Heavy ion physics at LHCb

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On behalf of the LHCb collaboration

The 21st Particles & Nuclei International Conference

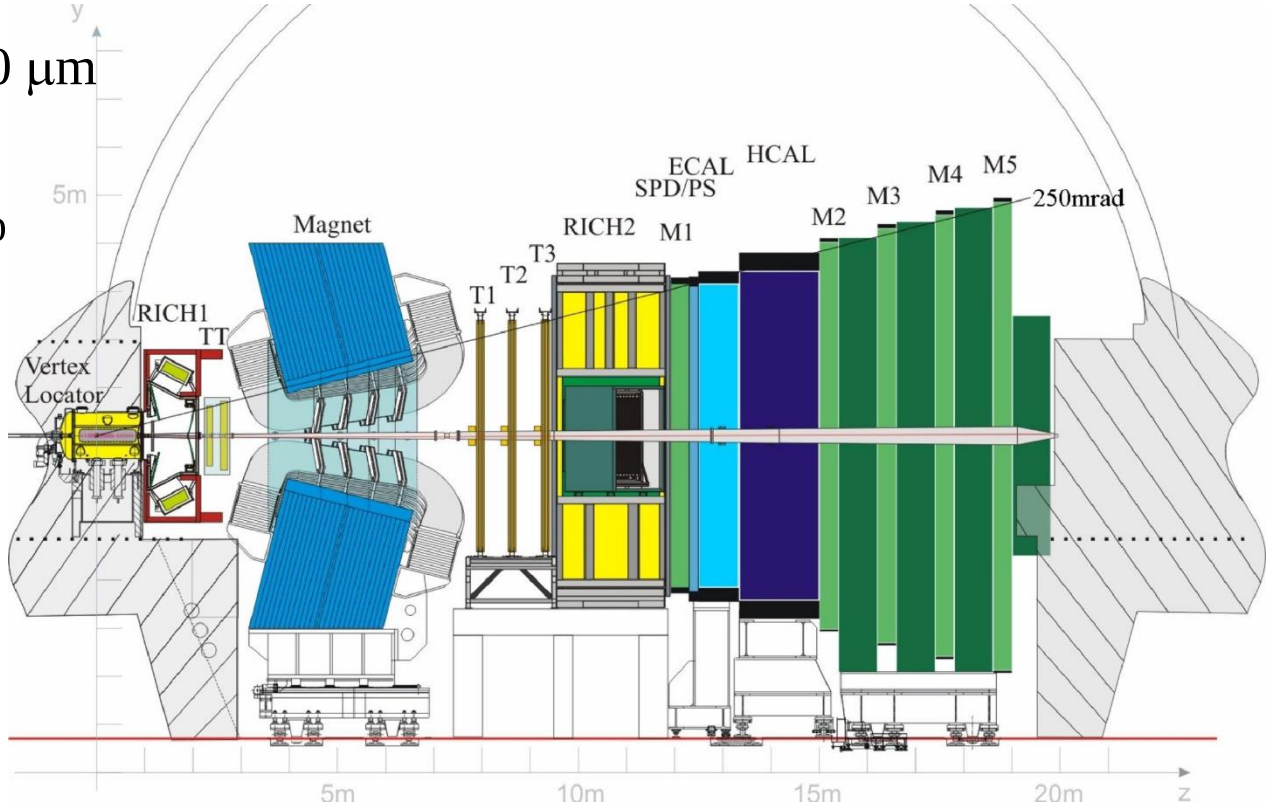
1-5 September 2017, IHEP, Beijing, China

Outline

- LHCb detector
- pPb collisions: recent results
  - Open heavy flavor results
  - Hidden heavy flavor results
- PbPb collisions: work in progress
- Fixed target: first results
  - Heavy flavor in pAr
  - Antiproton in pHe

LHCb detector

- A single arm forward spectrometer designed for the study of particles containing *c* or *b* quark.
- Acceptance: $2 < \eta < 5$
- Vertex detector
  - IP resolution ~ 20 μm
- Tracking system
  - $\frac{\Delta p}{p} = 0.5\% - 1\%$ (5-200 GeV/*c*)
- RICH
  - K/π/p separation
- Electromagnetic + hadronic Calorimeters
- Muon systems

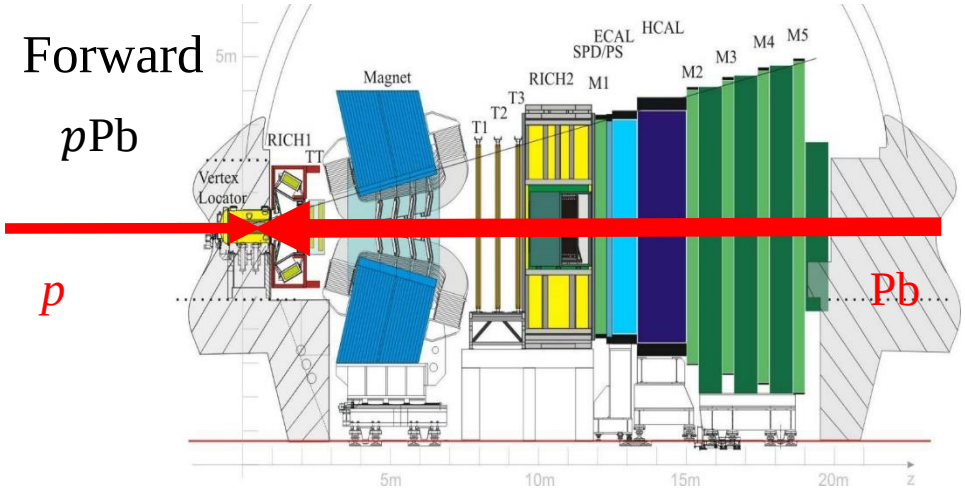


JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

pPb datasets and recent results

Forward

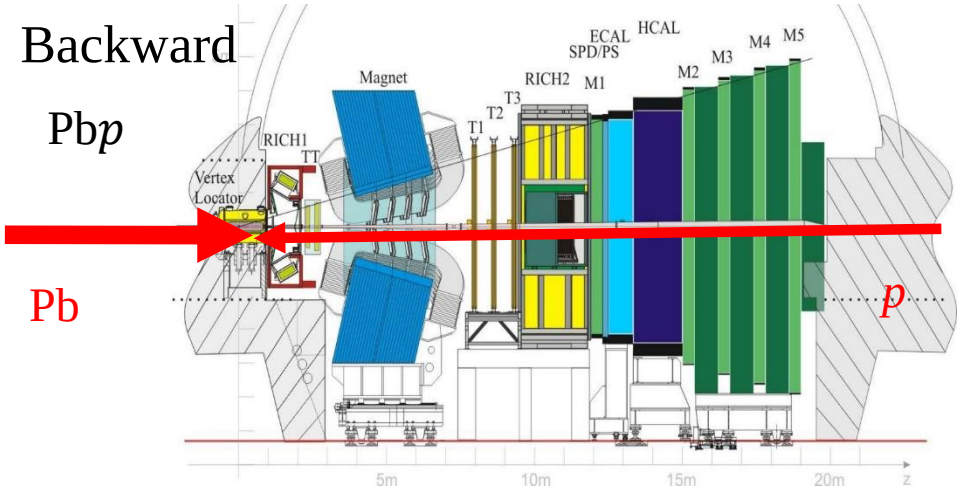
pPb



p Pb

Backward

Pbp

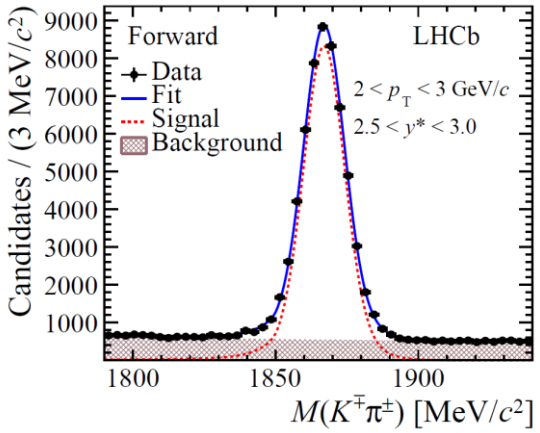


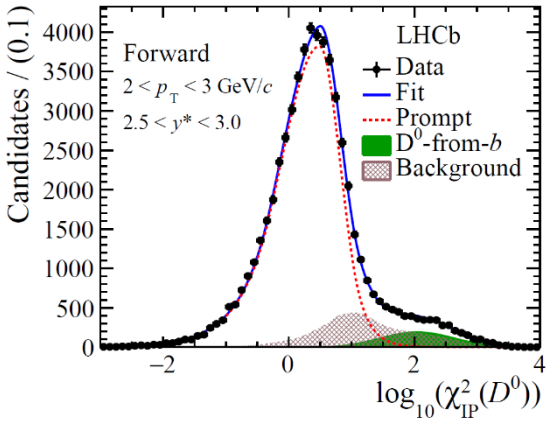
Pb p

- Rapidity Coverage
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{cms} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$
- $\sqrt{s_{NN}} = 5$ TeV (2013)
  - pPb (1.06 nb^{-1}) + Pbp (0.52 nb^{-1})
  - Open heavy flavor D^0 and Λ_c^+
  - Collectivity
- $\sqrt{s_{NN}} = 8$ TeV (2016)
  - pPb (13.6 nb^{-1}) + Pbp (21.8 nb^{-1})
  - Hidden heavy flavor J/ψ

Prompt D^0 measurement in pPb at 5TeV

Forward ↓





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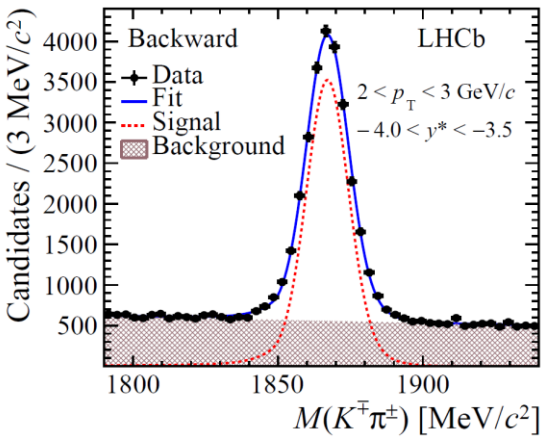
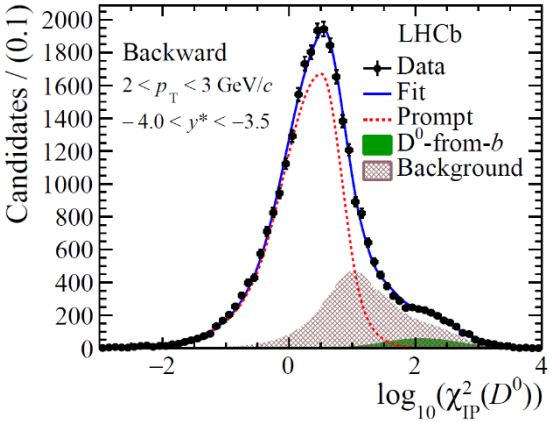
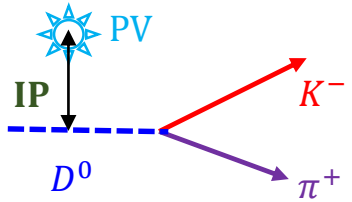




