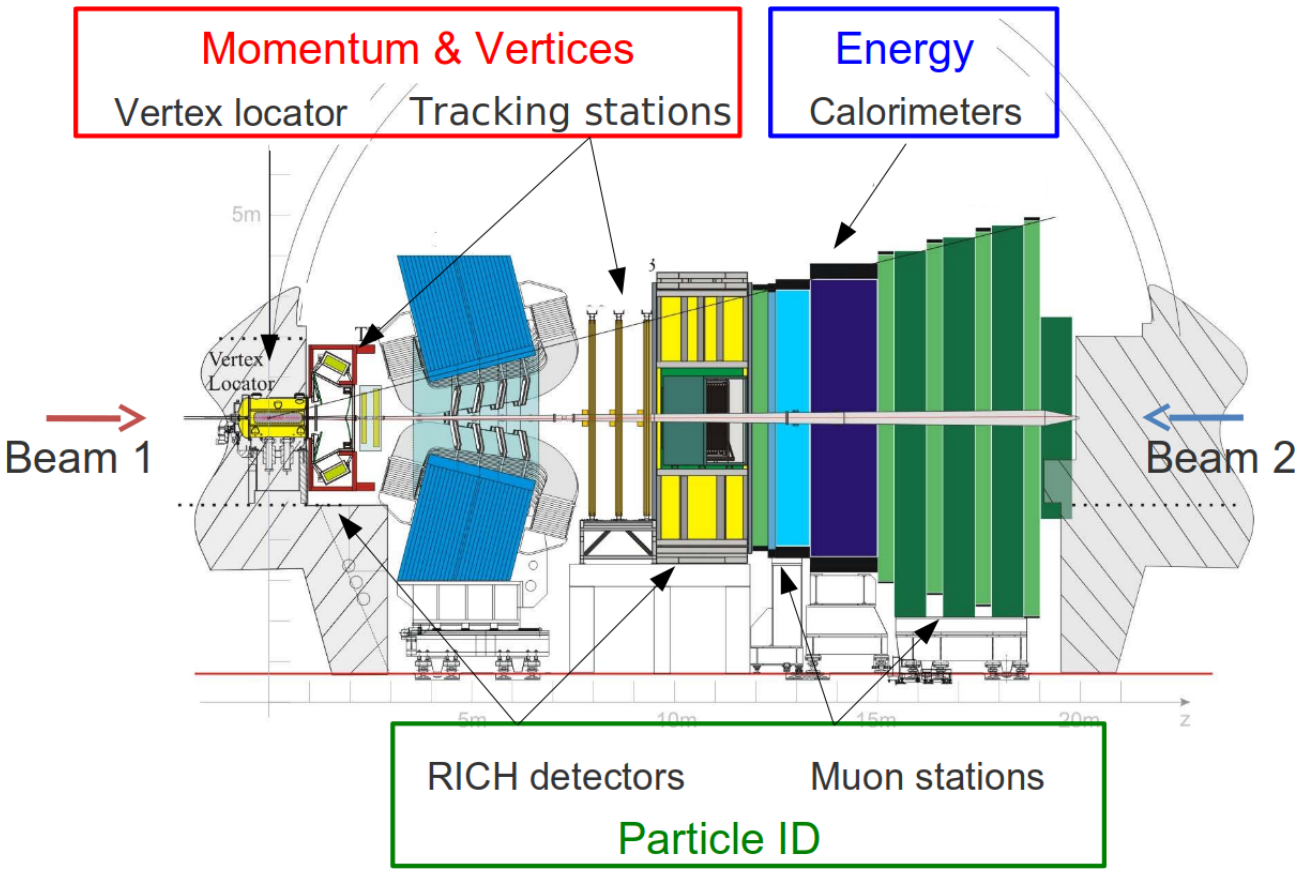
Int. J. Mod. Phys. A 30 (2015) 1530022
JINST 3 (2008) S08005

forward ($y > 0$):



backward ($y < 0$):

