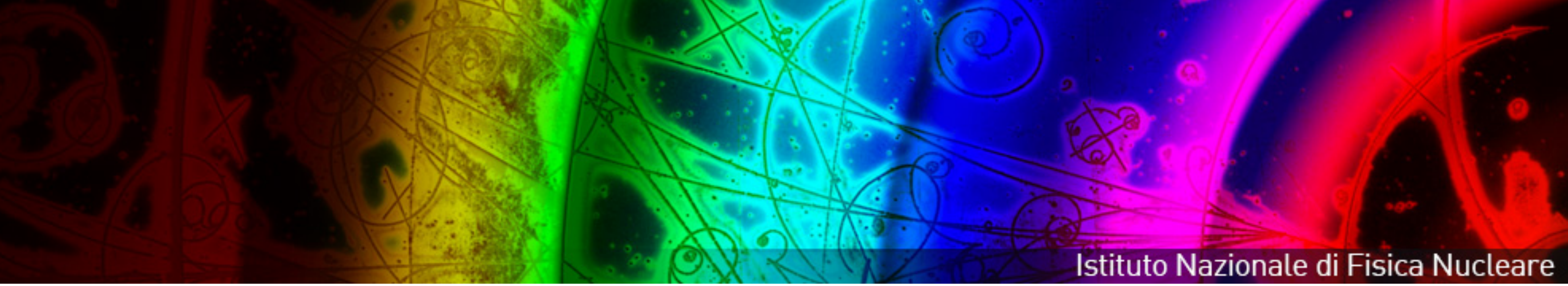


Heavy ion and fixed target results at LHCb

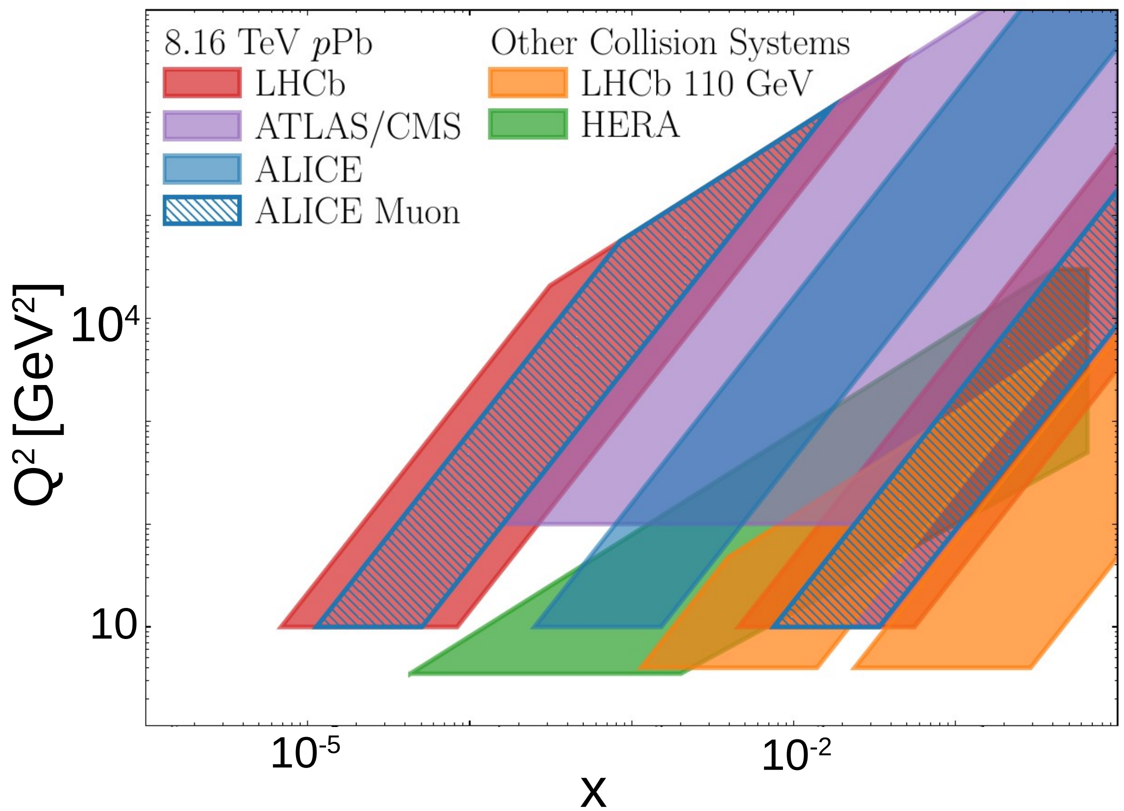
Pasquale Di Nezza INFN LNF Istituto Nazionale di Fisica Nucleare