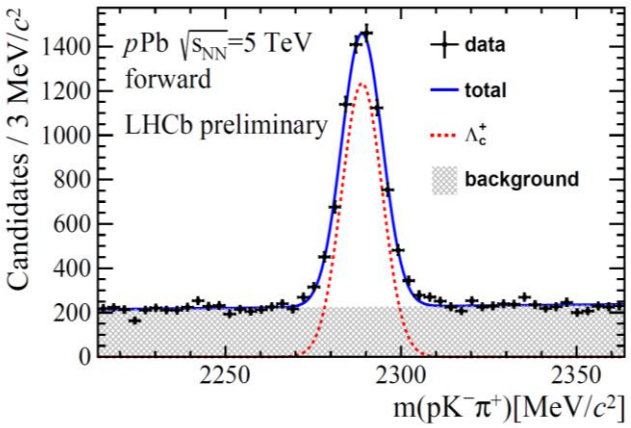
arXiv:1707.02750



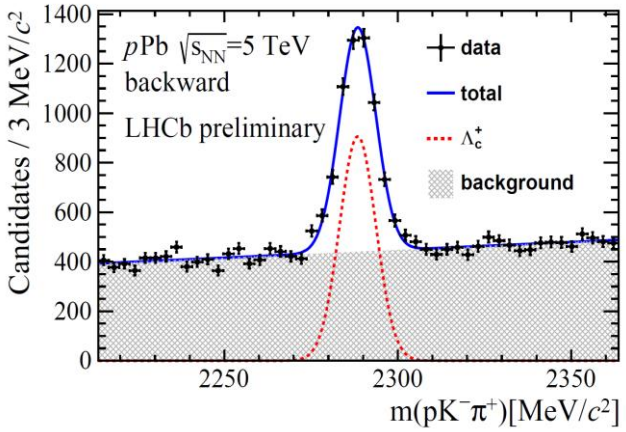
- Reconstructed through decay channel:
  $D^0 \to K^-\pi^+$
- Inclusive D^0 mesons from fitting invariant mass dist.:
  - Signal: Crystal Ball
  - Background: linear
- Prompt D^0 fraction extracted from fitting impact parameter dist.:
  - Prompt: simulation
  - D^0-from-b: simulation
  - Background: sideband in data

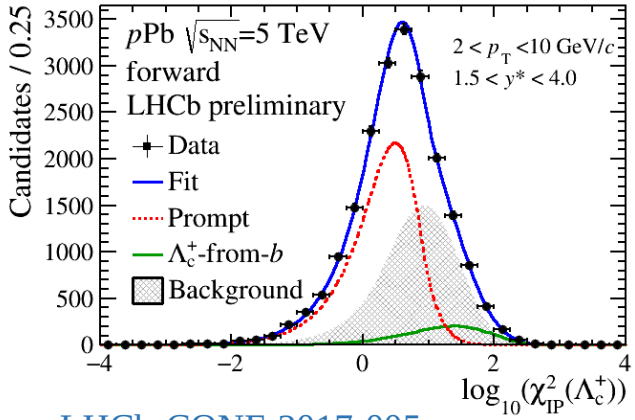
Prompt Λ_c^+ measurement in pPb at 5TeV

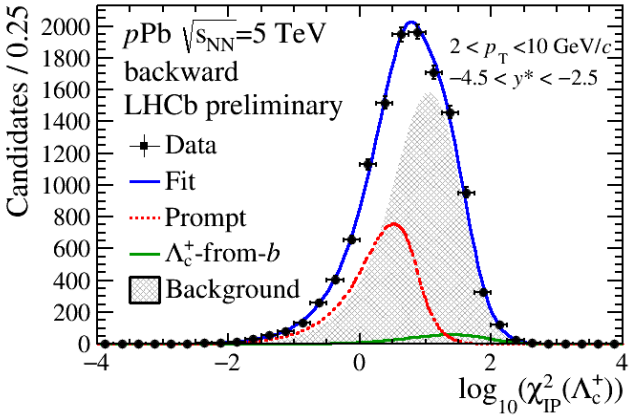
Forward ↓



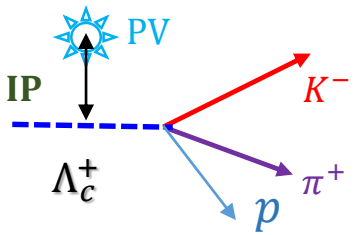
Backward ↓







LHCb-CONF-2017-005



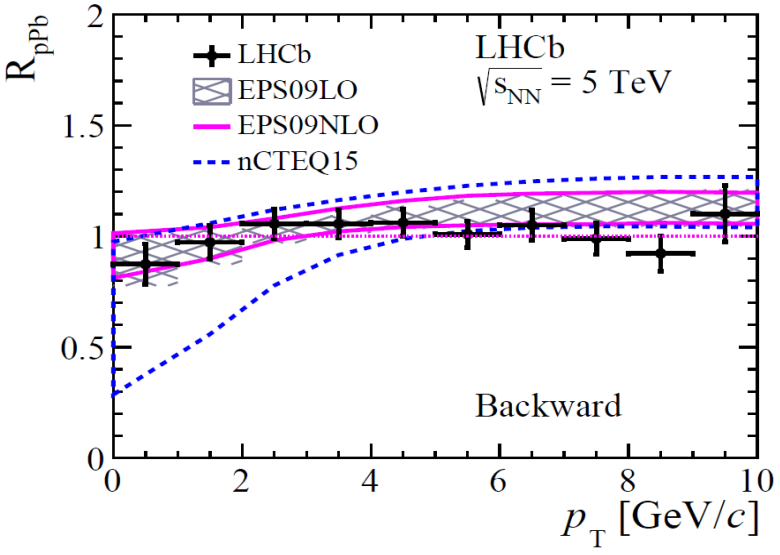
- Reconstructed through decay channel
  $\Lambda_c^+ \to pK^-\pi^+$
- Inclusive Λ_c^+ baryons from fitting invariant mass dist.:
  - Signal: Gaussian
  - Background: linear

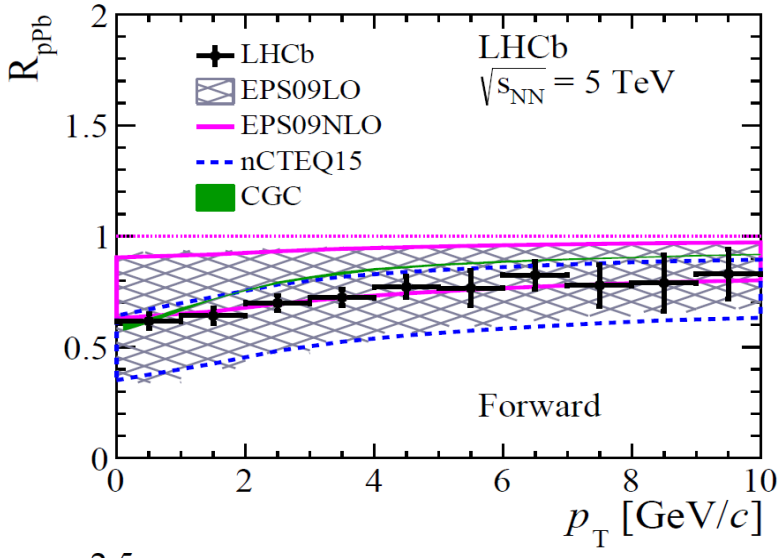
Prompt Λ_c^+ fraction extracted from fitting impact parameter dist.:

- Prompt: simulation
- Λ_c^+-from-b: simulation
- Background: sideband in data

Prompt D^0 at 5TeV nuclear modification factor in pPb

JHEP 10 (2003) 046
Eur. Phys. J. C77 (2017) 1,
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

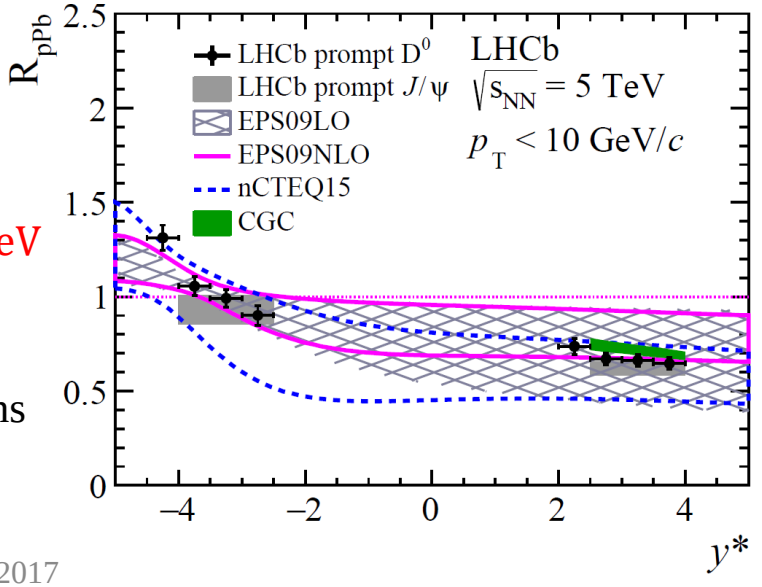




$$R_{pPb}(y^*, p_T) = \frac{1}{A} \times \frac{\sigma_{pPb}(y^*, p_T, \sqrt{s_{NN}})}{\sigma_{pp}(y^*, p_T, \sqrt{s_{NN}})},\ A{=}208$$

Updated since preliminary result:
Directly measured with prompt D^0 in pp at $\sqrt{s} = 5$ TeV
arXiv:1610.02230

- Nuclear modification factor smaller at large rapidity
- Measurements consistent with theoretical calculations