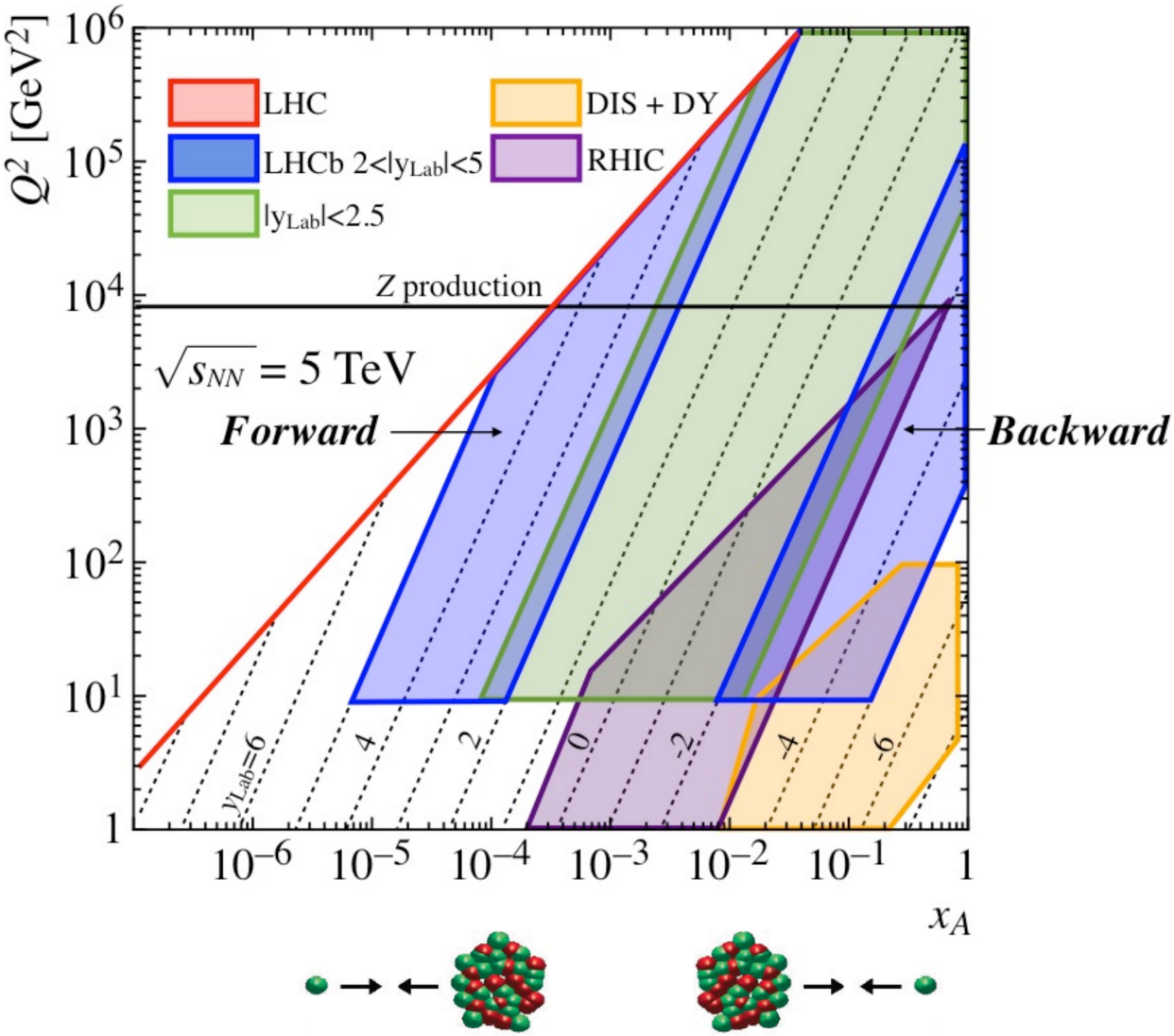




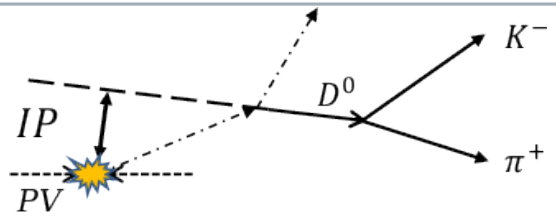
forward acceptance: $2 < y < 5$

Motivation

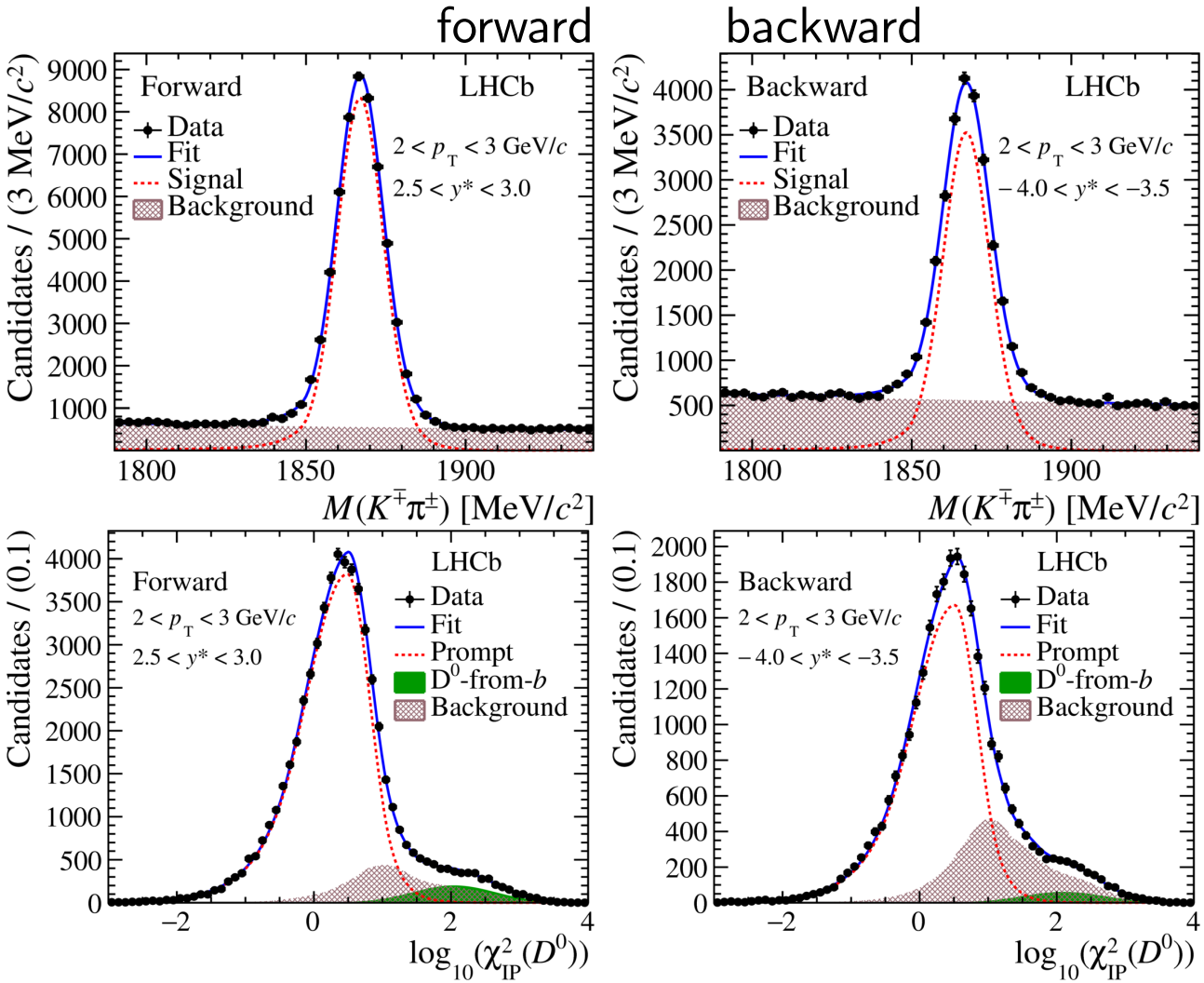
unique phase-space, down to low-x



Prompt D^0 production in proton-lead @ $\sqrt{s_{NN}} = 5$ TeV



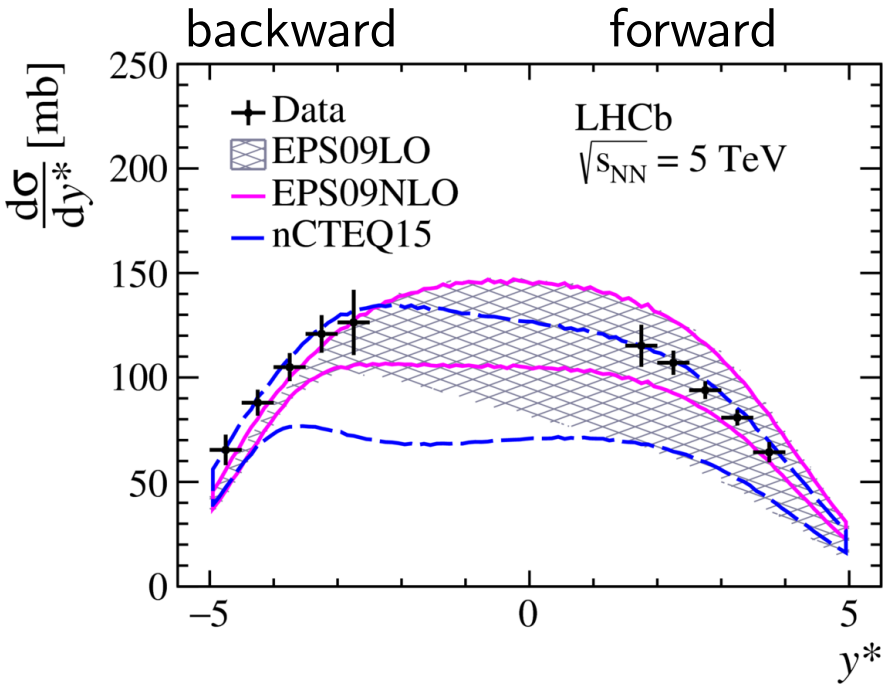
JHEP 10 (2017) 090

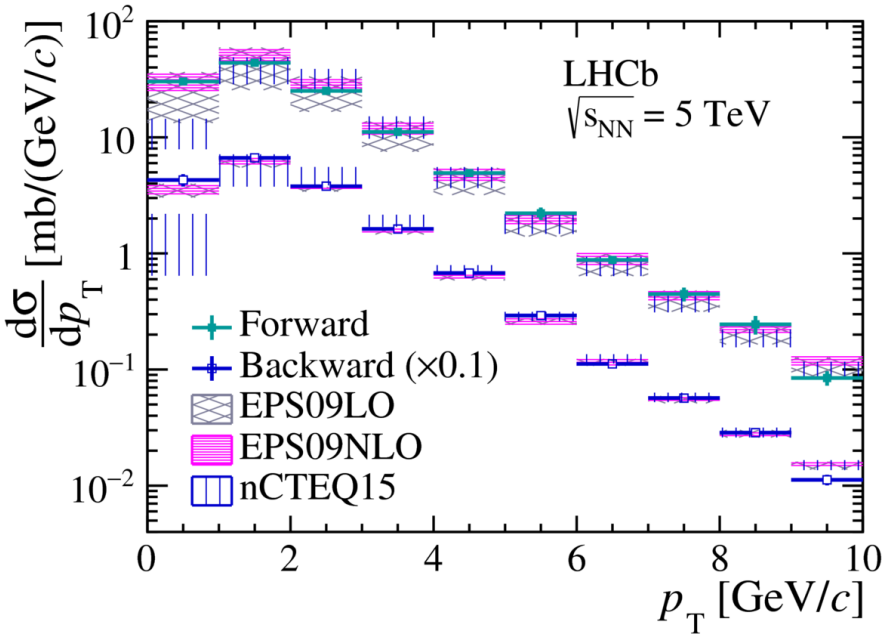


Prompt D^0 production in proton-lead @ $\sqrt{s_{NN}} = 5$ TeV

comparison to predictions

JHEP 10 (2017) 090





EPS09: [JHEP 04 (2009) 065, arXiv:0902.4154.]
nCTEQ15: [Phys. Rev. D93 (2016) 085037.]

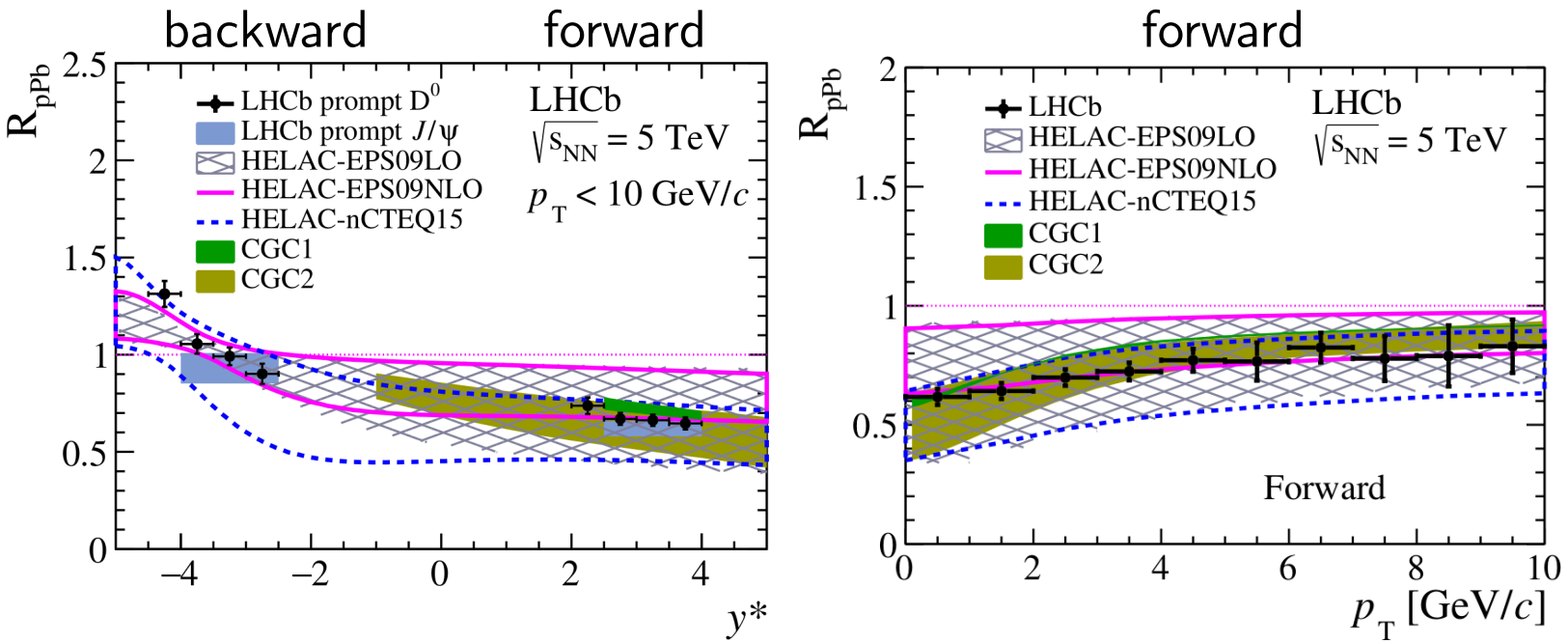
also measured double-differential cross-sections (see backup)

Prompt D^0: nuclear modification factor R_{pPb}

$$R_{\mathrm{pPb}} = \frac{1}{A} \cdot \frac{\sigma_{\mathrm{pPb}}}{\sigma_{\mathrm{pp}}}$$

JHEP 10 (2017) 090

σ_{pp} @ 5 TeV also measured by LHCb [JHEP 1706 (2017) 147]

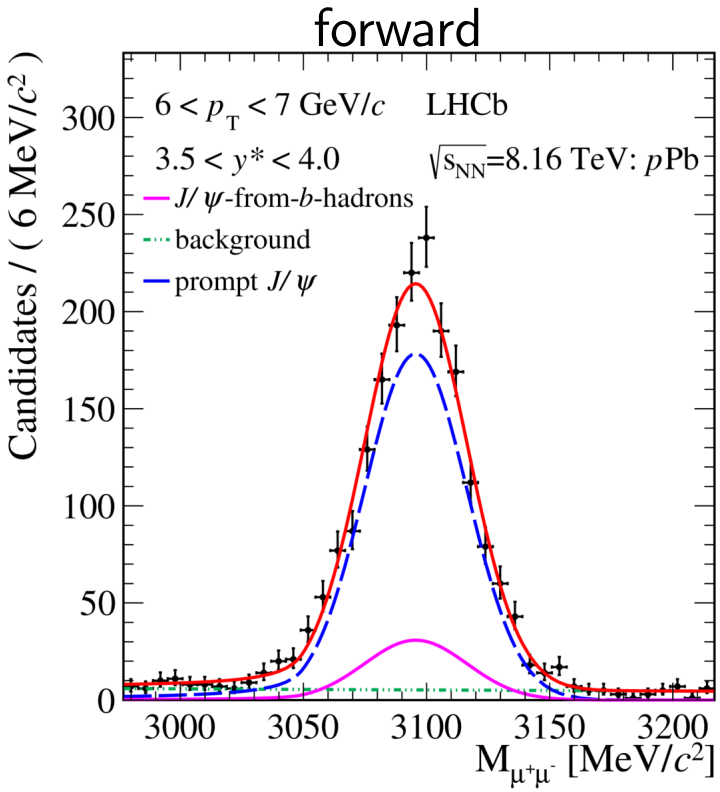


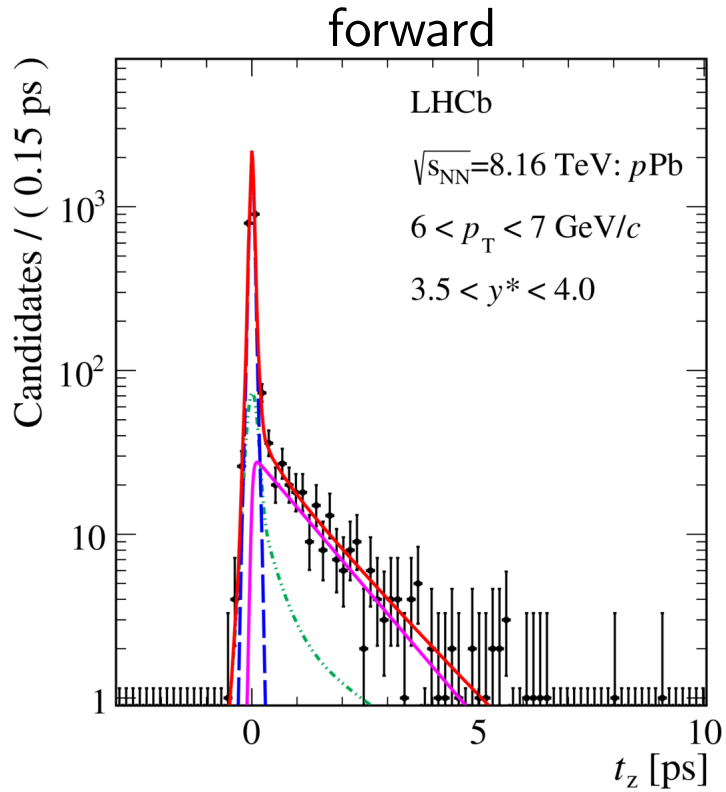
CGC1: [Phys. Rev. D 91 (2015) 114005]
CGC2: [arXiv:1706.06728]
EPS09: [JHEP 04 (2009) 065, arXiv:0902.4154.]
nCTEQ15: [Phys. Rev. D93 (2016) 085037.]

also measured R_{FB} (see backup)

J/Ψ production in proton-lead @ $\sqrt{s_{NN}} = 8.16$ TeV

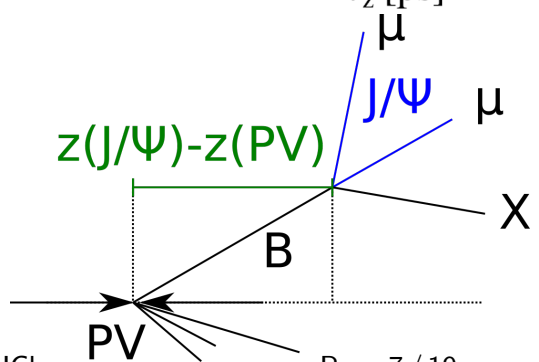
PLB 774 (2017) 159-178





separate prompt J/Ψ from J/Ψ from b-hadrons:

pseudo-proper time $t_z = \dfrac{\left(z_{J/\Psi} - z_{PV}\right) \cdot M_{J/\Psi}}{p_z}$