on behalf of the LHCb *collaboration*

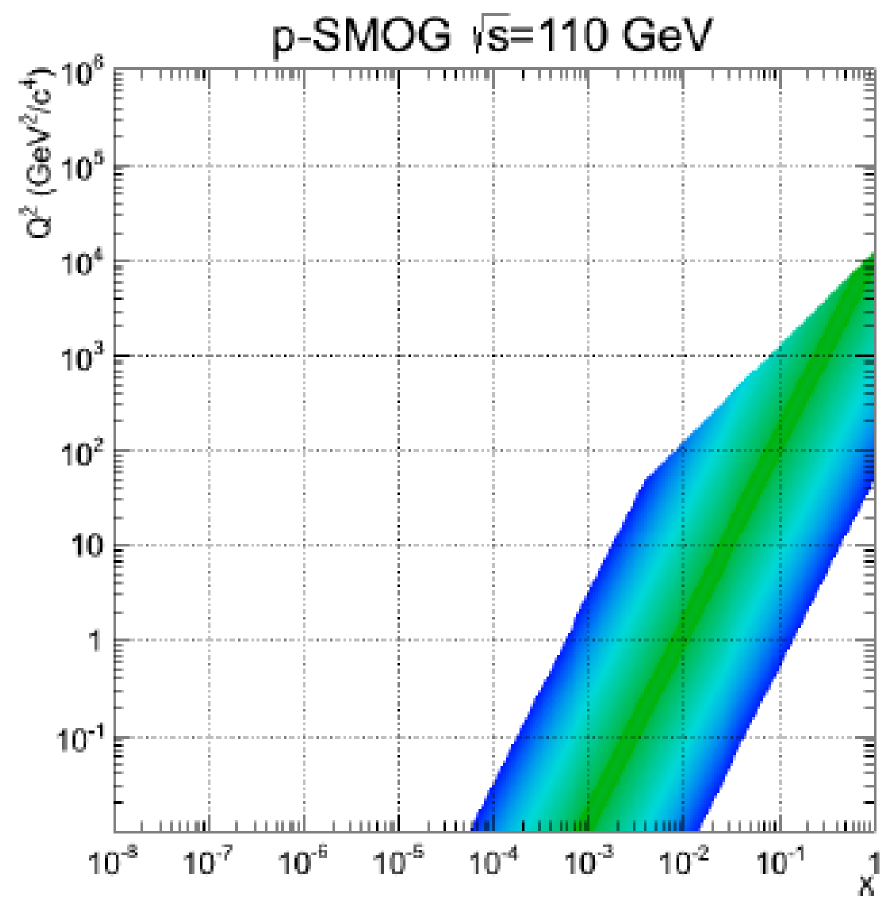
LHCb is a unique spectrometer in HEP due to its forward geometry

Unique kinematics in heavy-ion collider and fixed target mode

pPb



target



pPb run (2016) at $\sqrt{s_{NN}}$ = 8.16 TeV:

- 10^9 minimum bias collisions in *p*Pb and Pb*p* mode
- 34 nb^{-1} luminosity acquired (i.e. ≈ 0.5 million J/ψ in *p*Pb and Pb*p* each)

Ion-ion:

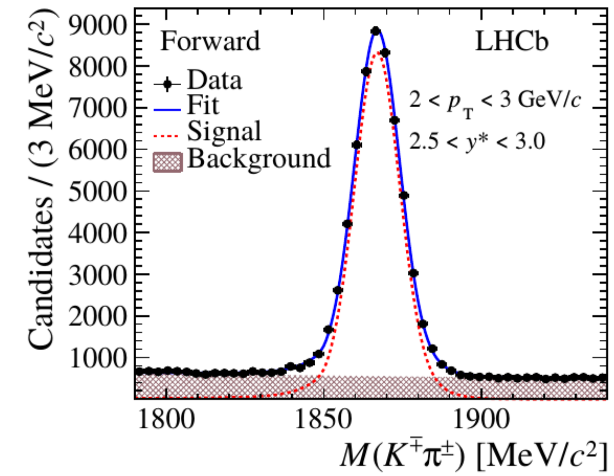
-10 μb^{-1} PbPb (2015) and 0.4 μb^{-1} XeXe → 2018 PbPb a factor >20

Fixed target pp, pA, Pb-p or Pb A collisions at the poorly explored energy of √s ~ 100 GeV and high Bjorken-x

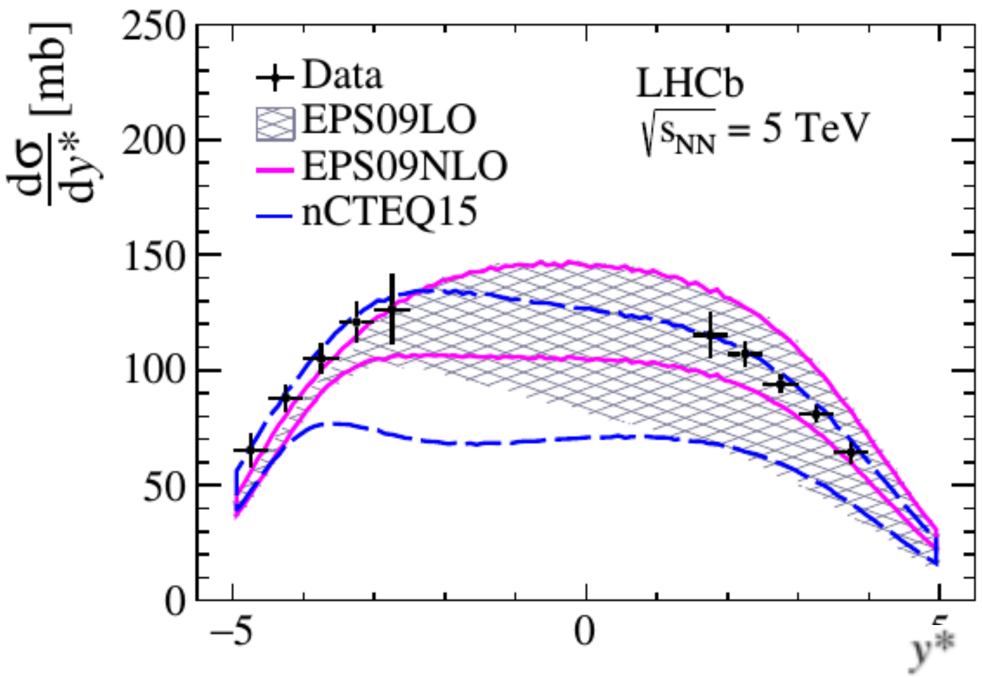
D^0 production in pPb collisions at 5.02 TeV