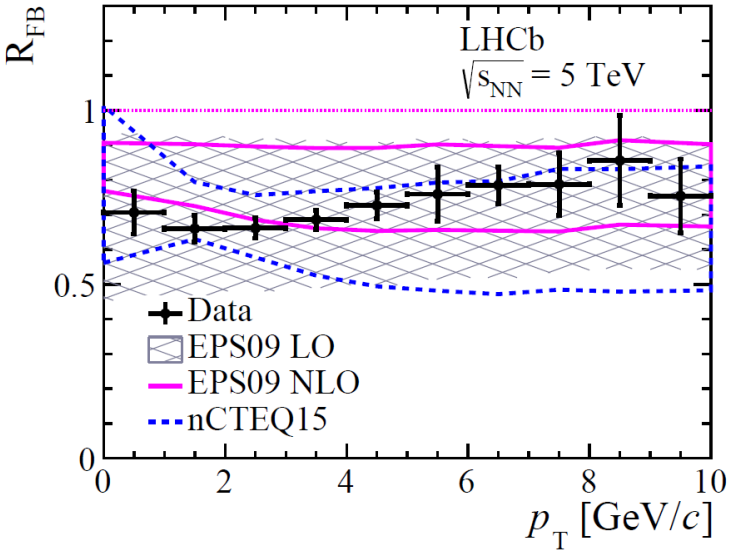


arXiv:1707.02750

Prompt D^0 at 5TeV forward-backward production ratio

- $R_{FB} = \frac{d\sigma(+|y^*|,p_T)/dx}{d\sigma(-|y^*|,p_T)/dx}$
- R_{FB} does not need results from pp collisions.
- Compared to next-to-leading order NLO calculations with different nPDFs
- Consistent with theoretical calculations within uncertainty

arXiv:1707.02750



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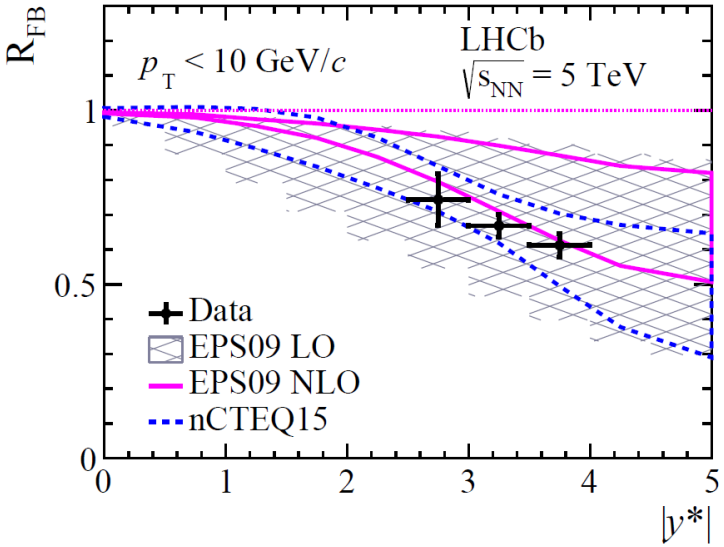

Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

Prompt Λ_c^+ at 5TeV forward-backward production ratio

LHCb-CONF-2017-005

- $R_{FB} = \frac{d\sigma(+|y^*|,p_T)/dx}{d\sigma(-|y^*|,p_T)/dx}$
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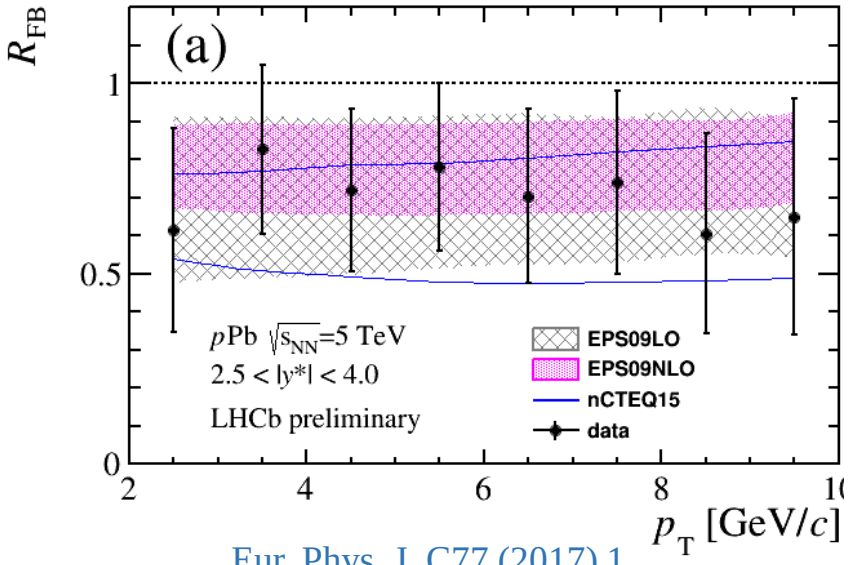

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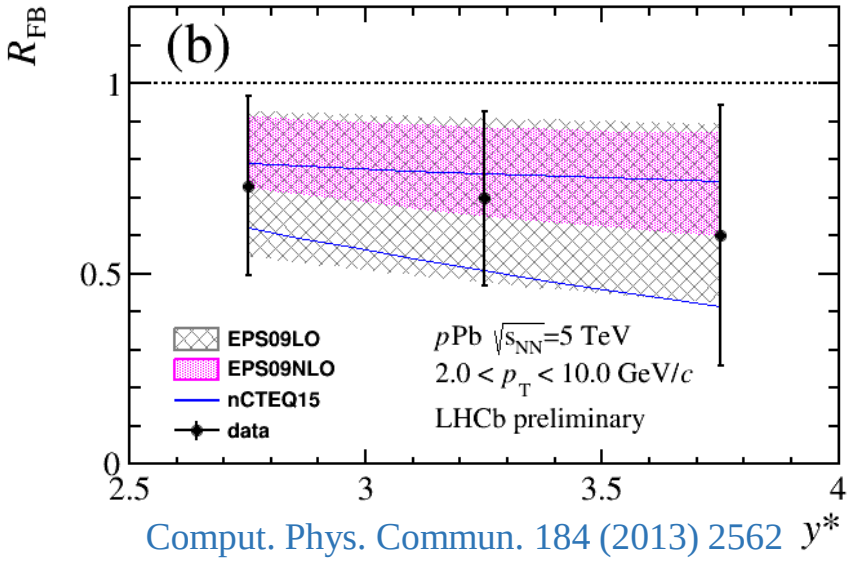

Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

Charmed baryon/meson production ratio $R_{\Lambda_c^+/D^0}$ at 5TeV

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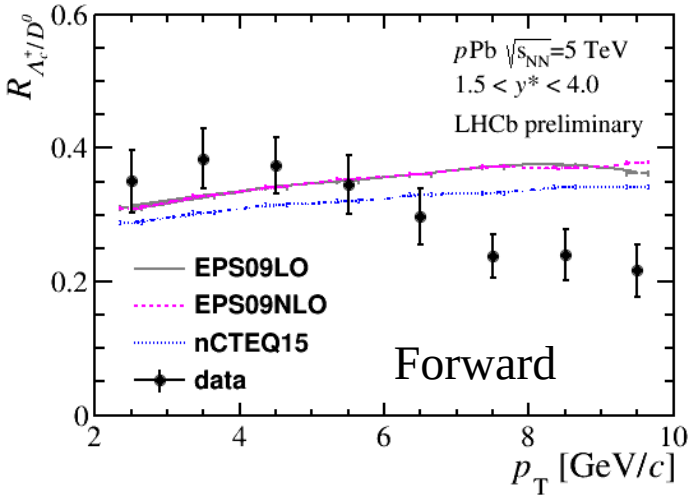
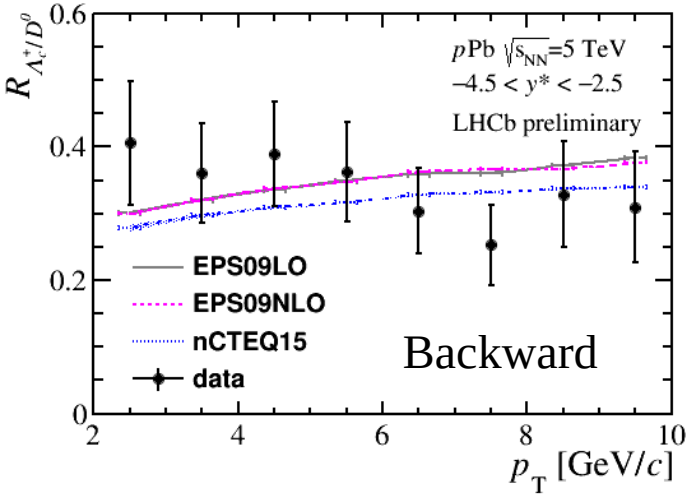
- $R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_T)}{\sigma_{D^0}(y^*, p_T)}$
- EPS09LO & EPS09NLO gives similar predictions.
- nCTEQ15 slightly lower.
- Forward:
  - Consistent at lower p_T
  - Below theory at higher p_T
- Backward:
  - Consistent for all p_T





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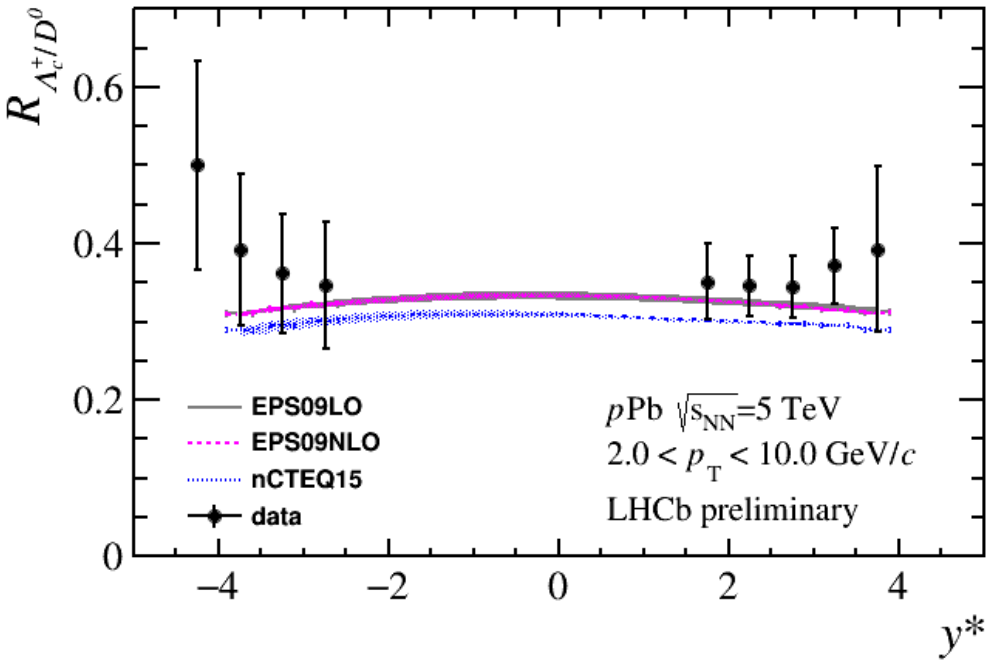
- EPS09LO & EPS09NLO gives similar predictions.
- nCTEQ15 slightly lower.