J/Ψ production in proton-lead @ $\sqrt{s_{NN}} = 8.16$ TeV

comparison to rescaled pp-results

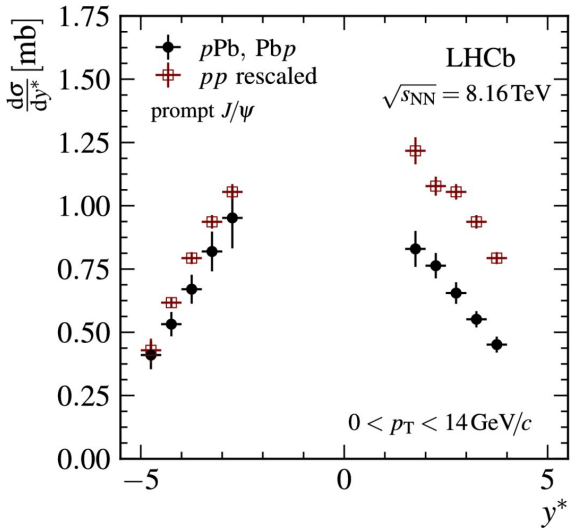
PLB 774 (2017) 159-178

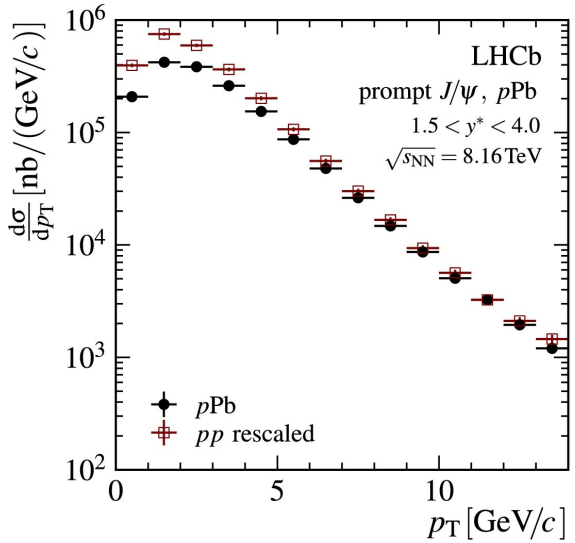
backward forward

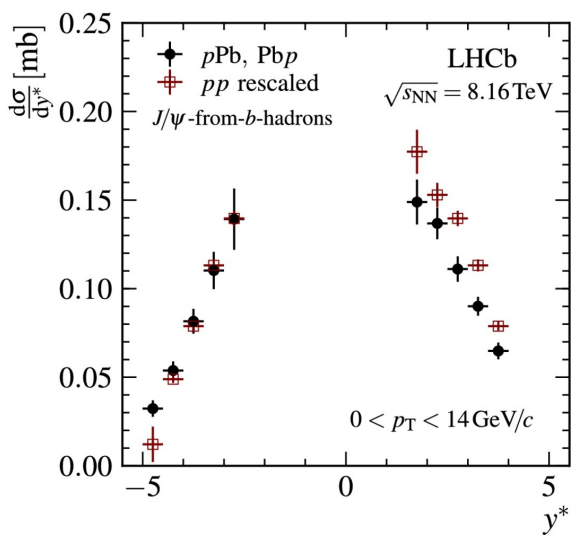
forward

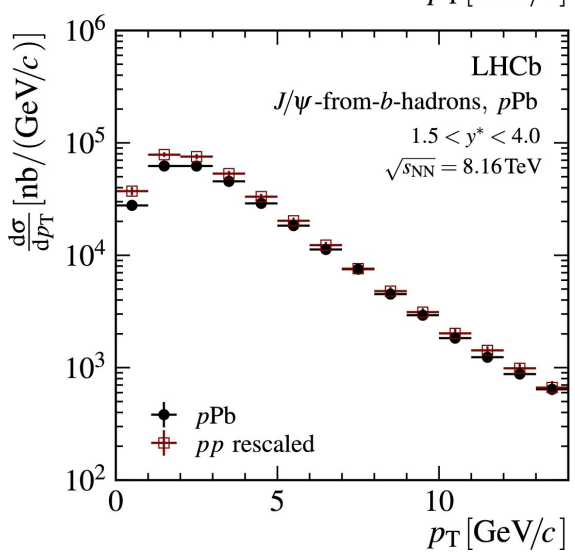
prompt J/Ψ:
suppression in forward region and at low p_T

J/Ψ from b:
suppression less strong





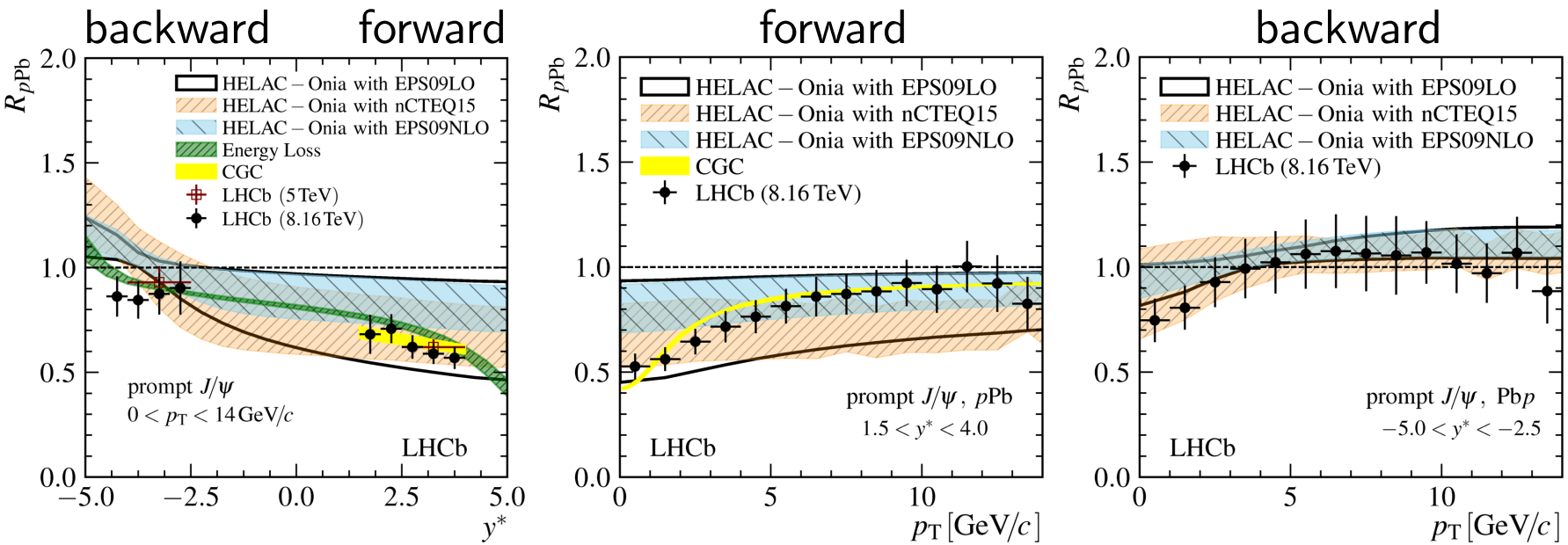




J/Ψ production in proton-lead @ $\sqrt{s_{NN}} = 8.16$ TeV

nuclear modification factor - prompt J/Ψ PLB 774 (2017) 159-178

$$R_{\mathrm{pPb}} = \frac{1}{A} \cdot \frac{\sigma_{\mathrm{pPb}}}{\sigma_{\mathrm{pp}}}$$



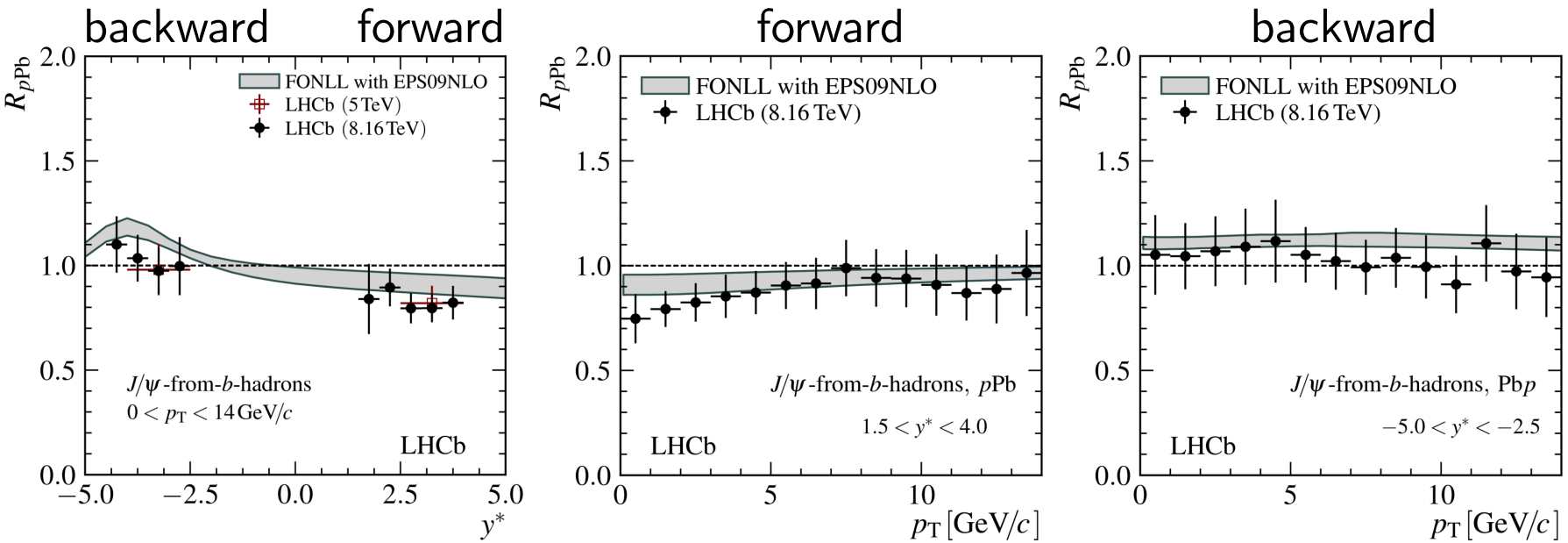
HELAC: [Eur. Phys. J. C77 (2017)1; CPC 184(2013) 2562, CPC198 (2016) 238.]
EPS09: [JHEP 04 (2009) 065, arXiv:0902.4154.]
nCTEQ15: [Phys. Rev. D93 (2016) 085037.]
Energy-Loss: [JHEP 03 (2013) 122, arXiv:1212.0434.]
CGC: [Phys. Rev. D91 (2015) 114005 28]

J/Ψ production in proton-lead @ $\sqrt{s_{NN}} = 8.16$ TeV

nuclear modification factor - from b

PLB 774 (2017) 159-178

$$R_{\mathrm{pPb}} = \frac{1}{A} \cdot \frac{\sigma_{\mathrm{pPb}}}{\sigma_{\mathrm{pp}}}$$



FONLL: [JHEP 05(1998) 007, JHEP03 (2001) 006]

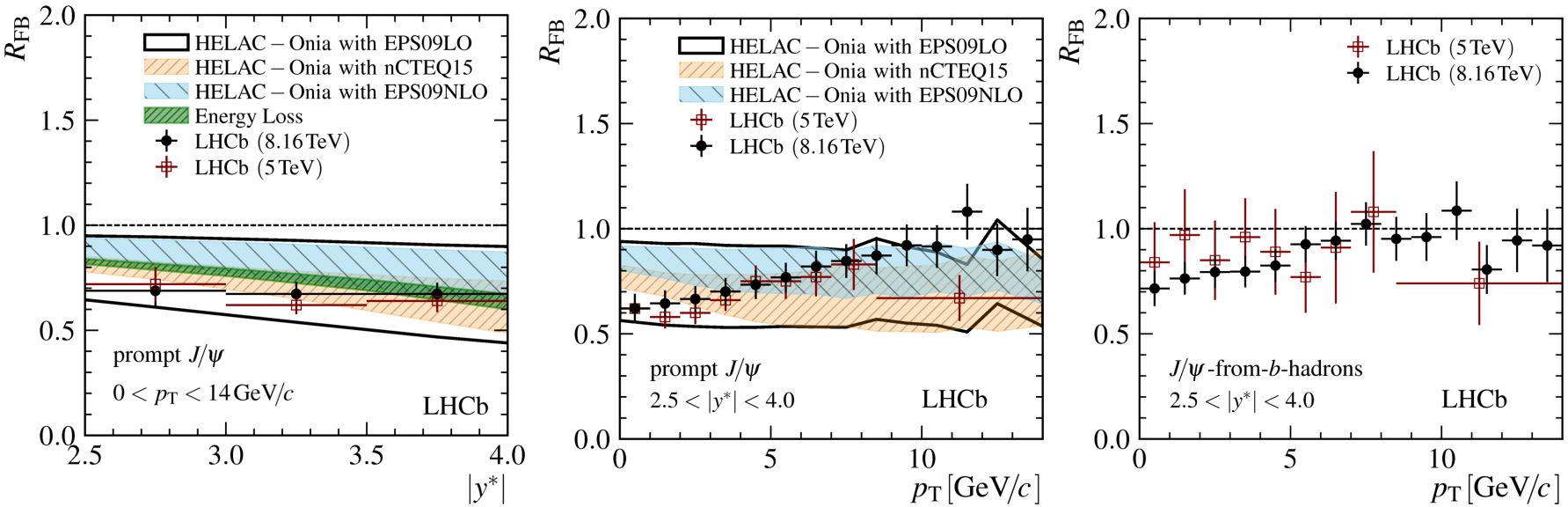
J/Ψ production in proton-lead @ $\sqrt{s_{NN}} = 8.16$ TeV

forward-backward ratio R_{FB}

PLB 774 (2017) 159-178

- no reference cross-section needed
- stronger suppression for prompt J/Ψ
- good agreement between 5 and 8 TeV

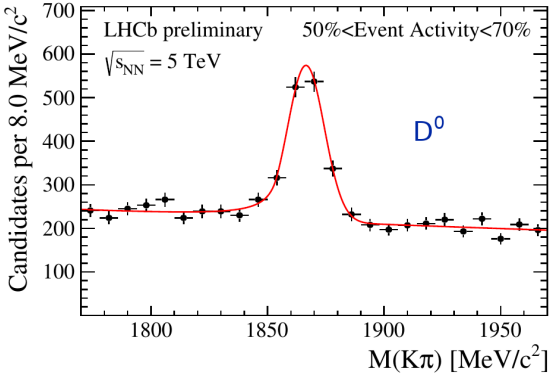
$$R_{FB} = \frac{\sigma_{\mathrm{pPb}}(\mathit{forward})}{\sigma_{\mathrm{pPb}}(\mathit{backward})}$$

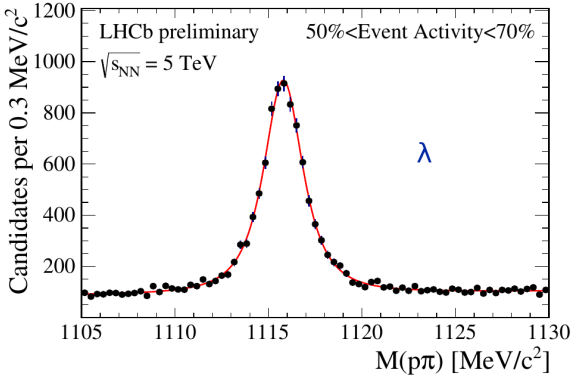


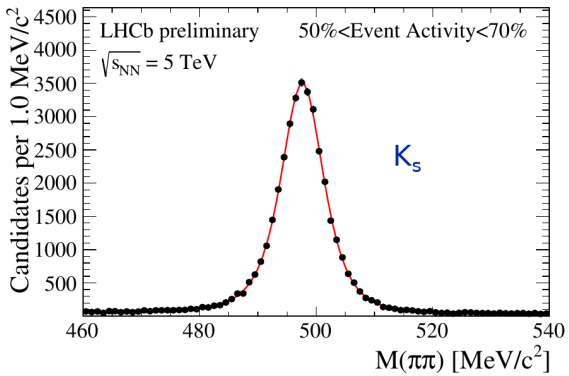
LHCb 5 TeV: [JHEP 02 (2014) 072]
HELAC: [Eur. Phys. J. C77 (2017)1; CPC 184(2013) 2562, CPC198 (2016) 238]
EPS09: [JHEP 04 (2009) 065, arXiv:0902.4154.]
nCTEQ15: [Phys. Rev. D93 (2016) 085037.]