HF are unique probes in HI collision:

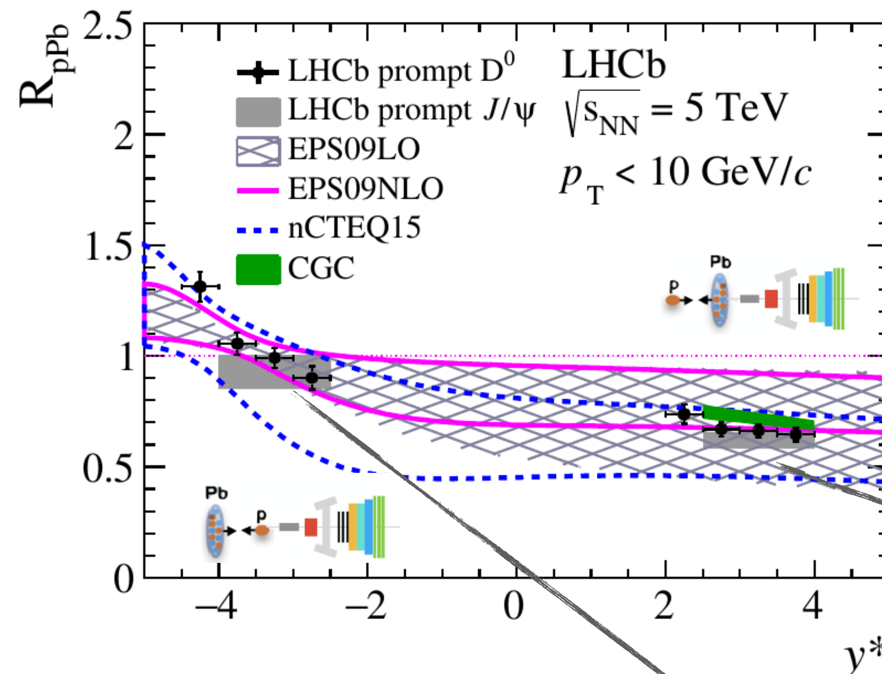
- *$m_Q >> \Lambda_{QCD}$ allows perturbative calculations*
- *$t_{prod} << t_{QGP}$ experiences the whole time evolution of the collision*



precision data



JHEP 10 (2017) 090



$$R_{pPb}(p_T, y^*) \equiv \frac{1}{A}\frac{d^2\sigma_{pPb}(p_T, y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_T dy^*}$$

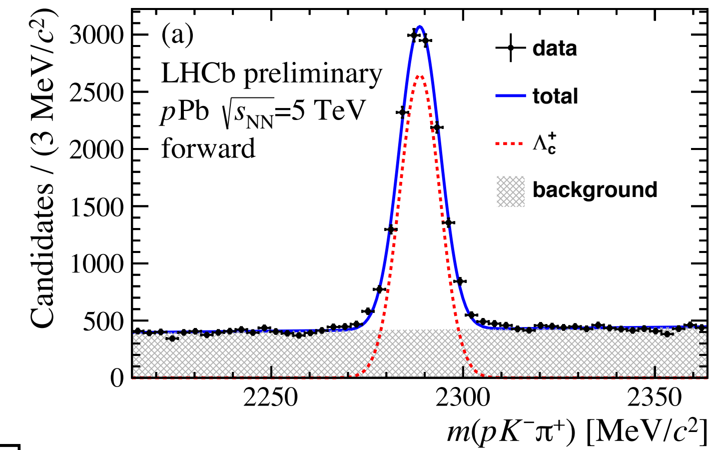
strong suppression wrt pp at forward rapidity (shadowing region)

increasing in the most backward bins (anti-shadowing region)