- Forward:
  - Consistent for all $|y^*|$
- Backward:
  - Consistent at lower $|y^*|$
  - Displays a rising trend with increasing $|y^*|$



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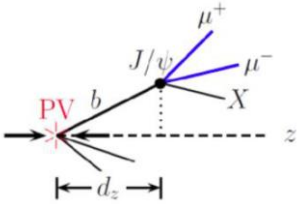
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

Prompt and nonprompt J/ψ in pPb at 8TeV



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

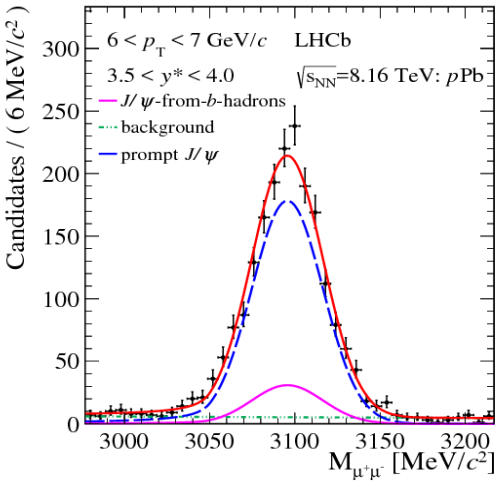
- Signal extraction with 2D simultaneous fit to mass and the pseudo proper decay time

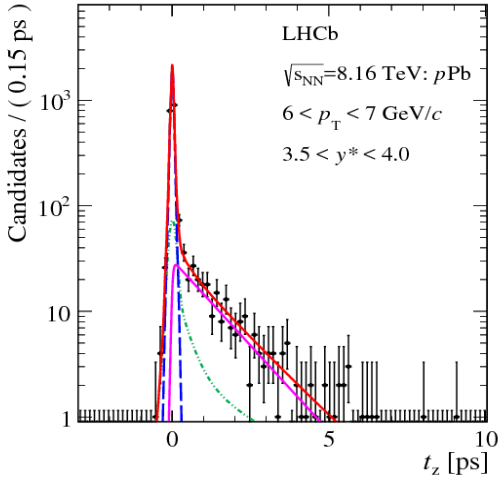
$$t_z \equiv \frac{\left(z_{J/\psi} - z_{PV}\right) \times M_{J/\psi}}{p_z}$$

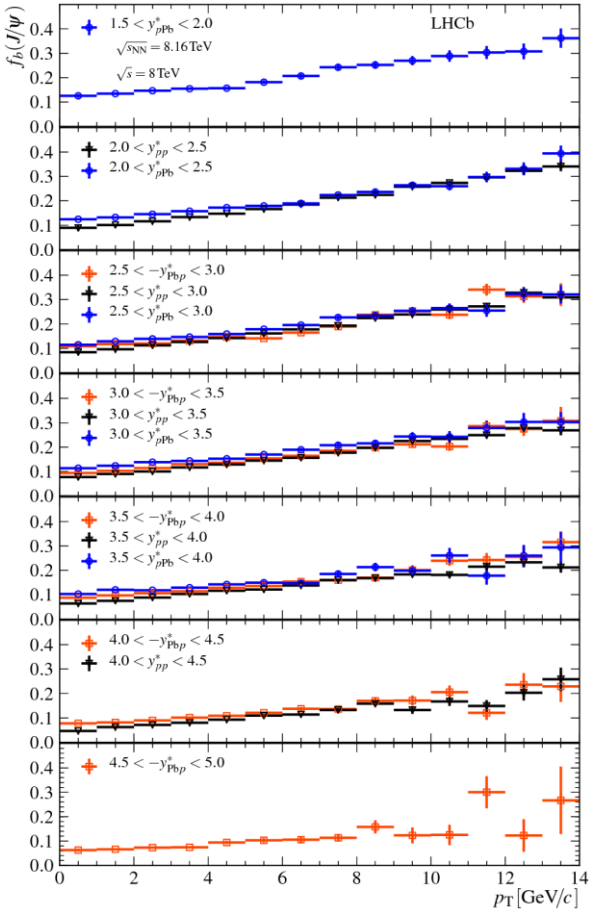
- Prompt and nonprompt (from-b-hadrons) separated

- Fraction from b hadrons:
  - Increasing trend
  - Low p_T : cold nuclear matter effects different for the prompt and nonprompt

arXiv:1706.07122





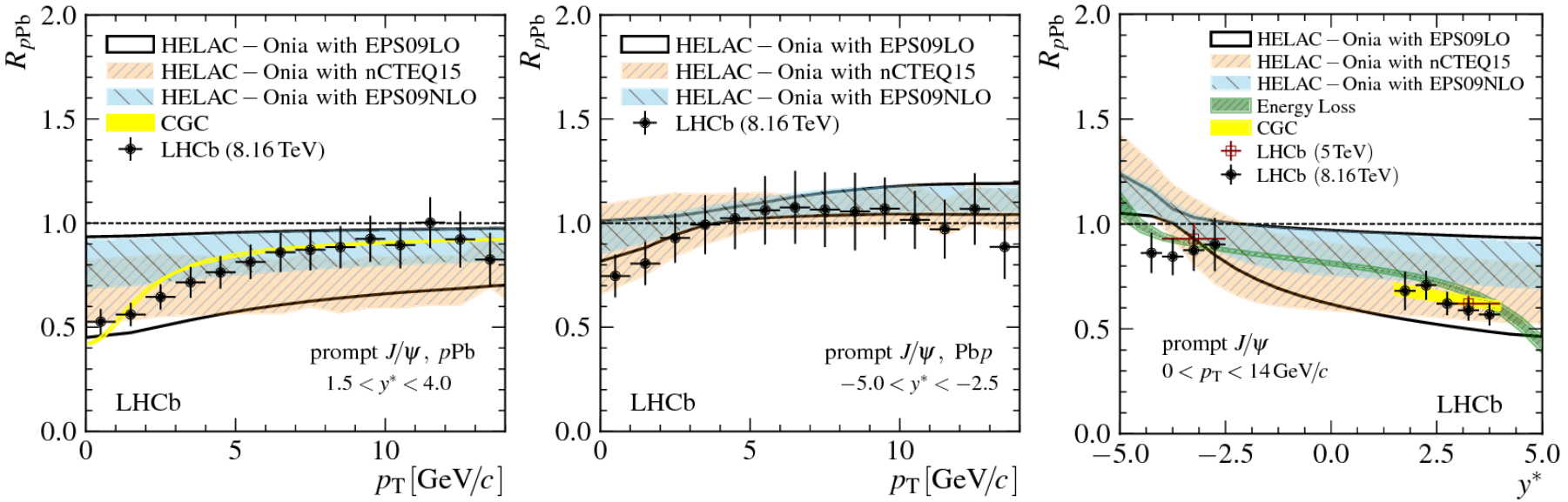


Prompt J/ψ at 8TeV nuclear modification factor in pPb

$$R_{p\mathrm{Pb}}(y^*, p_T) = \frac{1}{A} \times \frac{\sigma_{p\mathrm{Pb}}(y^*, p_T, \sqrt{s_{NN}})}{\sigma_{pp}(y^*, p_T, \sqrt{s_{NN}})},\ A{=}208$$

- pp reference: interpolation of LHCb measurements at 7, 8 and 13TeV
- Forward rapidity: suppression up to 50% at low p_{T}, decreasing with increasing p_{T}
- Backward rapidity: closer to unity
- Overall agreement with models with large uncertainties on the gluon PDFs at low x
- Compatible with 5TeV results

arXiv:1706.07122

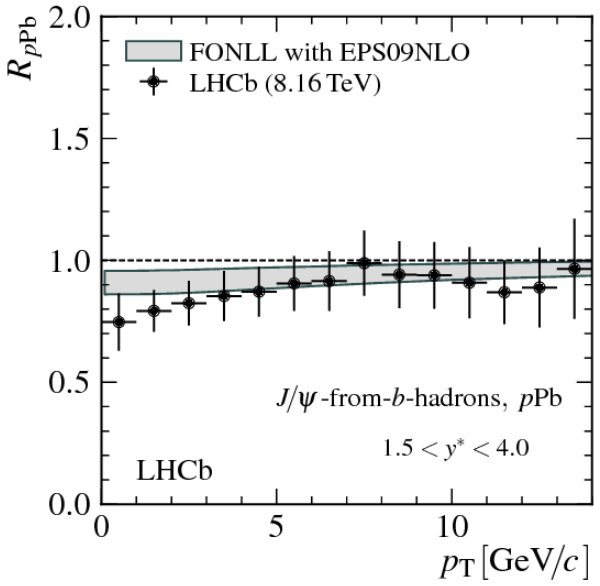


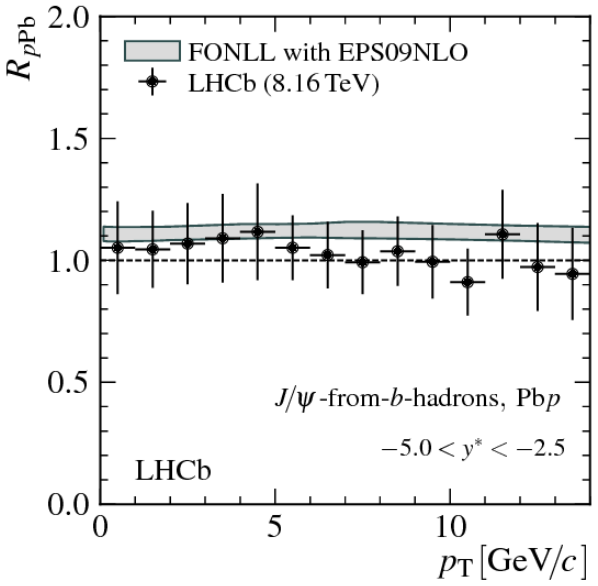
J/ψ-from-b-hadrons at 8TeV nuclear modification factor in pPb

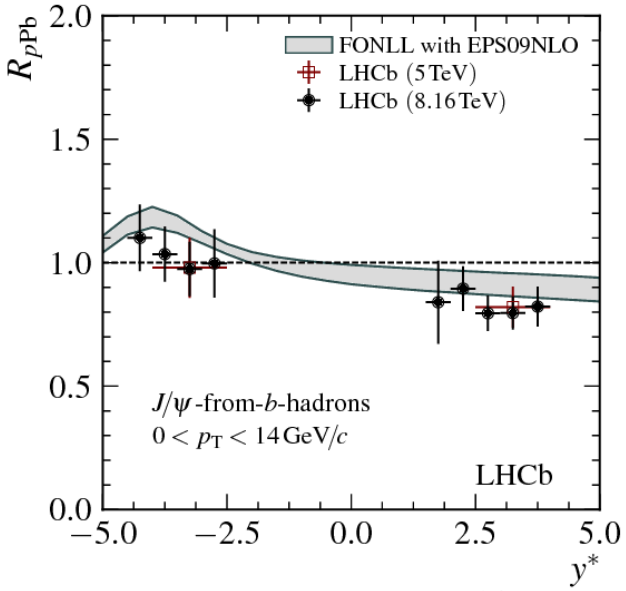
$$R_{p\mathrm{Pb}}(y^*, p_T) = \frac{1}{A} \times \frac{\sigma_{p\mathrm{Pb}}(y^*, p_T, \sqrt{s_{NN}})}{\sigma_{pp}(y^*, p_T, \sqrt{s_{NN}})},\ A{=}208$$

- pp reference: interpolation of LHCb measurements at 7, 8 and 13TeV
- Forward rapidity: smaller suppression up to 30% at low p_{T}, reach unity at higher p_{T}
- Backward: compatible with unity
- FONLL with EPS09NLO consistent with data
- Compatible with 5TeV results