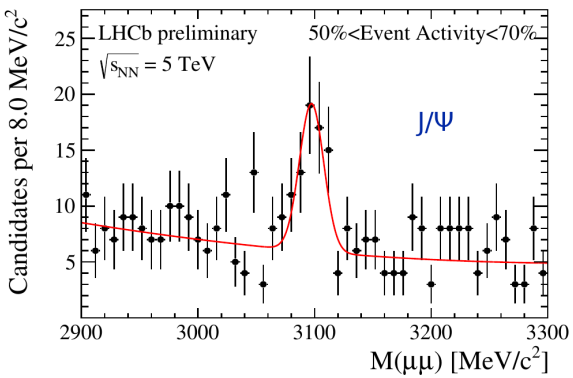
First signals in PbPb

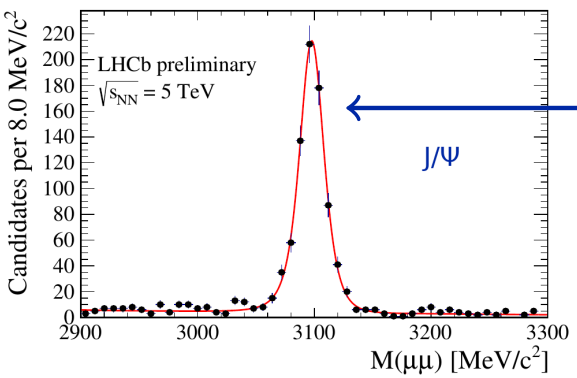
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015









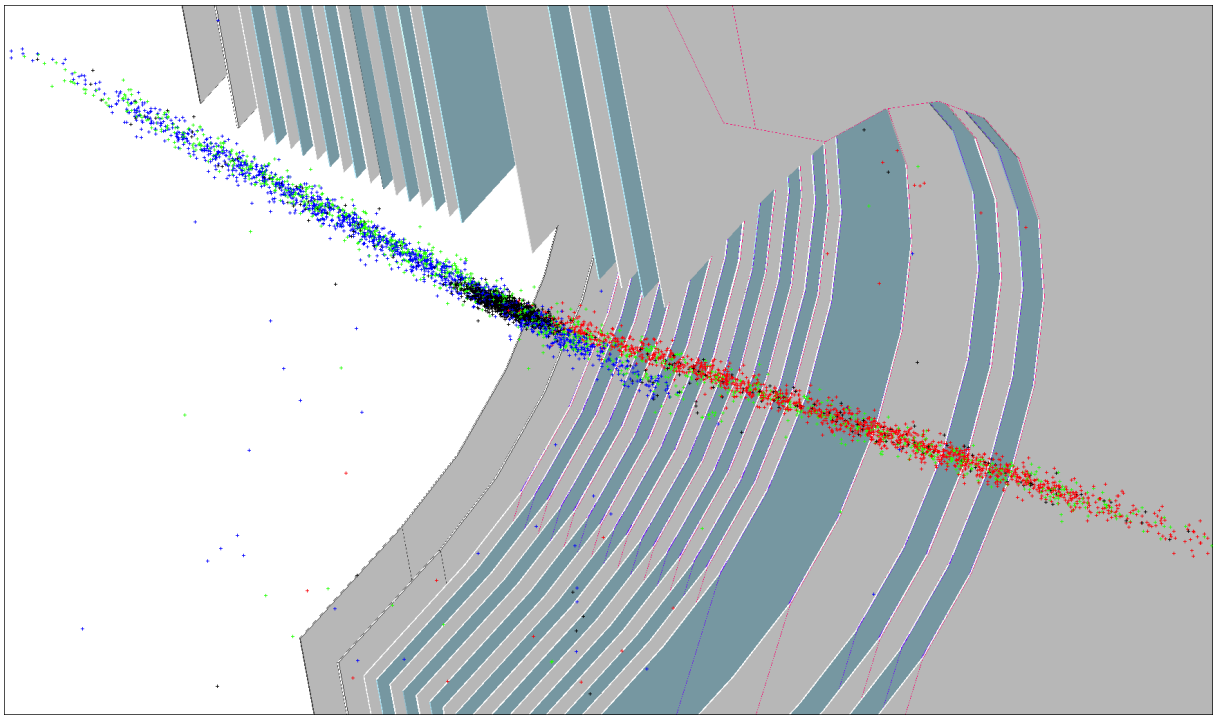


J/Ψ signal in ultra-peripheral collisions

- analyses ongoing
- clear signals, resolution similar to pp
- data-driven efficiency determinations challenging

Fixed target physics @ LHCb

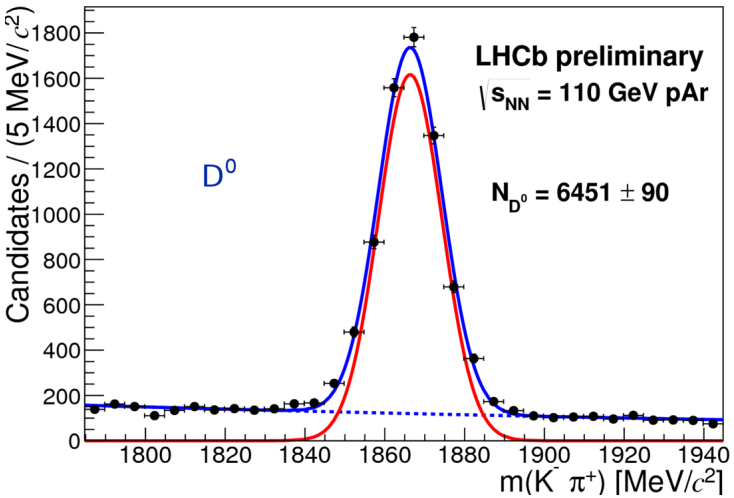
SMOG – System for Measuring Overlap with Gas

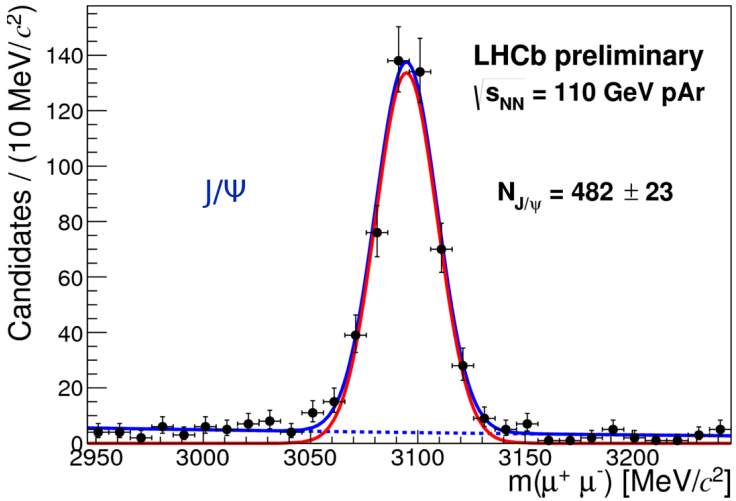


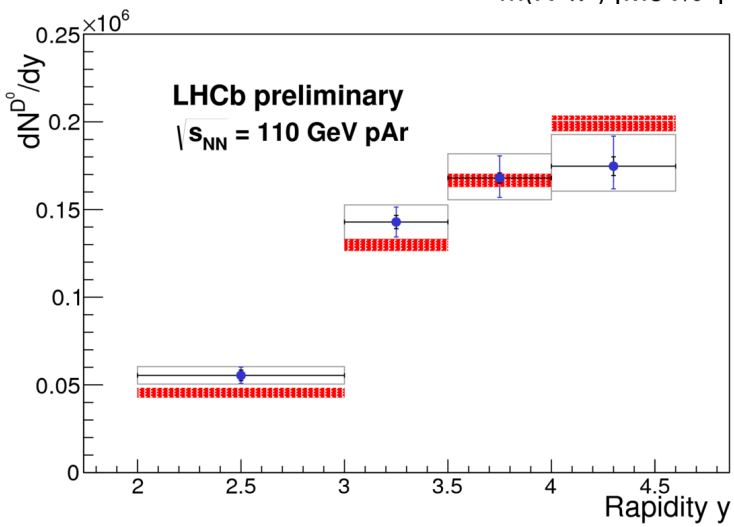
- injection of (nobel) gases: He, Ne, Ar in interaction region
- initially built for luminosity determination
- fixed target physics in pA and PbA configuration

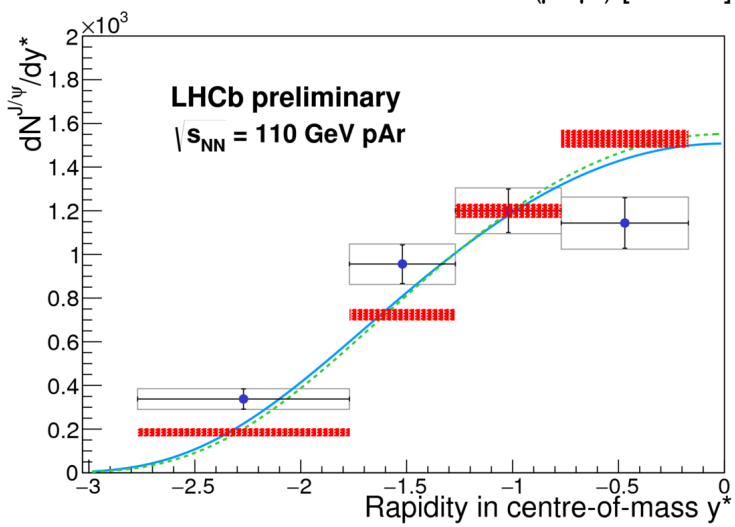
J/Ψ and D^0 in pAr @ $\sqrt{s_{NN}} = 110\,\text{GeV}$

LHCb-CONF-2017-001









PYTHIA using CT09MCS/NRQCD

F.Arleo et al. [JHEP(2013) 20113:122,JHEP(2013) 2013:155]

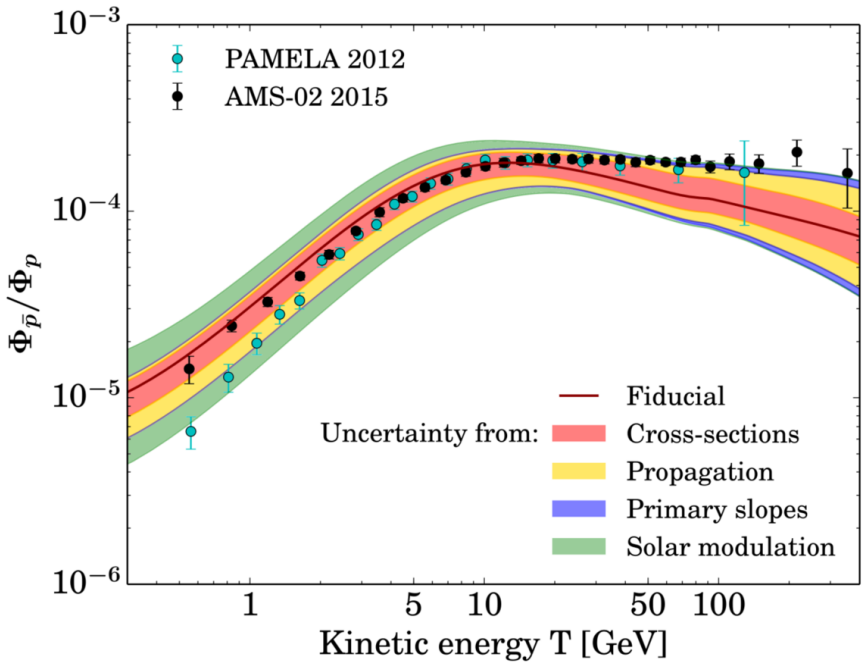
Anti-protons in pHe @ $\sqrt{s_{NN}} = 110\,\text{GeV}$