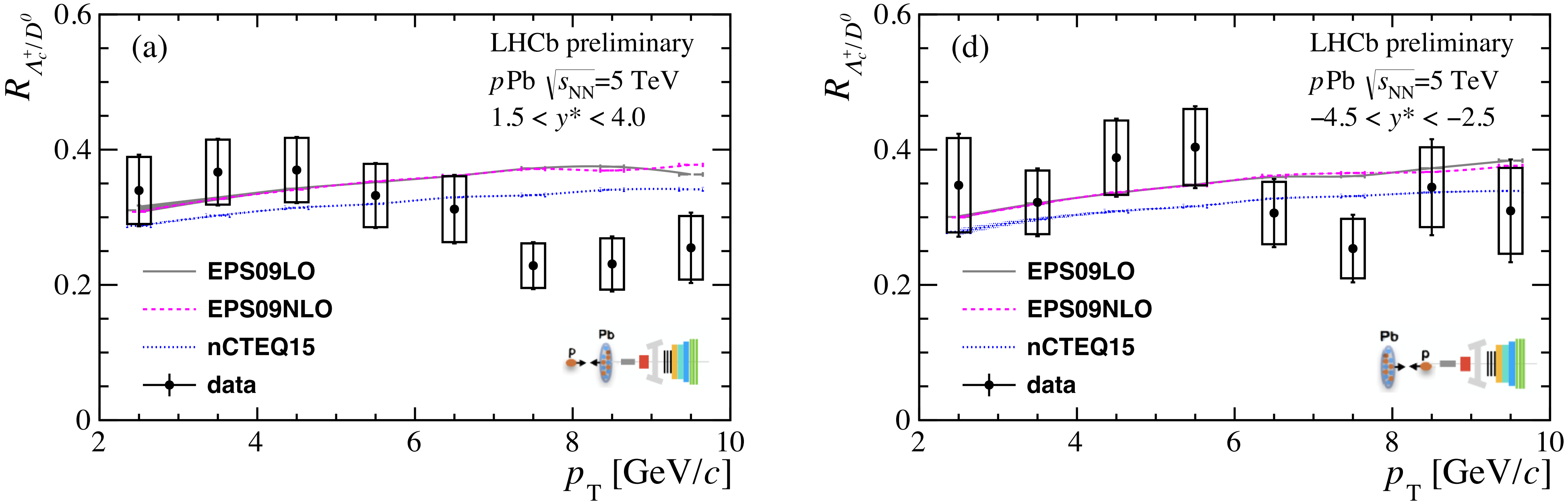
- *Both cross section (left) and Nuclear Modification Factor (right) are fairly described by nPDFs and Color Glass Condensate calculations*

- *LHCb data already used to constrain nPDFs in the unexplored region at low-x (PRL 121 (2018) 052004)*

Λ_C production in pPb collisions at 5.02 TeV

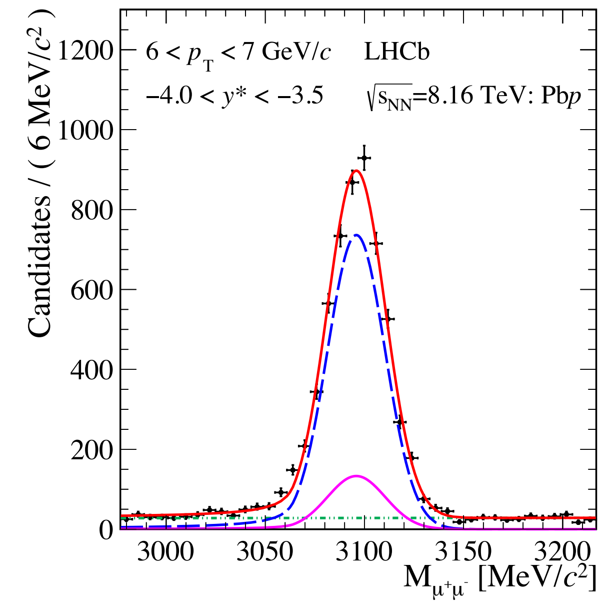


LHCb-Paper-2018-021, arXiv:1809.01404



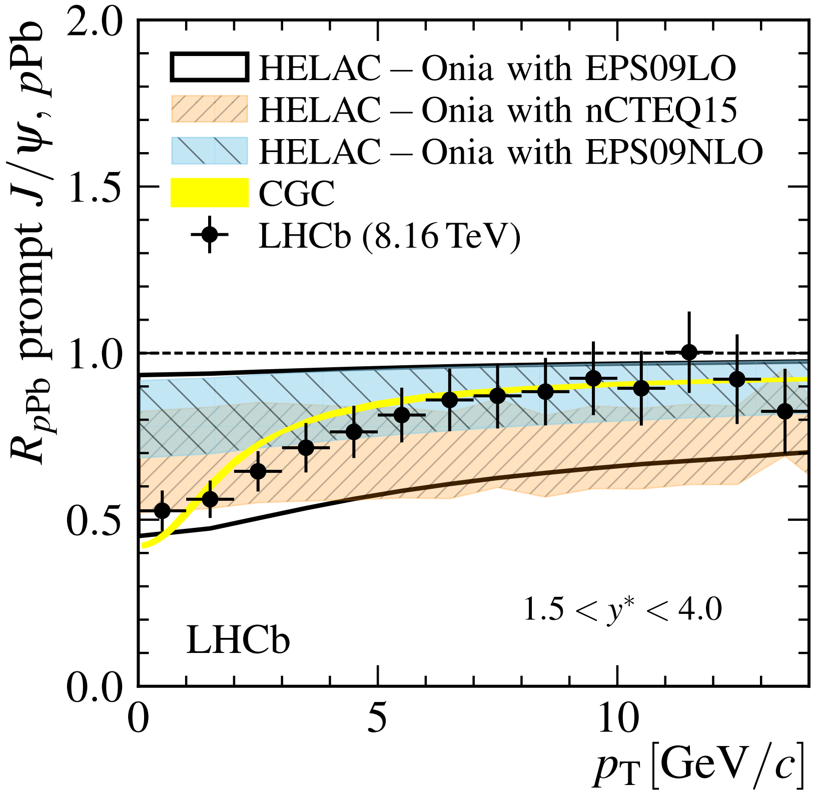
- *Λ_C 3-body decay: test of charm fragmentation*
- *In the ratio most of the nPDF uncertainties cancel out*
- *Important input for hadronization phenomenology: crucial comparison with other collision systems*
- *Hadronisation pattern of $c\bar{c}$ similar to model tuned to pp (R~0.3), same discrepancy high-p_T and forward rapidity*