JHEP 04 (2009) 065
arXiv:1706.07122



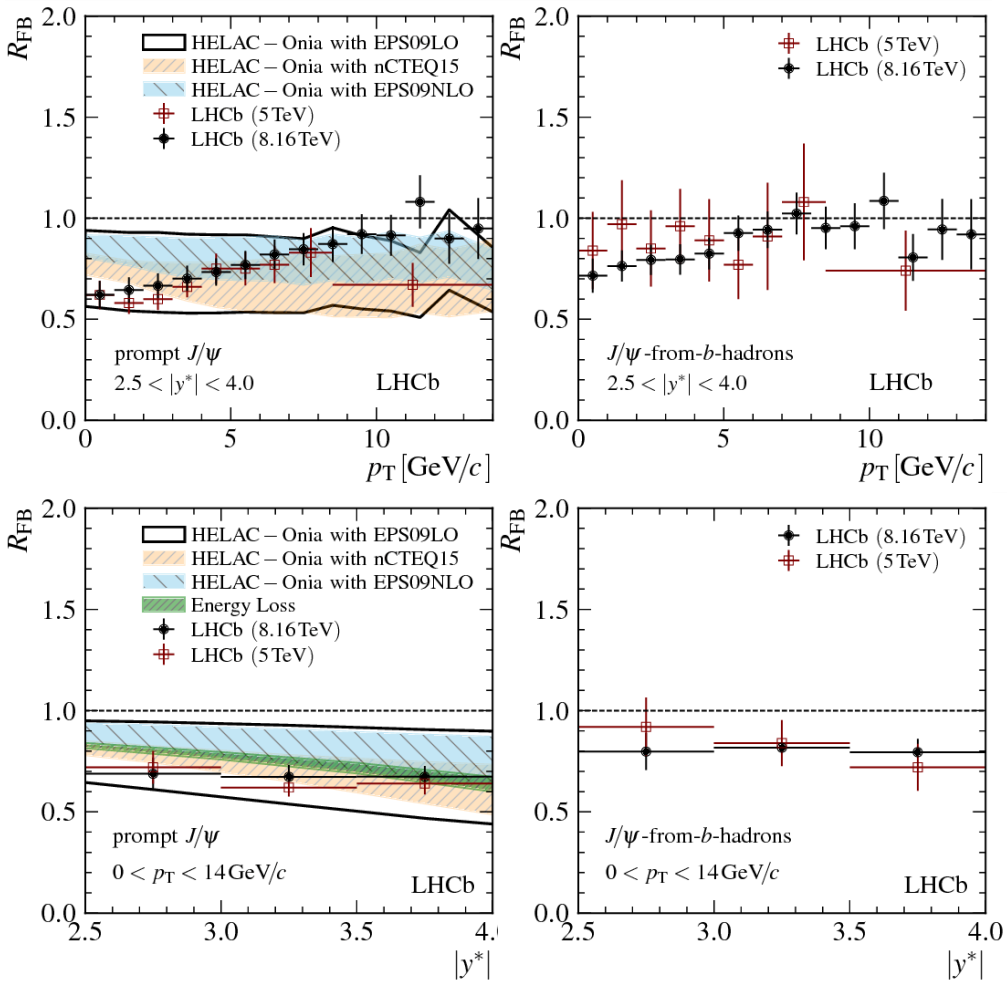




Prompt J/ψ at 8TeV forward-backward production ratio

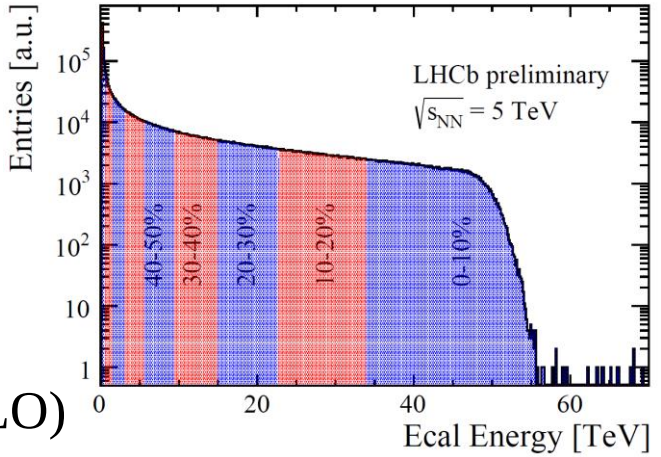
arXiv:1706.07122

- $R_{FB} = \frac{d\sigma(+|y^*|,p_T)/dx}{d\sigma(-|y^*|,p_T)/dx}$
- R_{FB} does not need results from pp collisions.
- Prompt J/ψ:
  - Clear forward-backward asymmetry
  - Increasing trend with increasing p_T
- Nonprompt J/ψ:
  - Closer to unity
- Models for prompt J/ψ only
- Consistent with 5TeV results

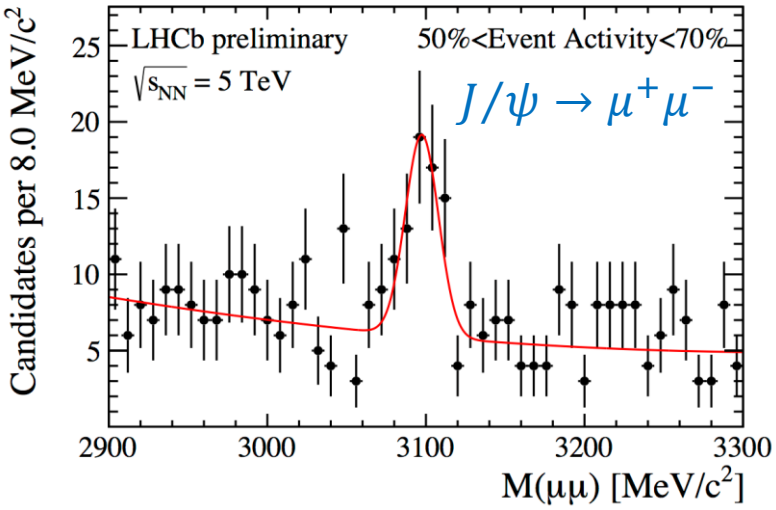


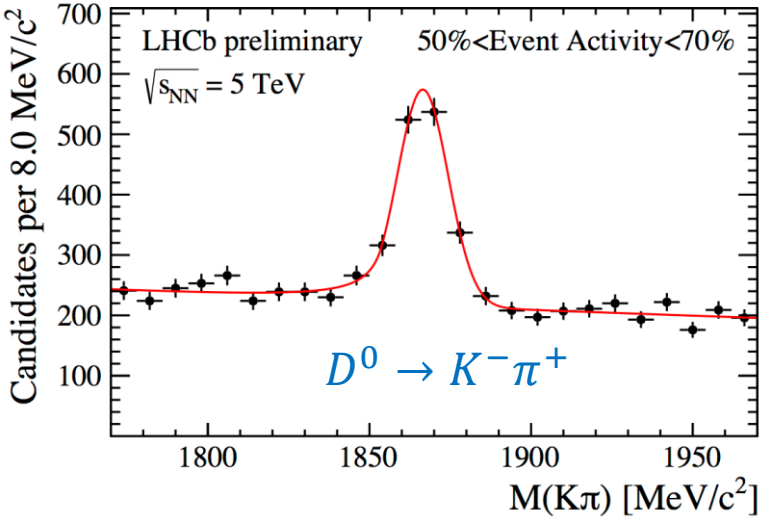
PbPb collisions

- December 2015: first LHCb PbPb data taken
- $\sqrt{s_{NN}} = 5$ TeV (3-5 μb^{-1})
- Event classification: total energy in the calorimeters (Ecal)
- Analyses limited by saturation in Vertex Locator (VELO)
- Track reconstruction: 50-100% event activity (~15k clusters)



Activity 50-70%

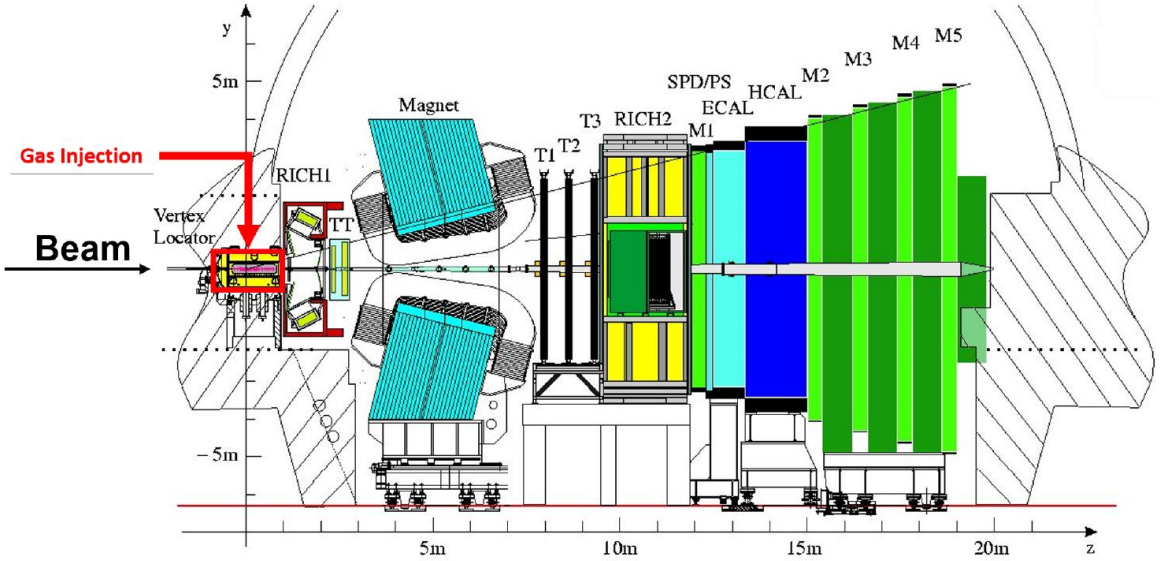


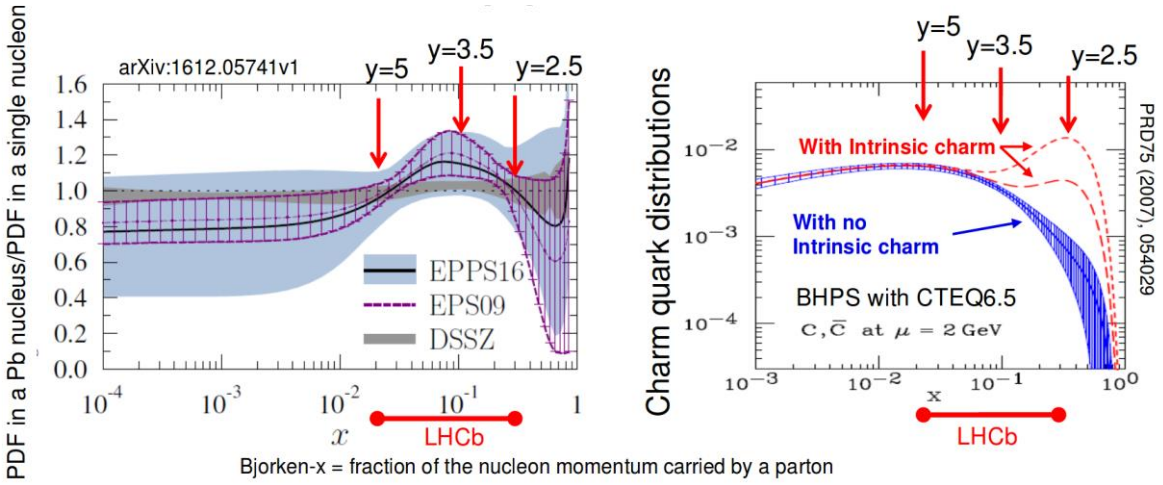


https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

Fixed target physics

- LHCb: only experiment at the LHC can operate in fixed-target mode
- SMOG: The System for Measuring Overlap with Gas
  - Unique feature
  - noble gas (He, Ne, Ar…) injection inside the LHC beam close to the interaction point
  - Luminosity measurement
  - Internal gas target
- Allows *p*-gas and ion-gas collisions
- $\sqrt{s_{NN}}$ region between 20 GeV (SPS) and 200 GeV (RHIC)
- Access nPDF anti-shadowing region and intrinsic charm content in the nucleon