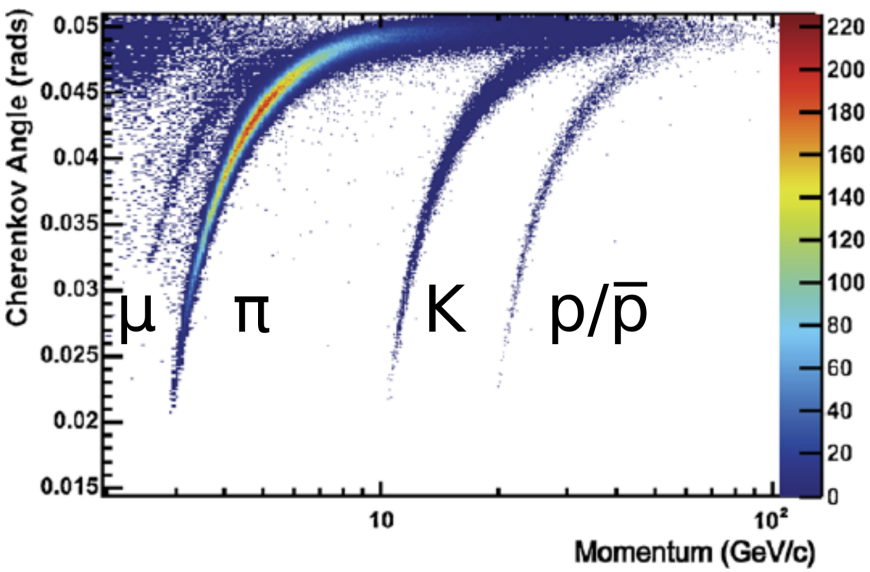
LHCb-CONF-2017-002

AMS02 [PRL117(2016)091103]
and Pamela [Nature458 (2009) 607-609]:
excess in $\overline{p}$ flux from cosmic rays
large uncertainties from $\overline{p}$ production

LHCb: SMOG with He

$\overline{p}$: $12 < p < 110\,\text{GeV}$, $p_T > 0.4\,\text{GeV}$





$\overline{p}$ identified in Cherenkov detectors

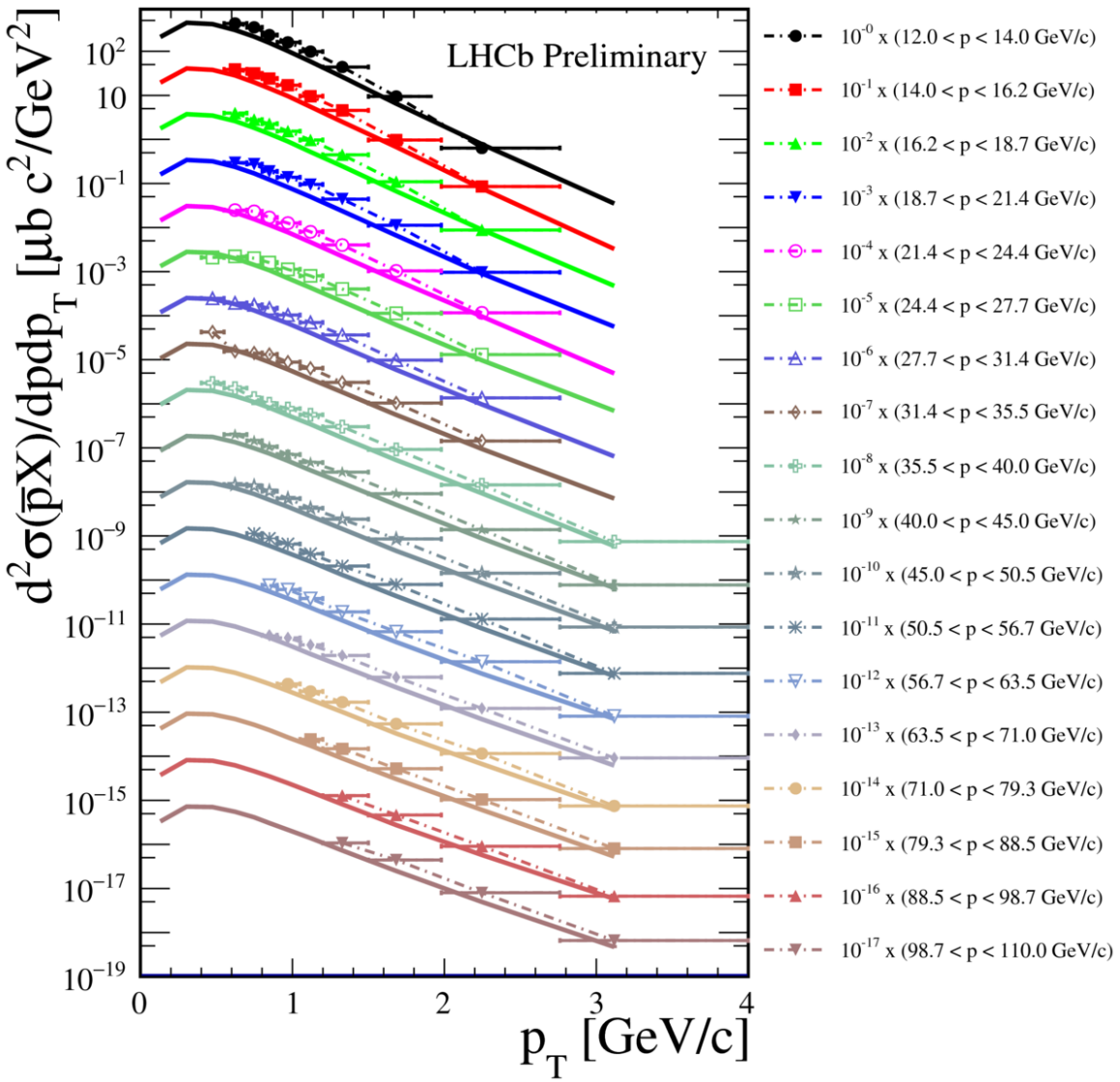
- luminosity depends on local gas density
- estimated using single electron events
- elastic pe scattering σ_{pe} well known
- He purity directly measured better than 1%

Prompt anti-protons in pHe @ $\sqrt{s_{NN}} = 110\,\text{GeV}$

LHCb-CONF-2017-002

$\sigma = (140 \pm 10)\,\text{mb}$
EPOS: 118 mb

EPOS: [Nucl. Phys. Proc. Suppl.196 (2009) 102, arXiv:0905.1198]



Prompt anti-protons in pHe @ $\sqrt{s_{NN}} = 110\,\text{GeV}$

comparison to models

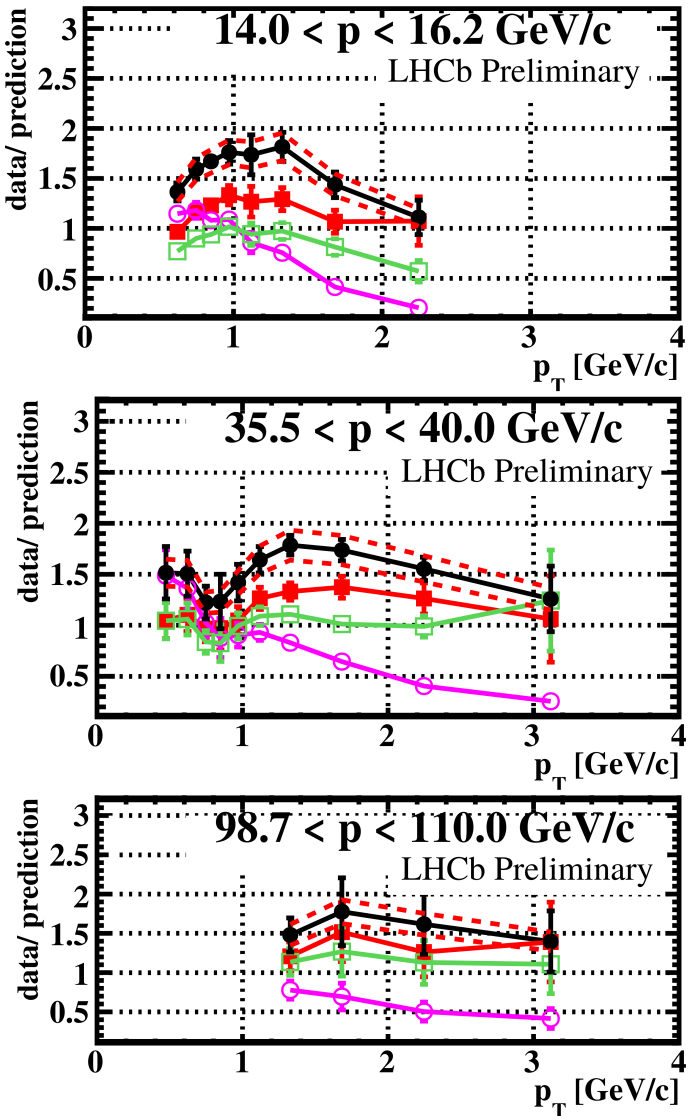
EPOS LHC
EPOS 1.99
HIJING 138
QGSJETII-04

EPOS: [Nucl. Phys. Proc. Suppl.196 (2009) 102, arXiv:0905.1198]

HIJING: [Comput. Phys Commun.83 (1994) 307, arXiv:nucl-th/9502021]

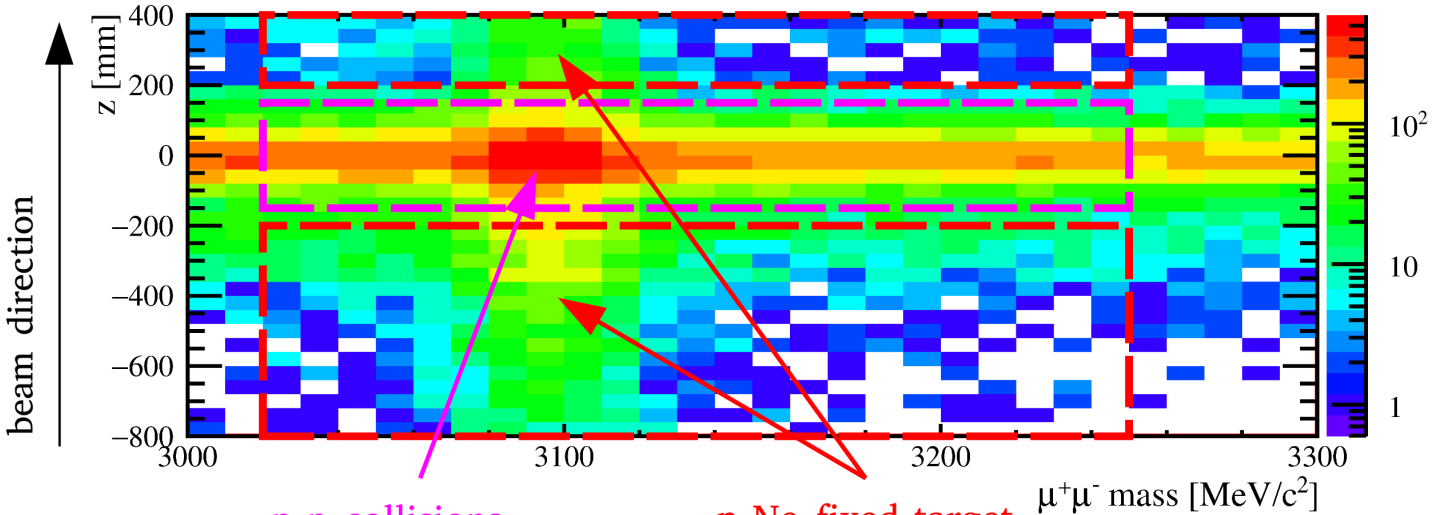
QGSJETII: [Phys. Rev.D83 (2011) 014018, arXiv:1010.1869]

LHCb-CONF-2017-002

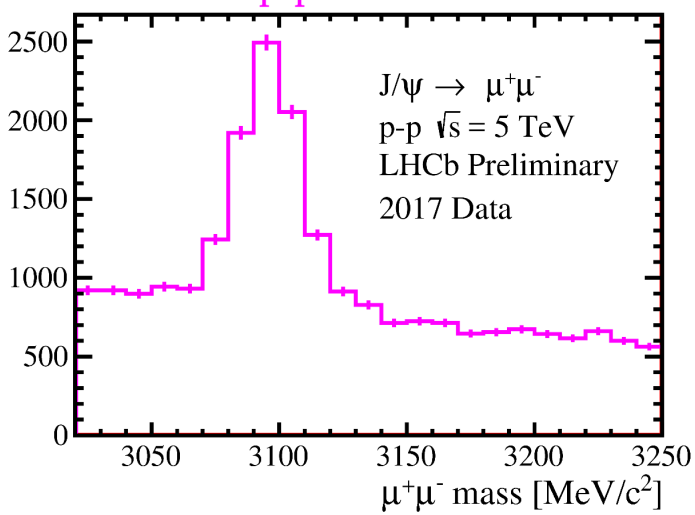


Outlook to J/Ψ in pNe @ $\sqrt{s_{NN}} = 68\,\text{GeV}$

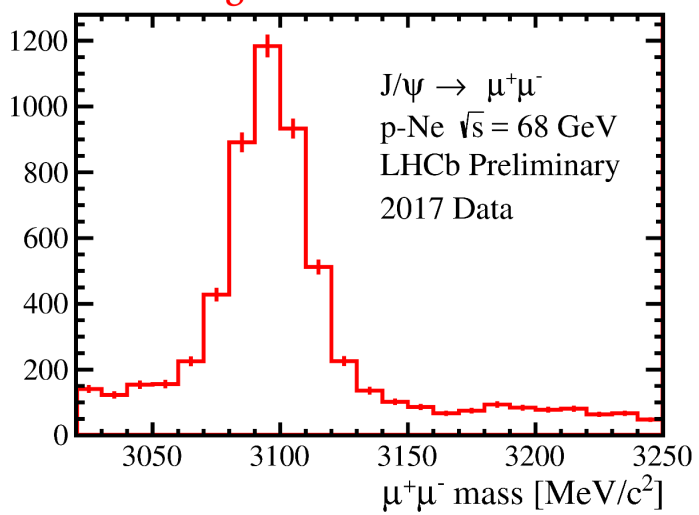
http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#End2017



p-p collisions



p-Ne fixed-target



simultaneous *pp* and *pNe* data collection

Conclusions

LHCb has an exciting heavy ion program

- proton-lead: LHCb took pPb data both in 2013 and 2016
  - 8 TeV: J/Ψ completed, many ongoing
  - 5 TeV: D^0, J/Ψ, $\psi(2S)$[1], λ_c^+[2], Υ[3] and Z[4] production completed
- lead-lead: LHCb collected PbPb collisions for the first time in 2015
  - no major problems with operation
  - preliminary results on the way
- fixed target physics: unique opportunity
  - SMOG system with different noble gases: Ar, He, Ne
  - bridge the gap from SPS to LHC physics with a single experiment