J/ψ production in pPb collisions at 8.16 TeV



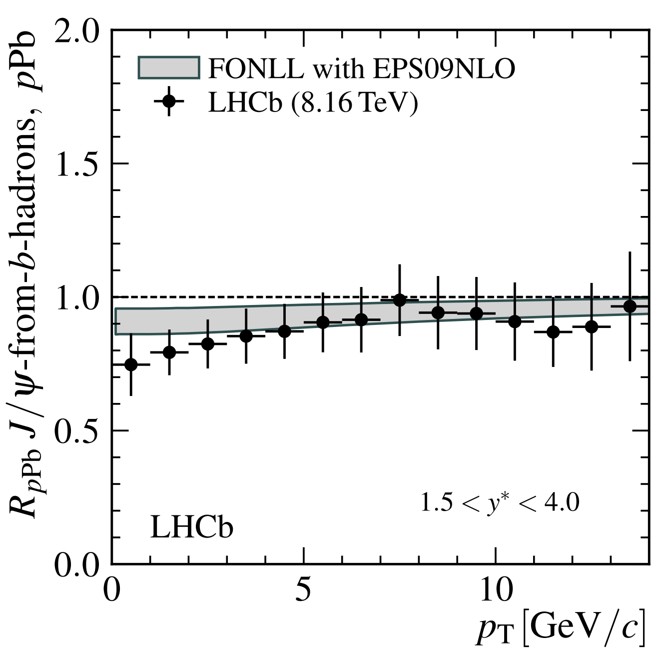
PLB 774 (2017) 159

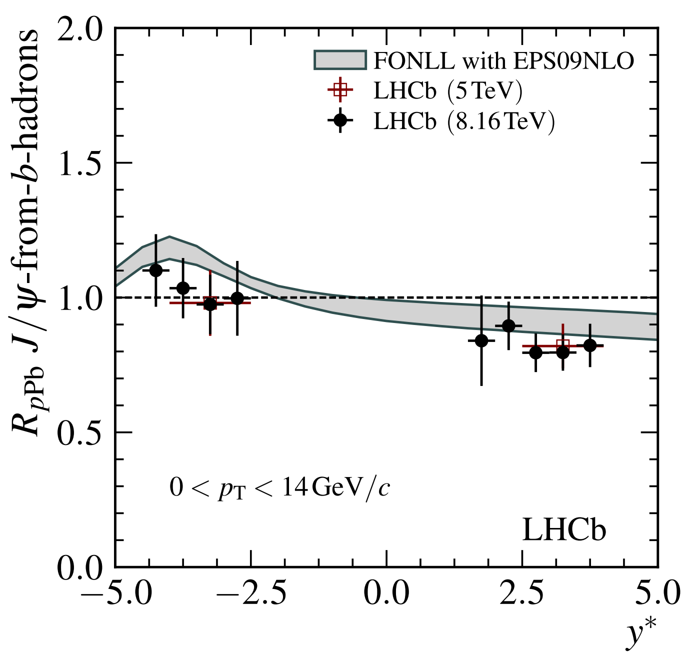
Prompt production



- strong suppression at forward rapidity: increasing from 0.5 at lowest p_T reaching 1 at highest p_T
- nPDFs & Color Glass Condensate calculations account for observations
- for rapidity dependence (not shown here) also the coherent energy-loss accounts for observation