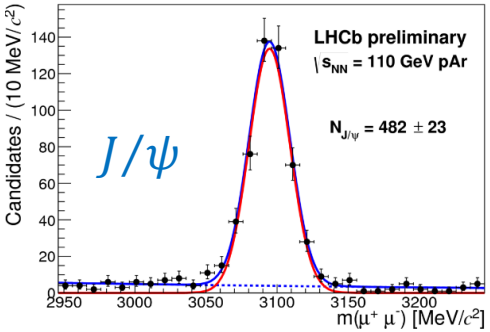
Charm production in pAr collisions

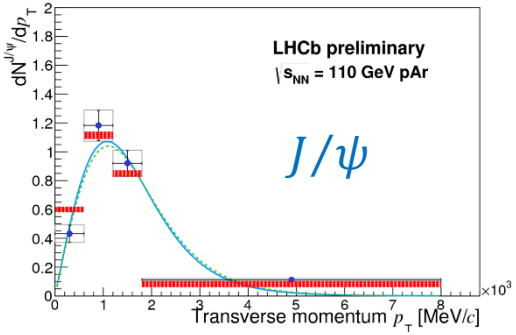
LHCb-CONF-2017-001

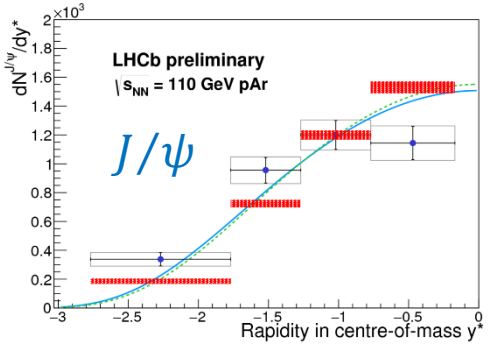
JHEP (2013) 2013:122

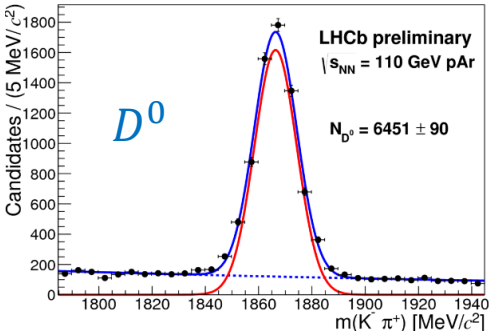
JHEP (2013) 2013: 155

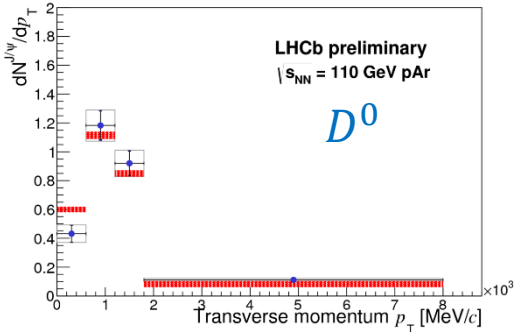
- Dataset:
  - $\sqrt{s_{NN}} = 110$ GeV (2015)
  - 6.5 TeV proton beam on Ar gas target
  - Protons on target: 4×10^{22}
  - ~500 J/ψ and ~6500 D^0
- Shapes consistent with PYTHIA and interpolation between HERA-B and PHENIX

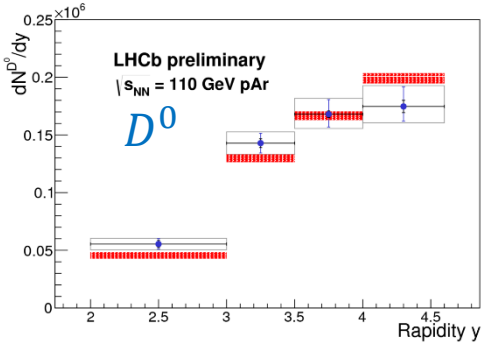








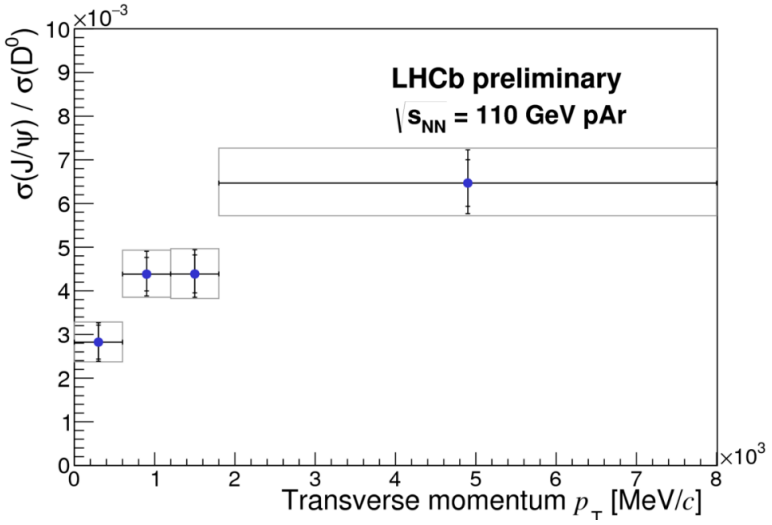


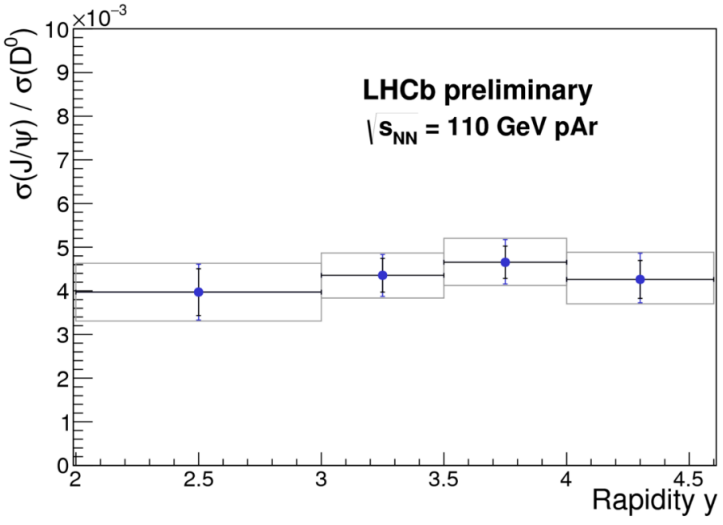


Charm production in pAr collisions

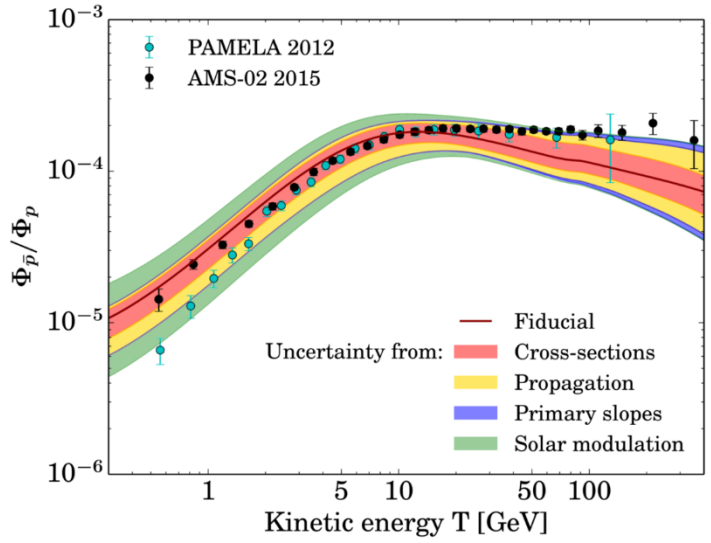
LHCb-CONF-2017-001

- J/ψ/ D^0cross section ratio
  - Luminosity cancels
  - Increase with p_{T}
  - Little dependence on rapidity
- Demonstrate the feasibility of a heavy−flavor−fixed−target program at LHCb
- Theoretical calculations are welcome

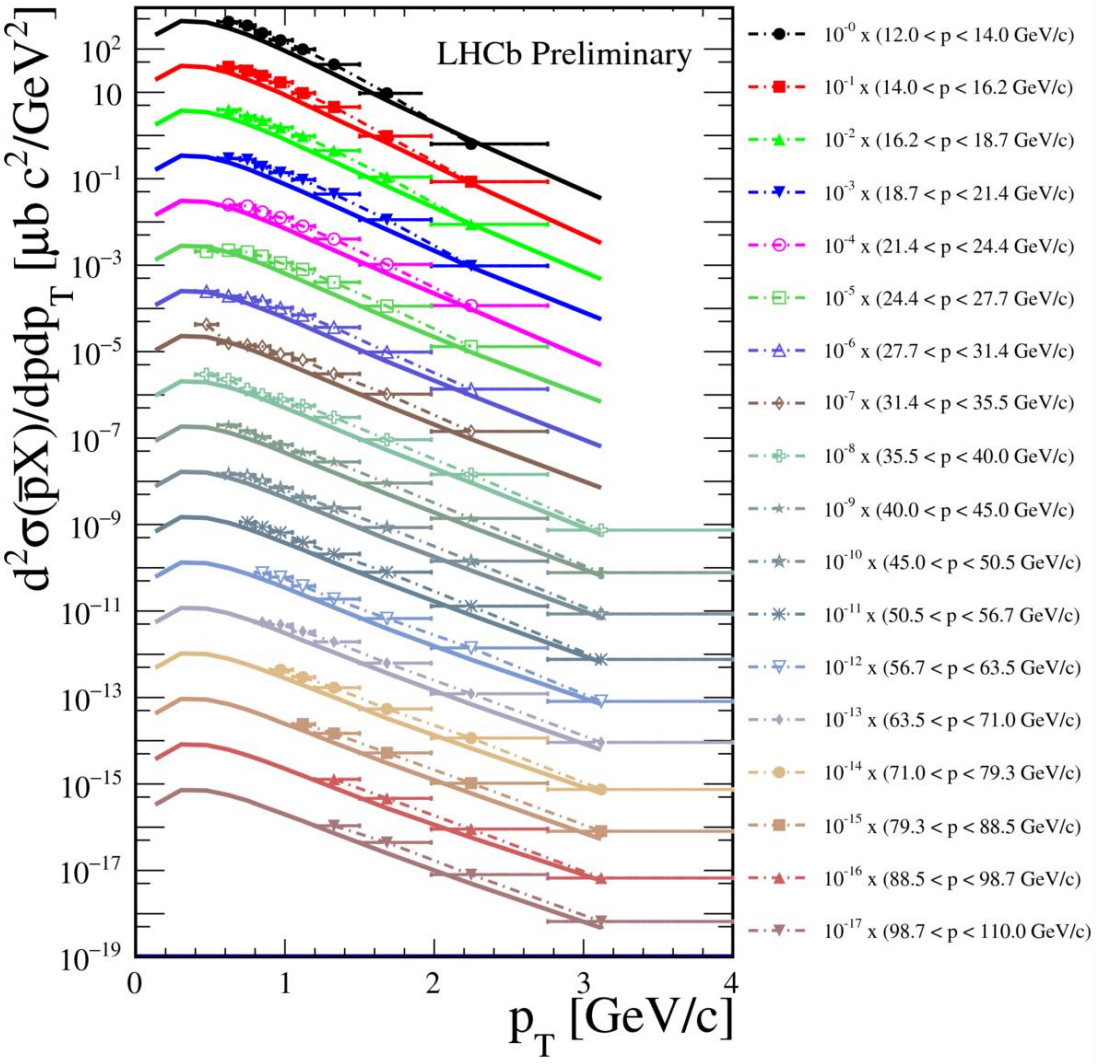




Measurement of $\bar{p}$ production in pHe collisions



LHCb-CONF-2017-002



- AMS-2: possible anti-proton excess at high energies
- $\bar{p}/p$ ratio predictions limited by uncertainties on $\bar{p}$ production cross-sections, particularly for p-He
- Prompt production at $\sqrt{s_{NN}} = 110$ GeV in pHe collisions
- EPOS LHC prediction:
  - Data/MC ~ 1.19 ±0.08