LHCb physics can cover pp, pA, and AA interactions with a rich program in heavy flavour, electroweak and soft QCD physics

1 [JHEP (2016) 03 133]
2 [LHCb-CONF-2017-005]
3 [JHEP 07 (2014) 094]
4 [JHEP 09 (2014) 030]

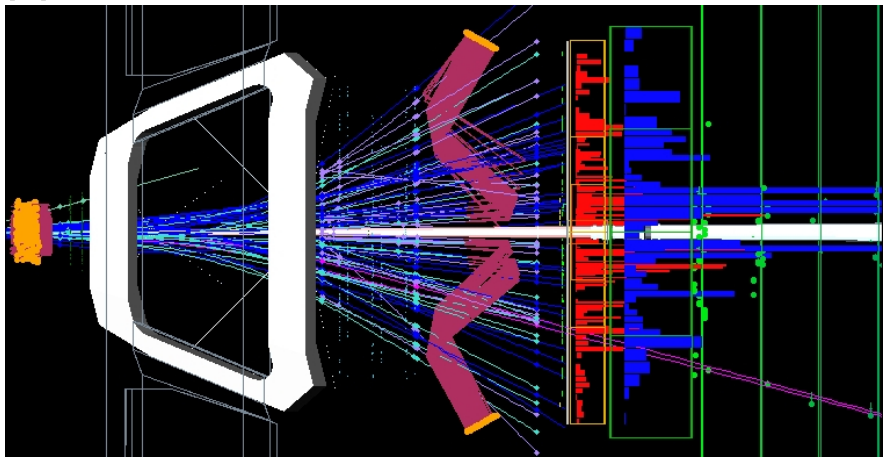
Appendix

LHCb detector specifications

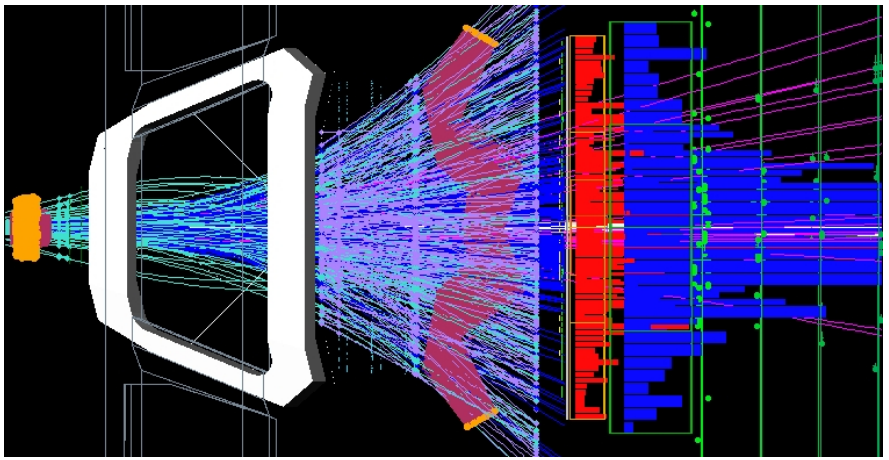
- single arm spectrometer – designed for precision measurements in b and c physics
- fully instrumented in the forward region ($2 < \eta < 5$)
- primary vertex resolution: $\sigma_{xy} \approx 15\,\mu$m, $\sigma_z \approx 80\,\mu$m
- tracking resolution: $\Delta p/p : 0.5 - 1\%$
- RICH: excellent $K/\pi/p$ separation: kaon ID $\varepsilon = 90\%$; π mis-id $< 5\%$

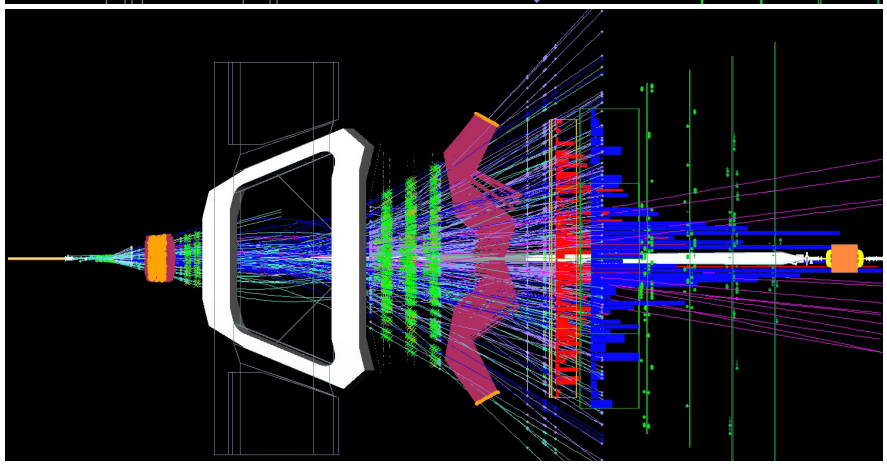
Multiplicities

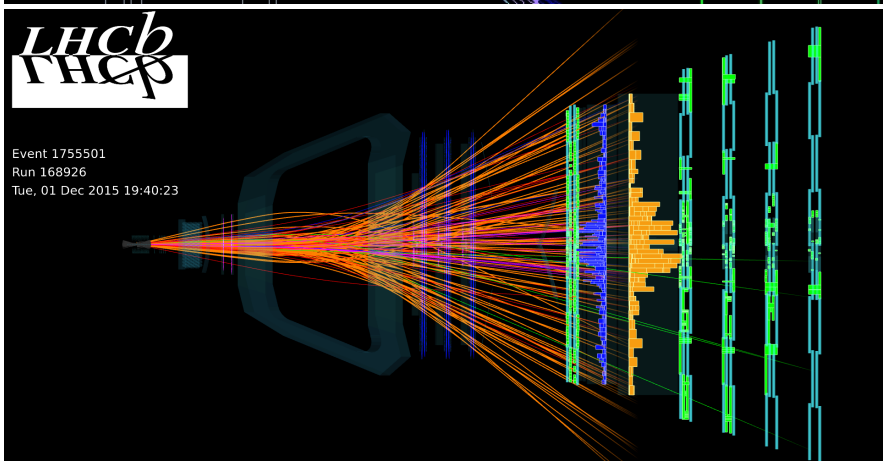
pp, 2012



PbAr, Simulation



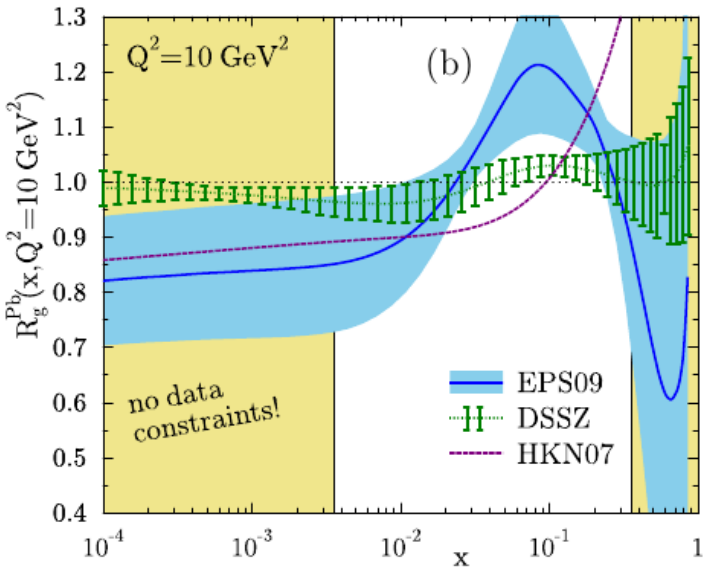


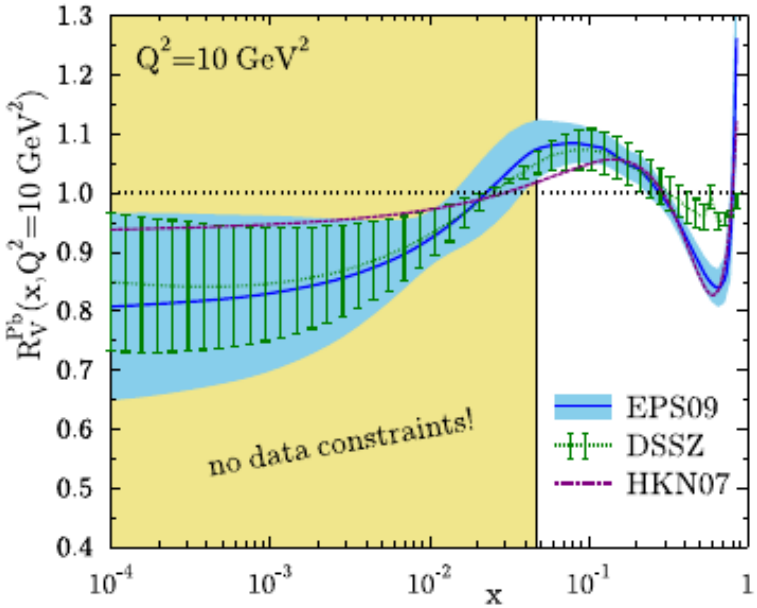


pPb, 2013

PbPb 2015

Current knowledge of nuclear PDFs (nPDF)





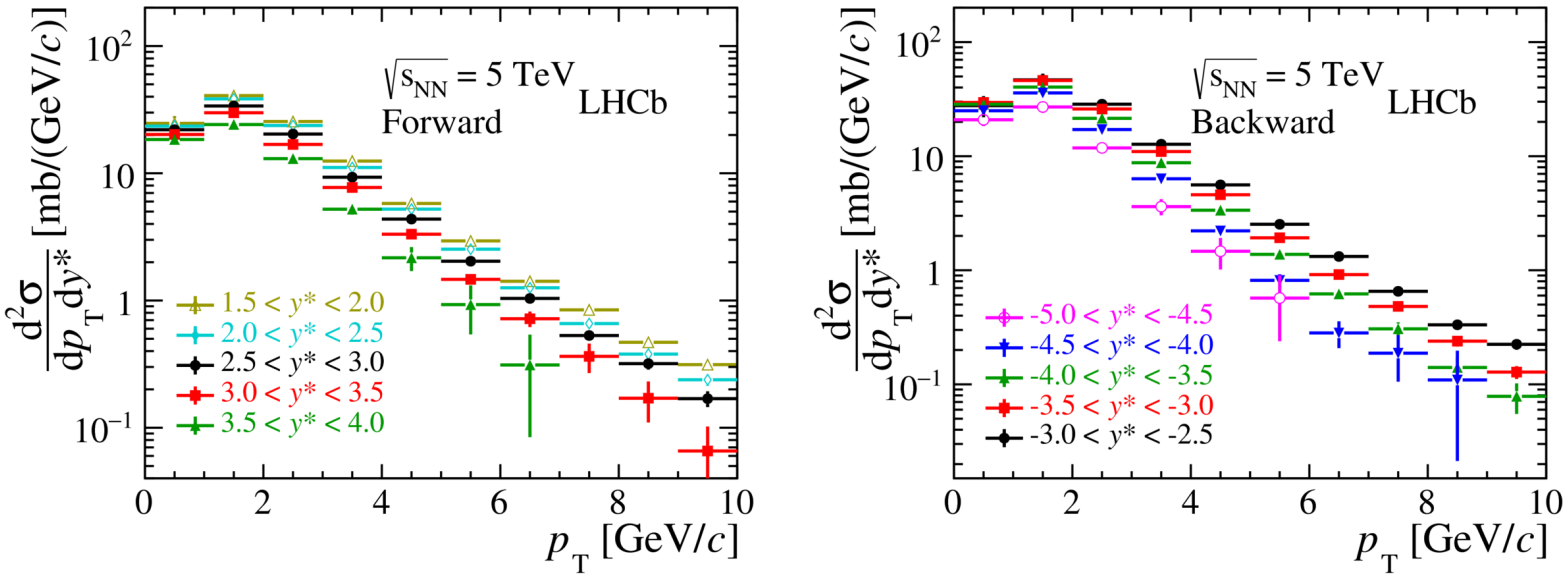
fixed target physics @ LHCb: x about 0.1