Non-prompt production



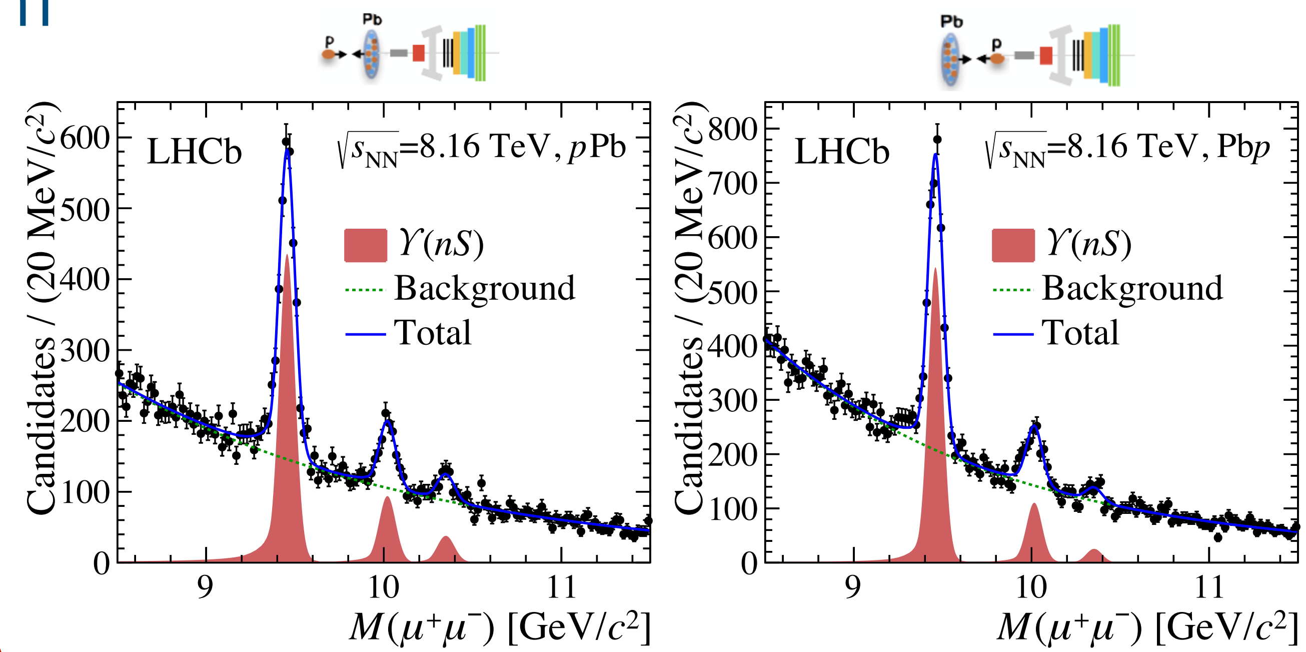


- first precise b-production measurement in pPb down to p_T~0
- suppression at forward rapidity, modification factor close to 1 at backward rapidity
- crucial input for the HI phenomenology

Very valuable constraint of nPDFs in unexplored area at low-x (PRL 121, 052004 (2018))