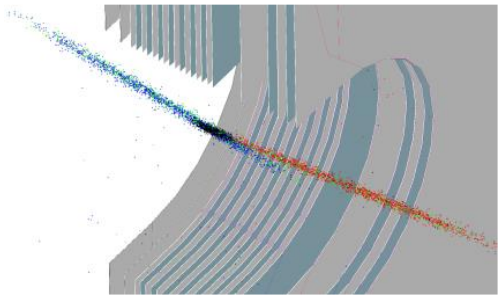
Conclusion

- Heavy ion collisions
  - pPb collisions at $\sqrt{s_{NN}} = 5$ and 8 TeV in 2013/2016
    - Open heavy flavor analyses: prompt D^0 and Λ_c^+
    - Hidden heavy flavor: prompt and nonprompt J/ψ
    - Angular correlation measured (not included)
  - PbPb collisions at $\sqrt{s_{NN}} = 5$ TeV in 2015
    - Ongoing analyses on semi-central to peripheral collisions

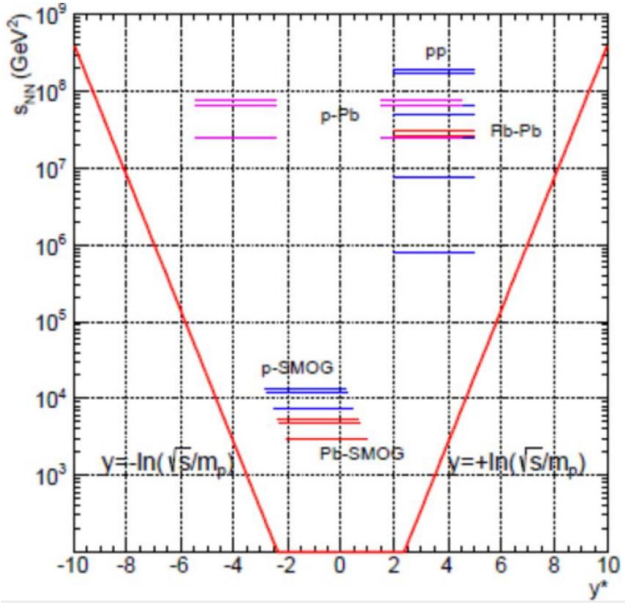
- Fixed target collisions
  - SMOG: unique feature enabling a fixed target program in LHCb
  - First results on
    - D^0 and J/ψ production in pAr collisions $\sqrt{s_{NN}} = 110$ GeV
    - $\bar{p}$ production in pHe collisions $\sqrt{s_{NN}} = 110$ GeV

backup

SMOG: Gas target in LHCb



- SMOG: System for Measuring Overlap with Gas
  - Inject noble gas (He, Ne, Ar…) into the LHC beam (~±20 m) around the LHCb collision region
  - Gas pressure ~ 2×10^{-7} mbar
  - Primarily for measuring luminosity at LHC JINST 9, (2014) P12005
  - Fixed target: use non-colliding bunches
- Fixed target collisions:
  - Covers mid to backward rapidity region:
    - $y^* = y - 4.77$

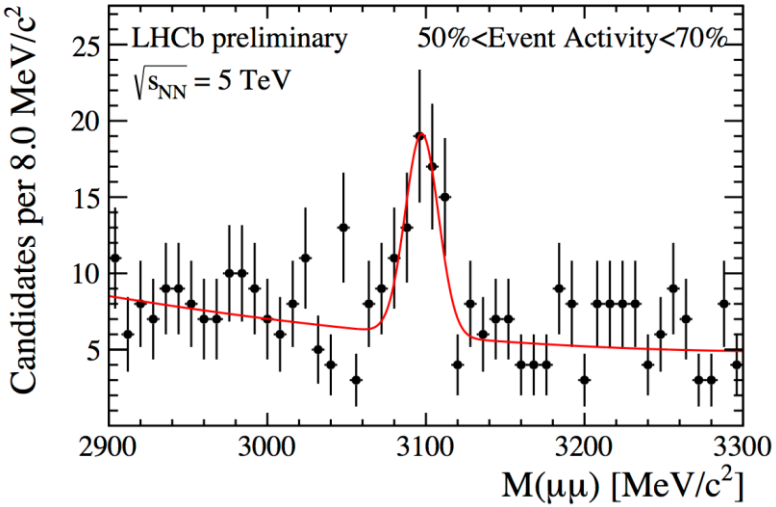


$E_{\text{beam}}(p)$	p-SMOG	Pb-SMOG
2.5 TeV	69 GeV	
6.5 TeV	110 GeV	69 GeV
7.0 TeV	115 GeV	72 GeV

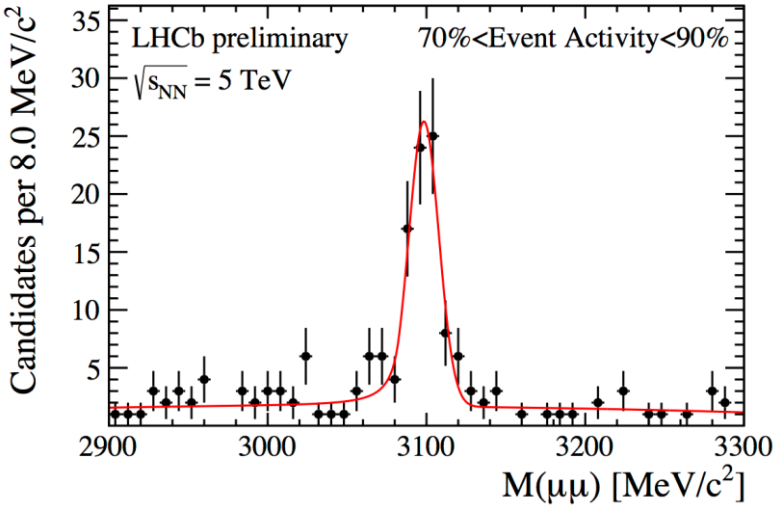
Charm signals in PbPb dataset

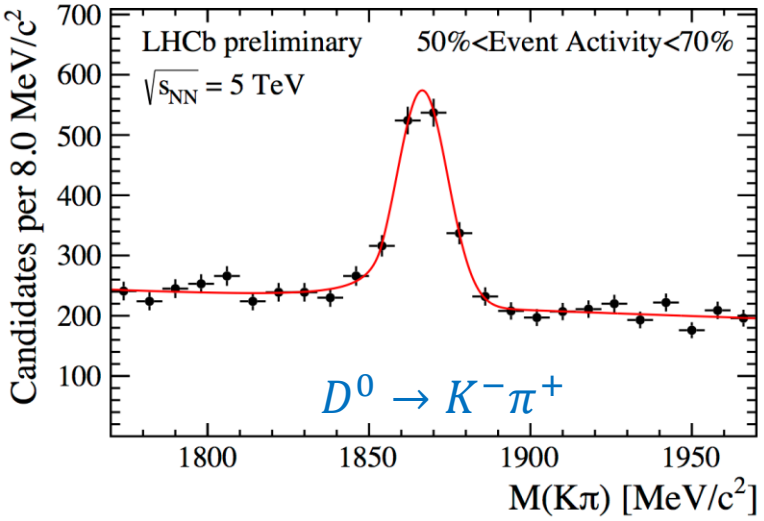
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