D^0 meson production in pPb @ 5 TeV

double-differential cross-section

arXiv: 1707.02750

unique measurement down to $p_T = 0$



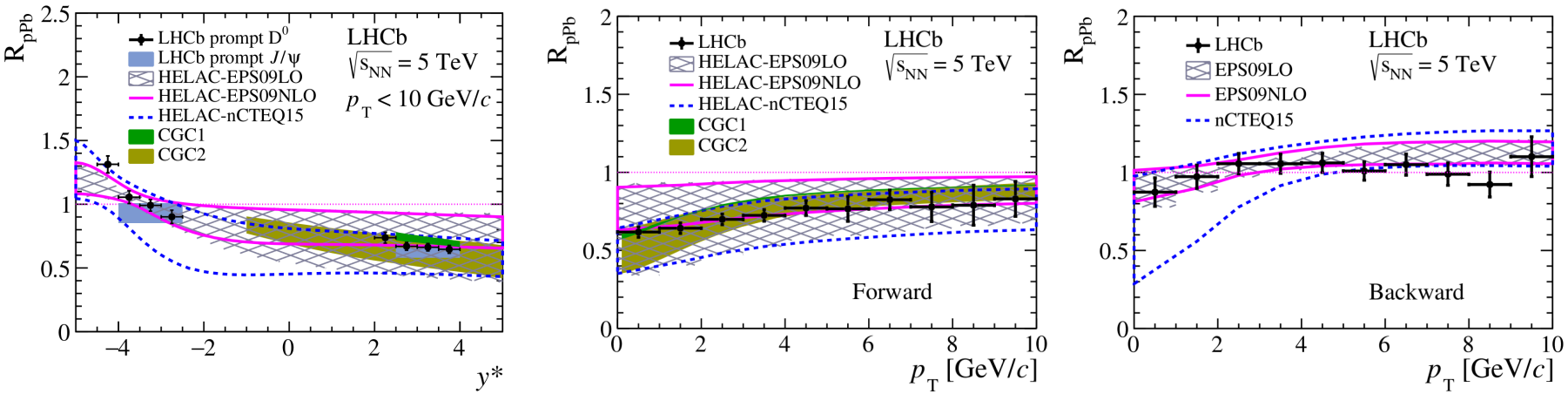
forward (left) and backward (right), $2 < p_T < 10$GeV

Prompt D^0: nuclear modification factor R_{pPb}

arXiv: 1707.02750
submitted to JHEP

$$R_{\mathrm{pPb}} = \frac{1}{A} \cdot \frac{\sigma_{\mathrm{pPb}}}{\sigma_{\mathrm{pp}}}$$

σ_{pp} @ 5 TeV also measured by LHCb [JHEP 1706 (2017) 147]



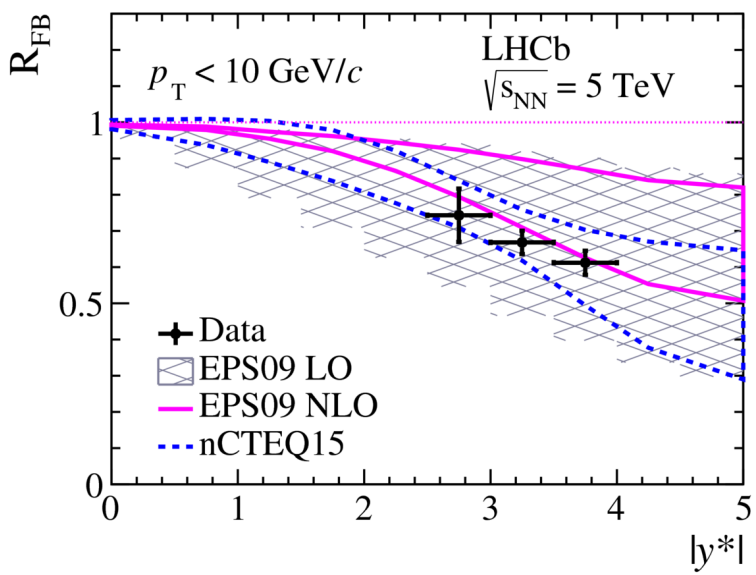
CGC: [Eur. Phys. J. C77 (2017) 1, CPC 184 (2013) 2562, CPC [198 (2016) 238]
EPS09 [JHEP 04 (2009) 065, arXiv:0902.4154.]
nCTEQ15 [Phys. Rev. D93 (2016) 085037.]

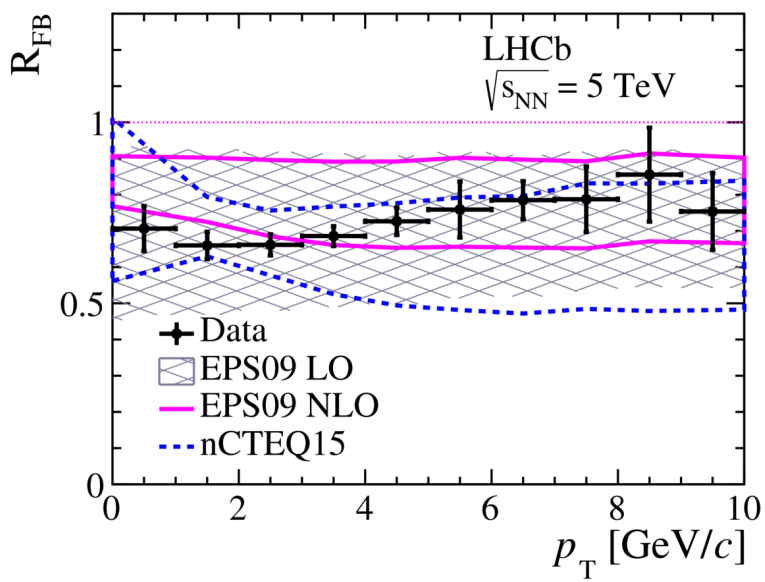
Also measured R_{FB} (see backup)

D^0: forward-backward ratio R_{FB}

arXiv: 1707.02750

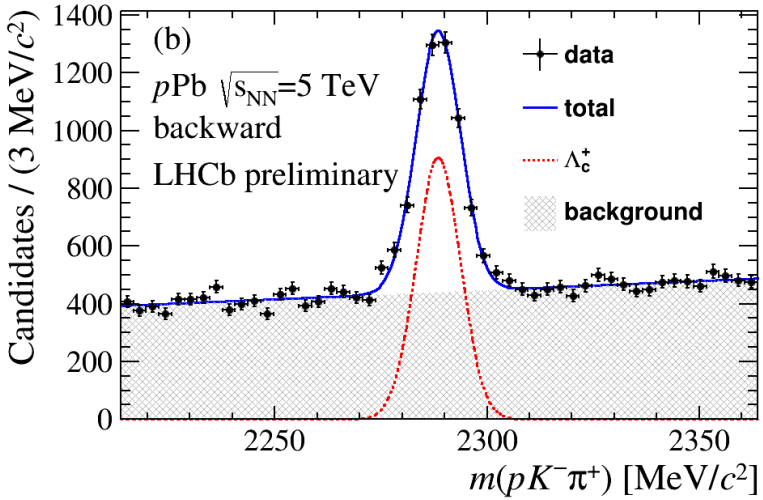
$$R_{FB} = \frac{\sigma_{pPb}(forward)}{\sigma_{pPb}(backward)}$$