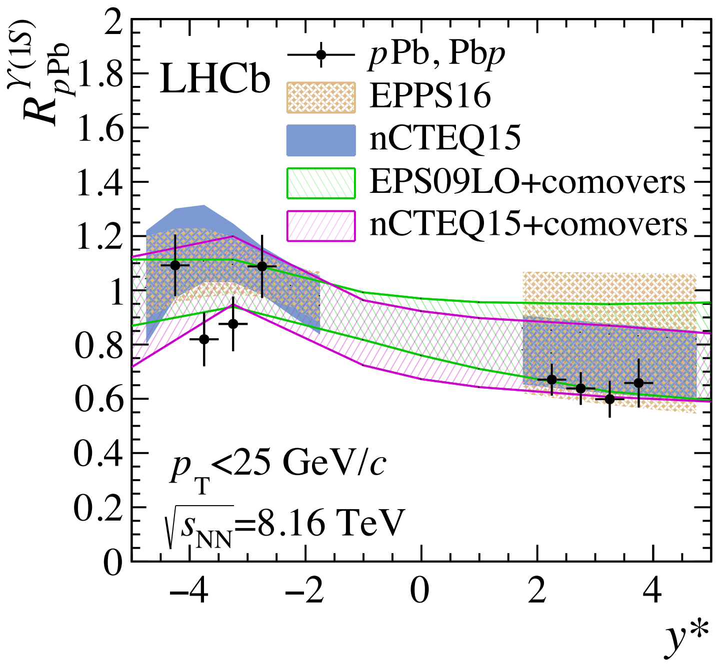
Υ(nS) in HI: probe of deconfinement

LHCb-PAPER-2018-035, arXiv:1810:07655

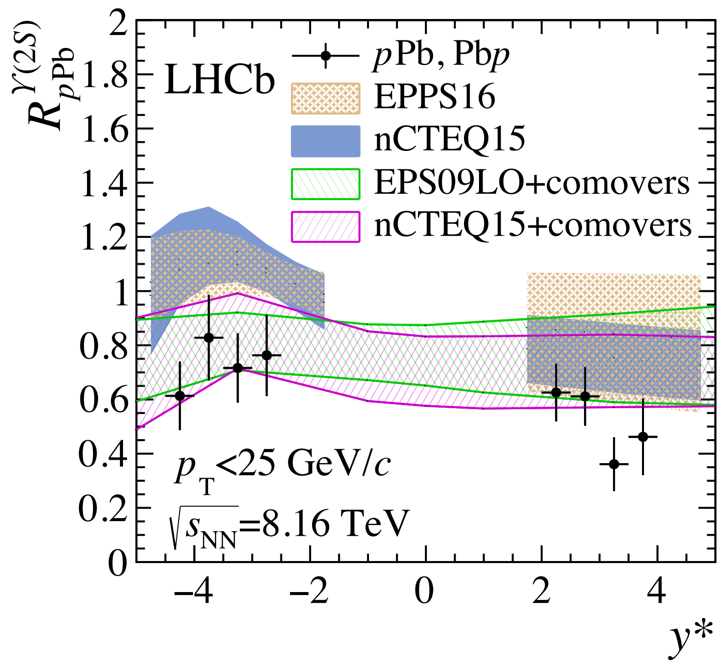


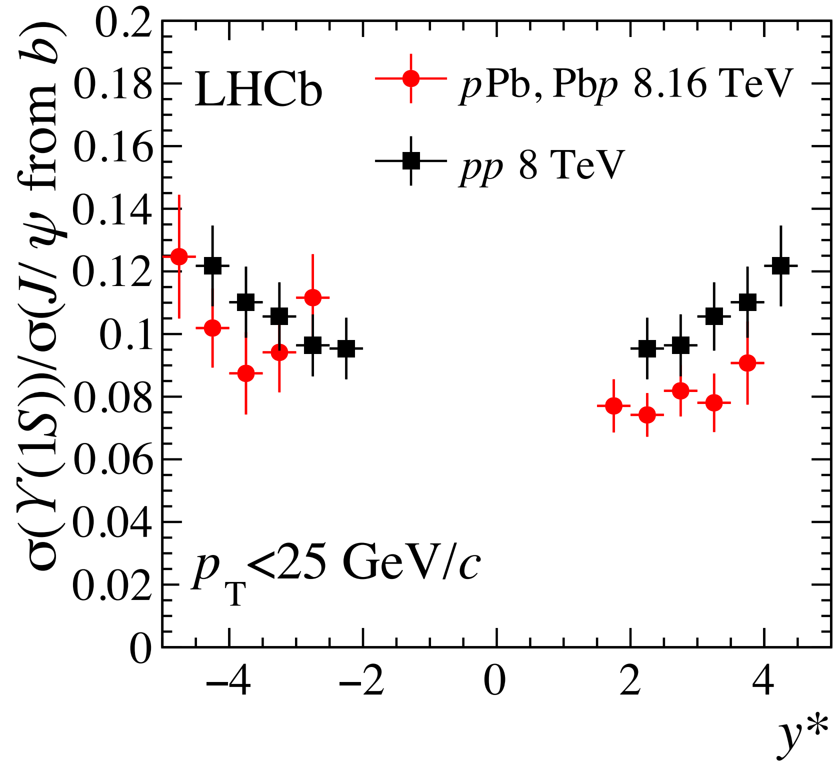
Clean separation of the three nS states

R$_{pPb}$ for Υ(1S)



R$_{pPb}$ for Υ(2S)