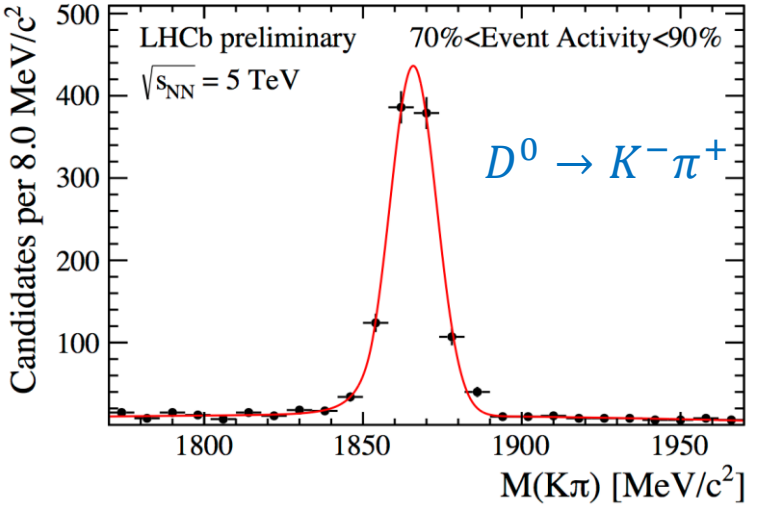
$J/\psi \to \mu^+\mu^-$



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

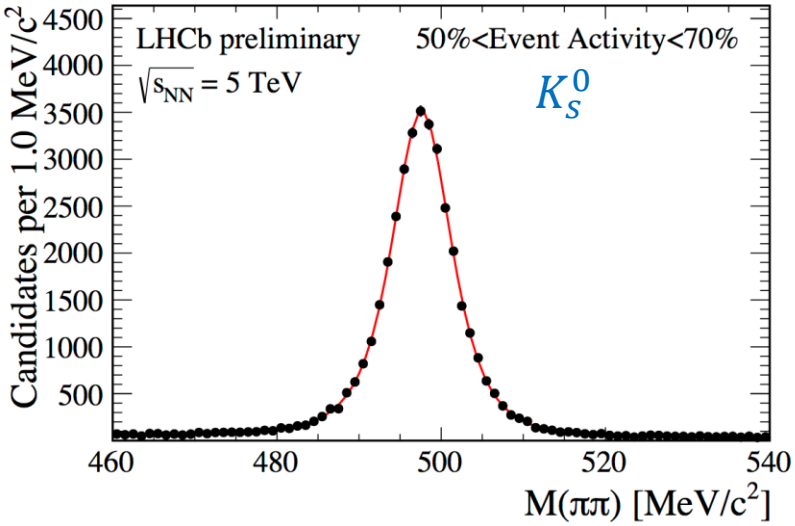


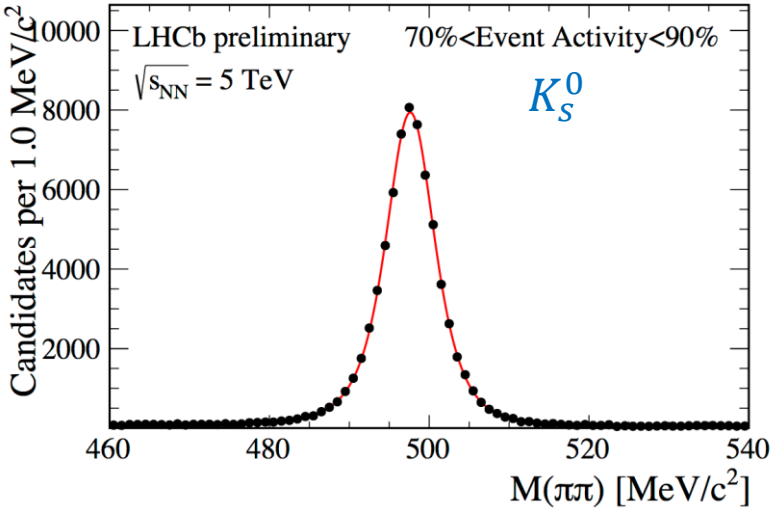


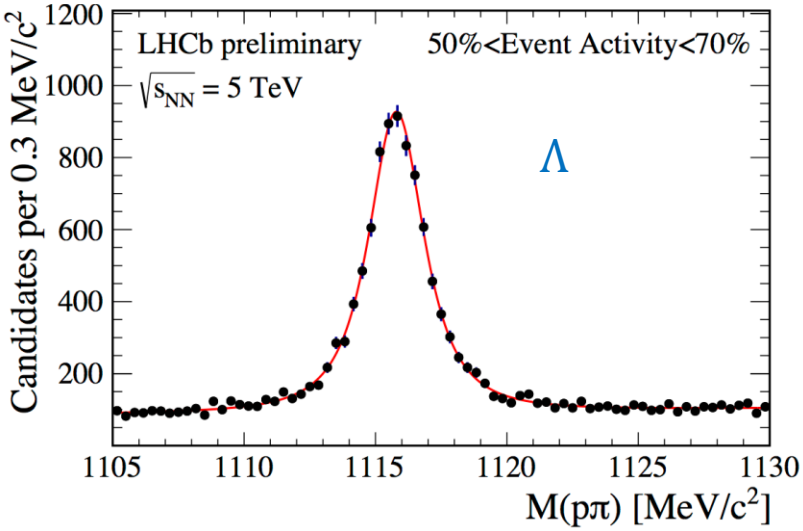


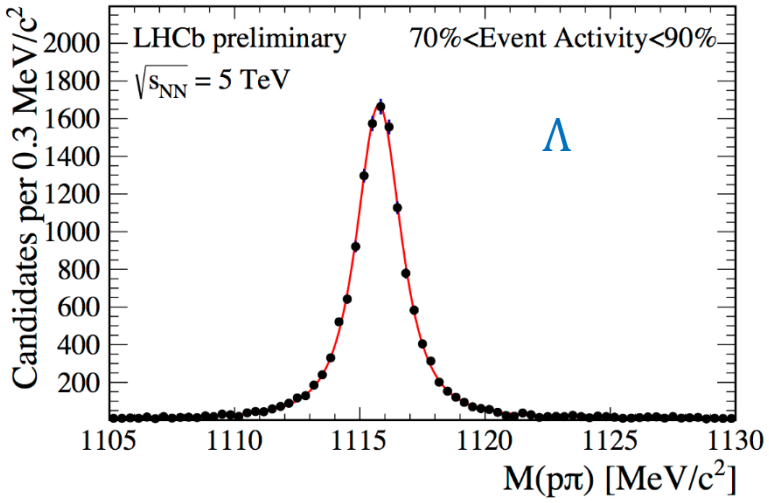
Strange signals in PbPb dataset

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



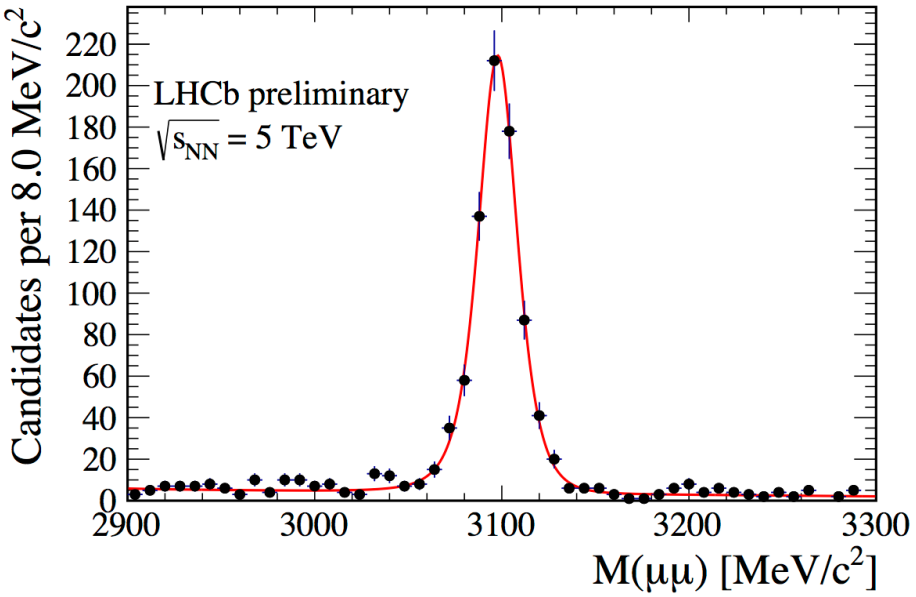


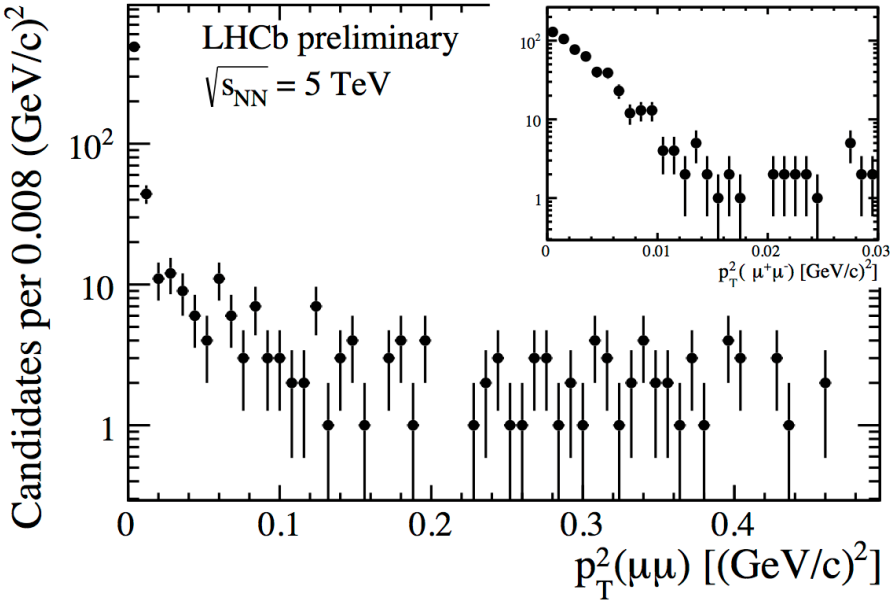




Ultraperipheral J/ψ photo-production

- Selecting events containing only two muon tracks

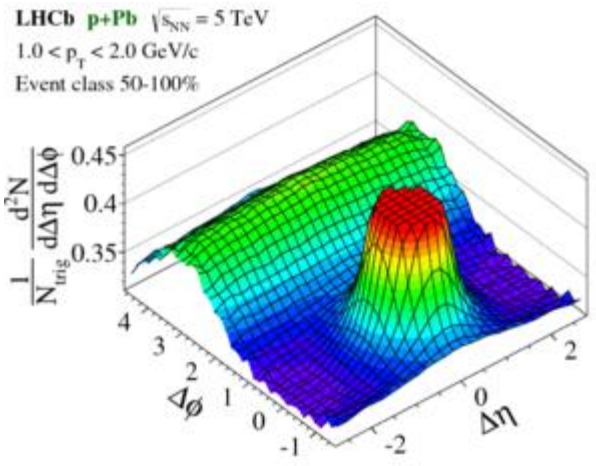




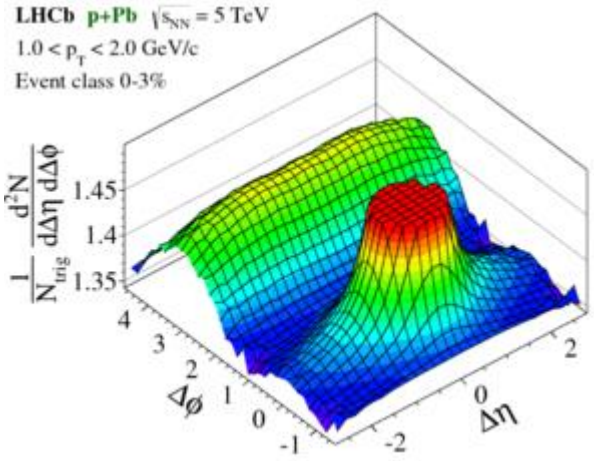
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

Long-range near-side angular correlations

forward
Low activity

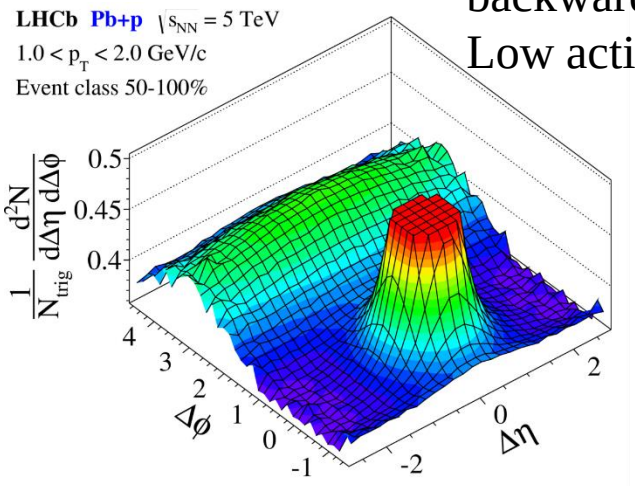


forward
High activity



- In high-activity events, a long-range correlation on the near side is observed in the pseudorapidity range
  $2.0 < \eta < 4.9$

backward
Low activity



backward
High activity