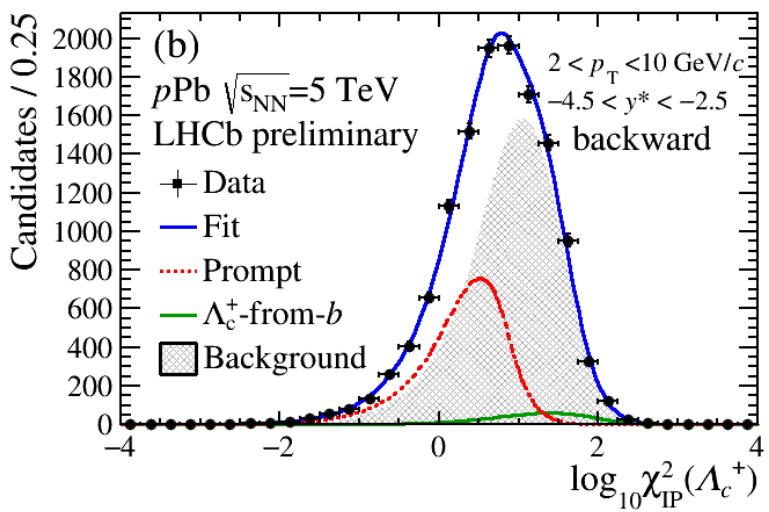




Prompt λ_c^+ in pPb @ 5 TeV

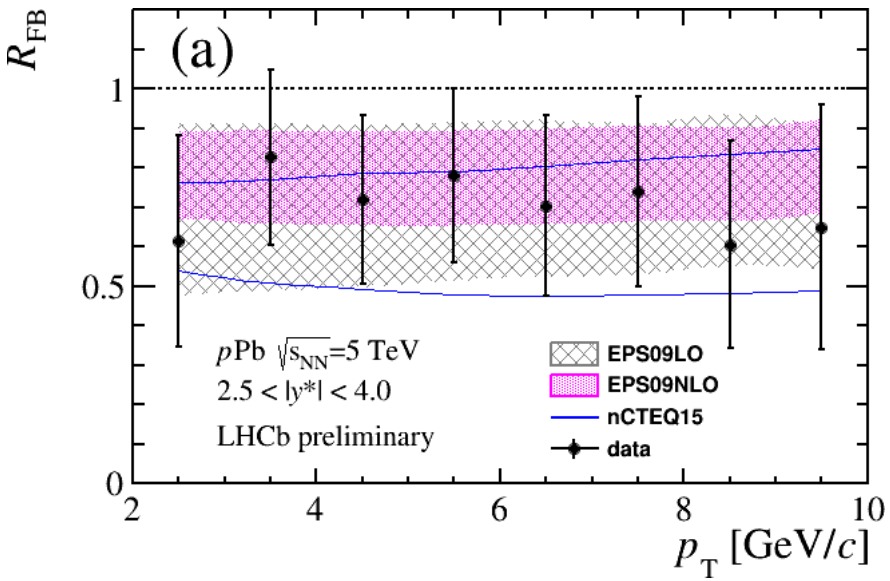
LHCb-CONF-2017-005

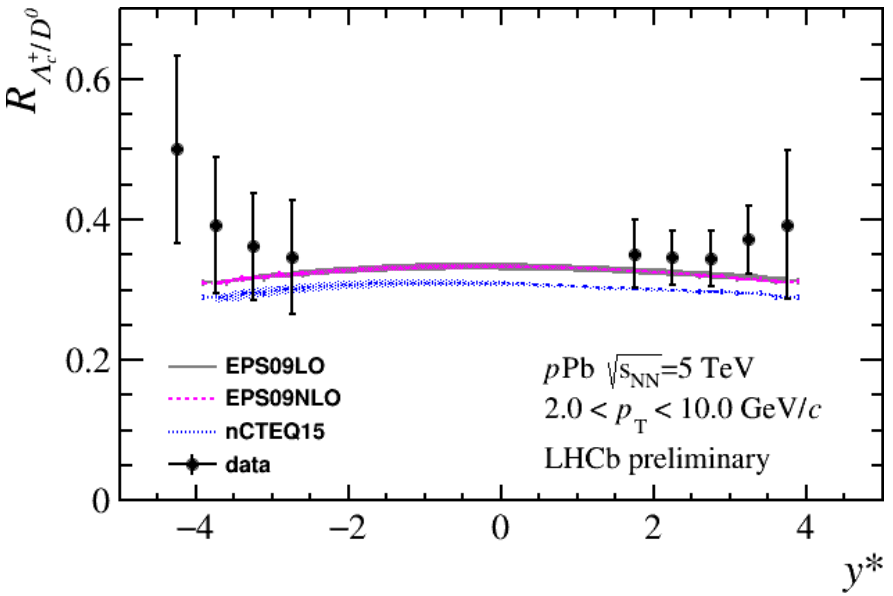




Prompt λ_c^+ in pPb @ 5 TeV

LHCb-CONF-2017-005

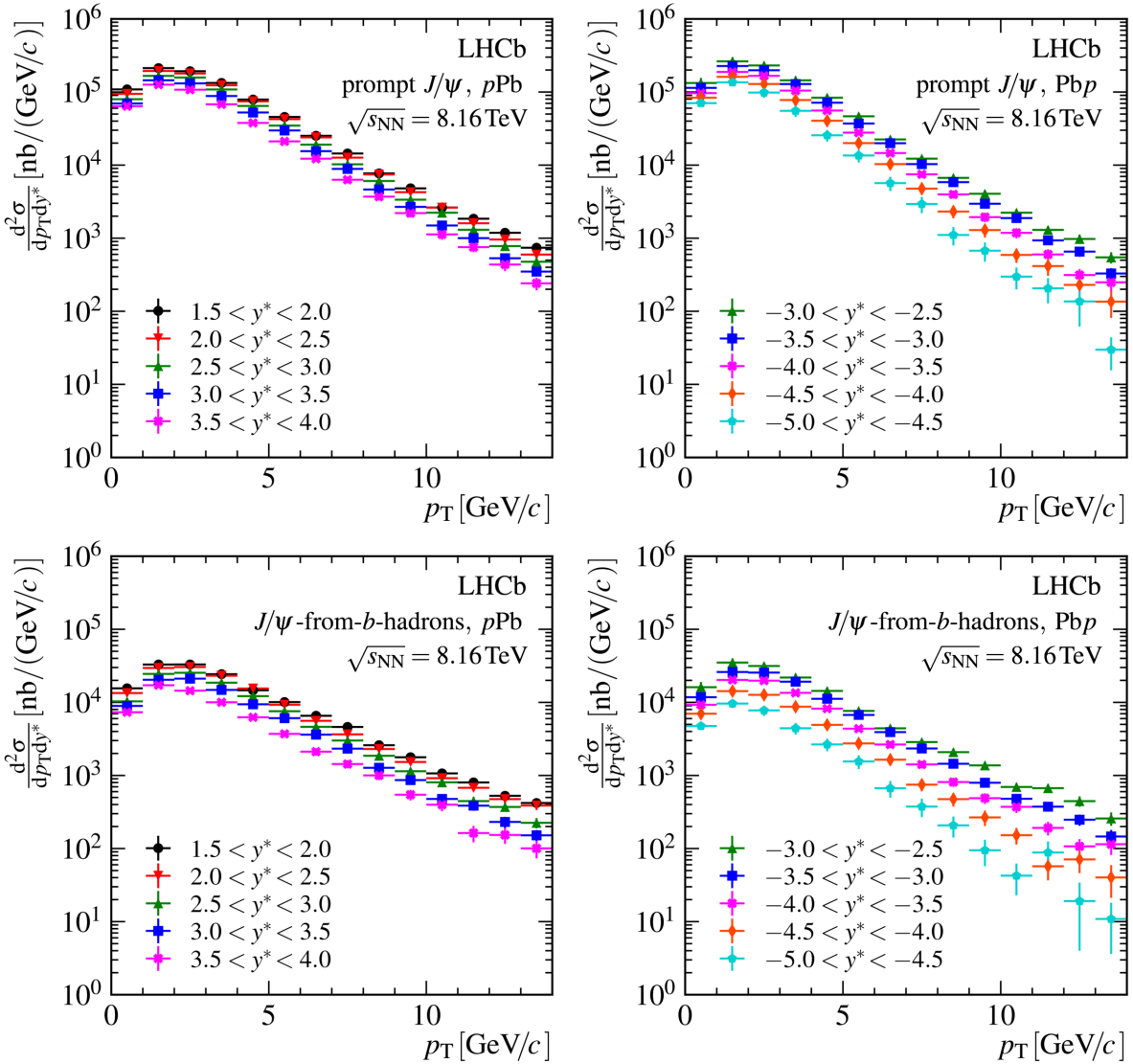




J/ψ in proton-lead @ 8.16 TeV

double-differential measurement

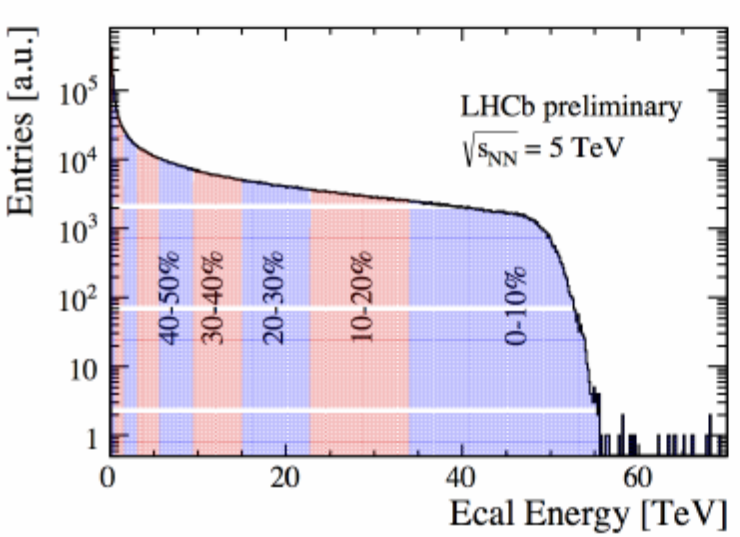
arXiv: 1706.07122

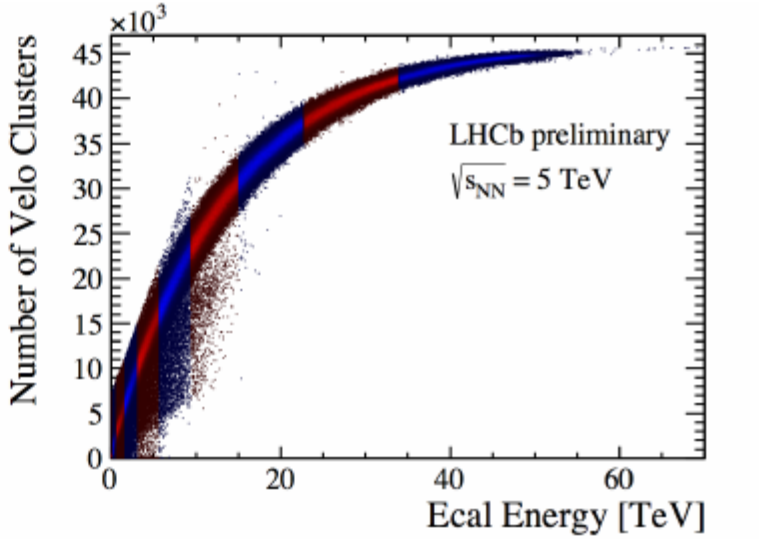


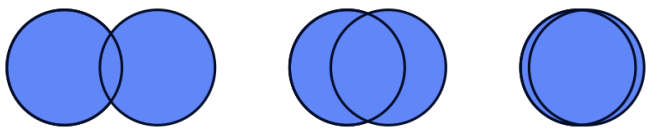
Centrality determination

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

- crucial for physics measurement
- energy deposition in electromagnetic calorimeter and VELO clusters
- PbPb studies ongoing, still gaining experience with large multiplicities
- current tracking algorithm: 50% centrality reach

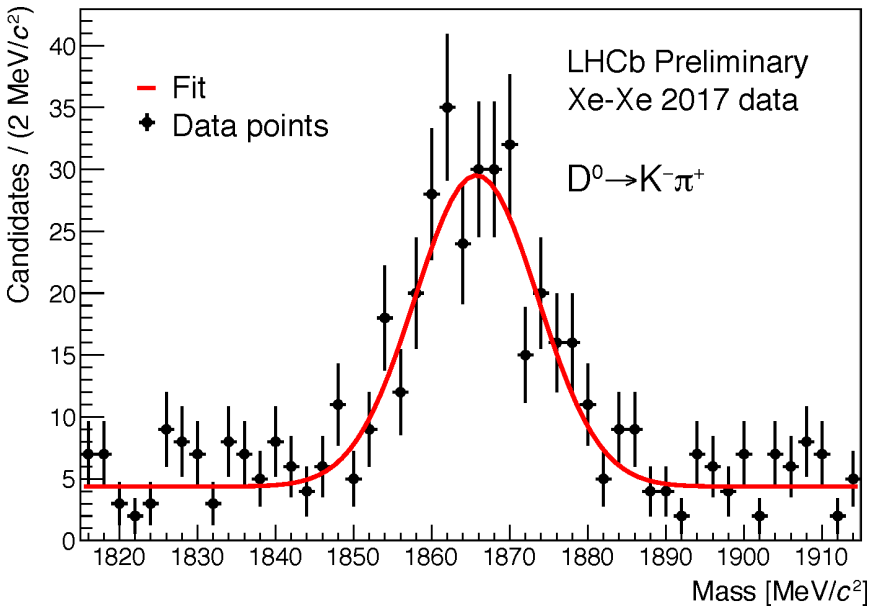


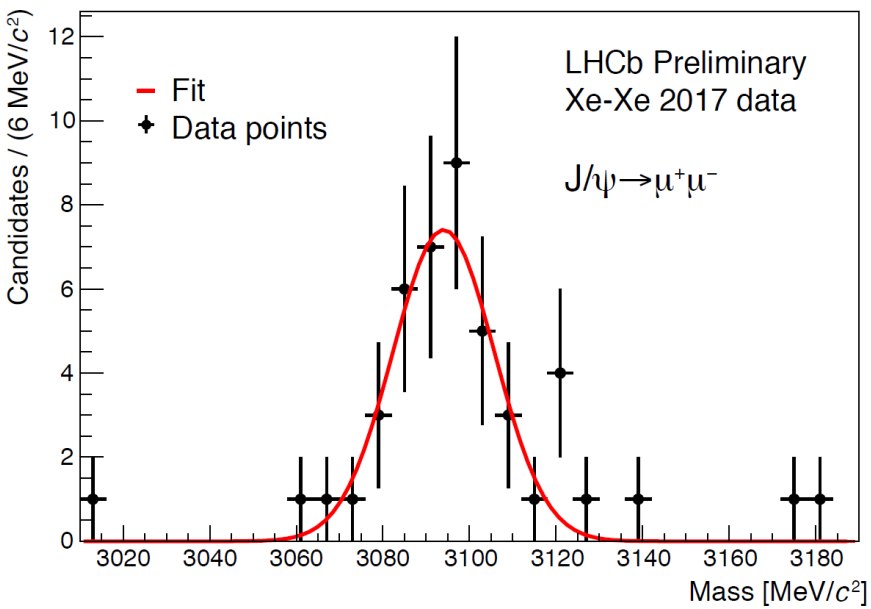




D^0 and J/Ψ production in xenon-xenon @ $\sqrt{s} = 5.44$ TeV

http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#Xenon





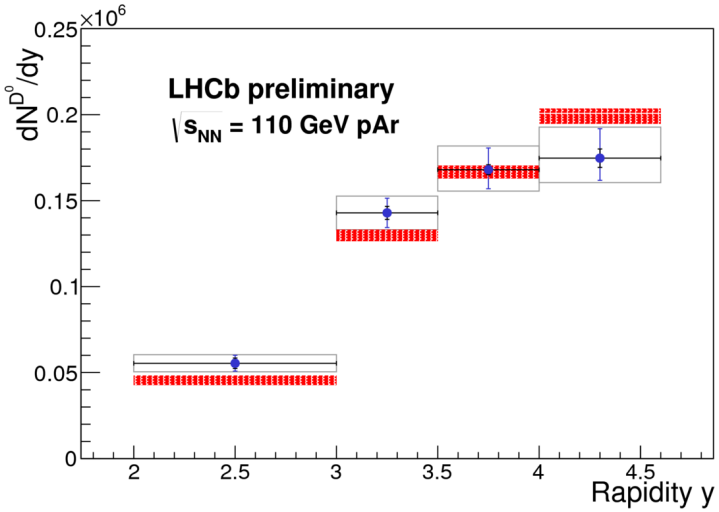
One day LHC run with XeXe.

J/ψ and D^0 in pAr @ 110 GeV

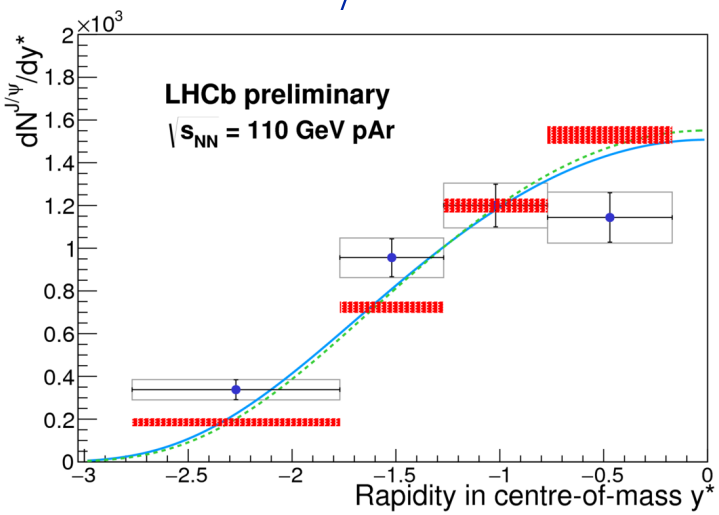
LHCb-CONF-2017-001

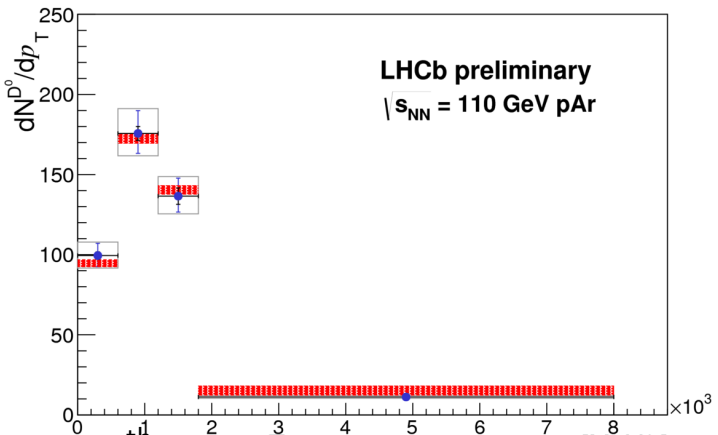
reasonable description by PYTHIA using CT09MCS/NRQCD
and predictions from F.Arleo et al. [JHEP(2013) 20113:122, JHEP(2013) 2013:155]

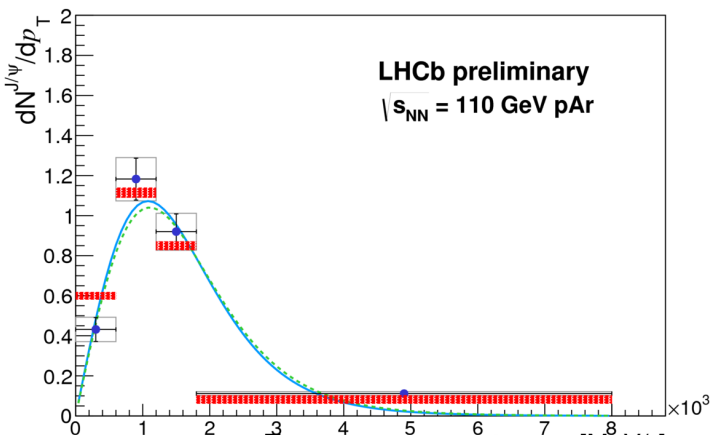
D^0



J/ψ







Anti-protons in pHe @ 110 GeV

Luminosity determination

- luminosity depends on local gas density
- estimated using single electron events
- elastic pe scattering σ_{pe} well known
- He purity directly measured better than 1%

write more