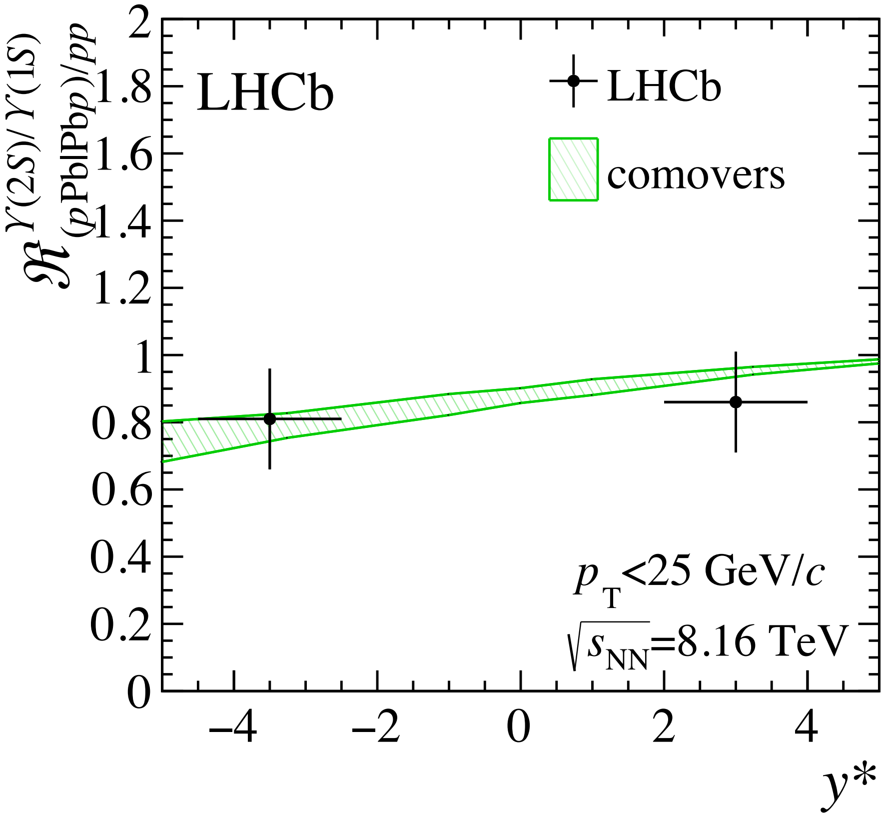




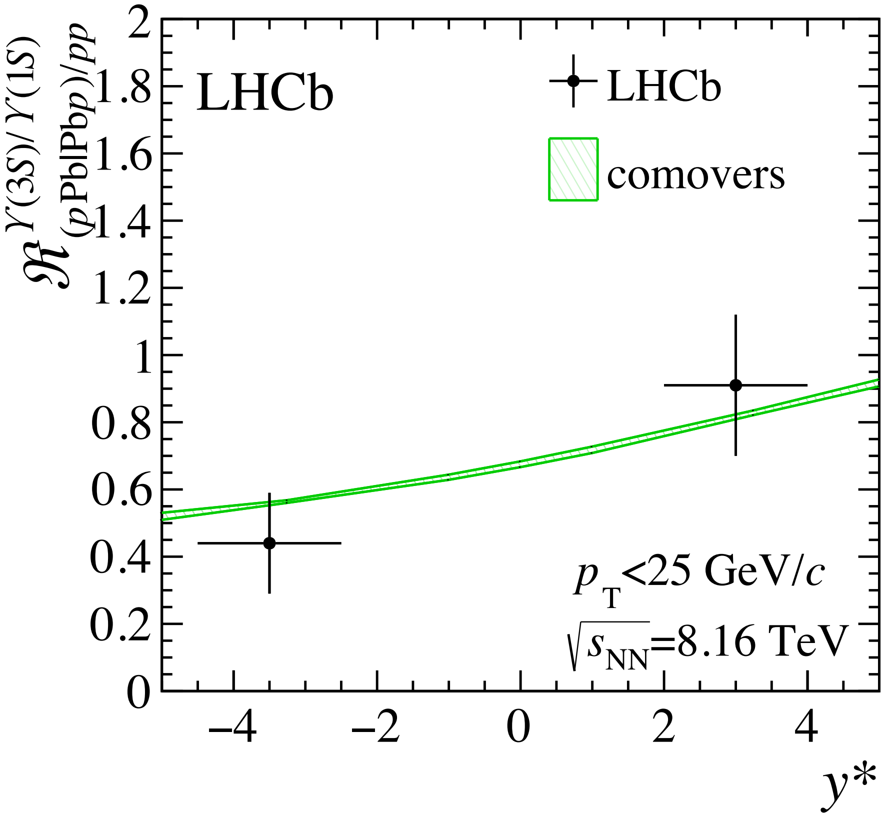
Υ(1*S*): suppressed forward, compatible with unity backward (within nPDF uncertainties)

Υ(1*S*)/J/ψ-from-*b* similar in *pp* & in *p*Pb/Pb*p*:
→ naive approximate expectation in pure nuclear PDF & coherent energy-loss
→ 'additional' suppression for the ground state seems limited

$R_{pPb}(\Upsilon(2S))/R_{pPb}(\Upsilon(1S))$



$R_{pPb}(\Upsilon(3S))/R_{pPb}(\Upsilon(1S))$



$$R(p\mathrm{Pb}/pp)[\Upsilon(2S)] = 0.86 \pm 0.15$$

$$R(p\mathrm{Pb}/pp)[\Upsilon(3S)] = 0.81 \pm 0.15$$

$$R(\mathrm{Pb}p/pp)[\Upsilon(2S)] = 0.90 \pm 0.21$$

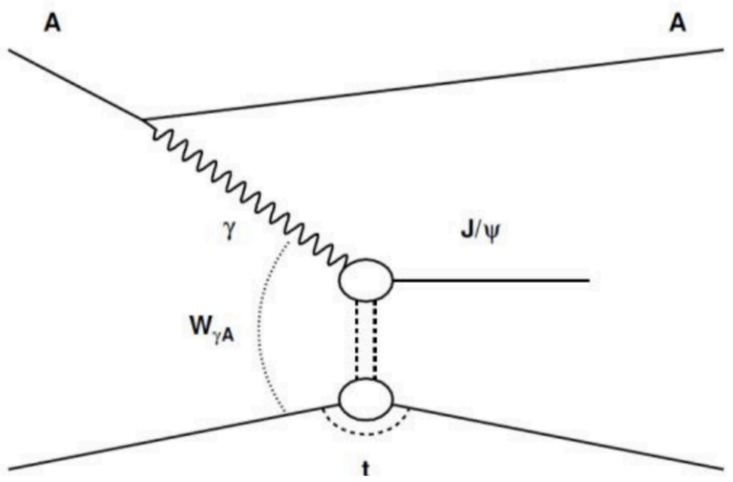
$$R(\mathrm{Pb}p/pp)[\Upsilon(3S)] = 0.44 \pm 0.15$$

Comovers theory model predicts large final-state effects, larger for excited states and in backward direction *(JHEP 10 (2018) 094)*

Additional suppression for exited states, in particular for (3S)

- Patterns observed in data support the comover picture
- Its understanding is crucial for the correct interpretation of the QGP-induced sequential suppression observed in PbPb collisions *(CMS arXiv:1805.09215)*

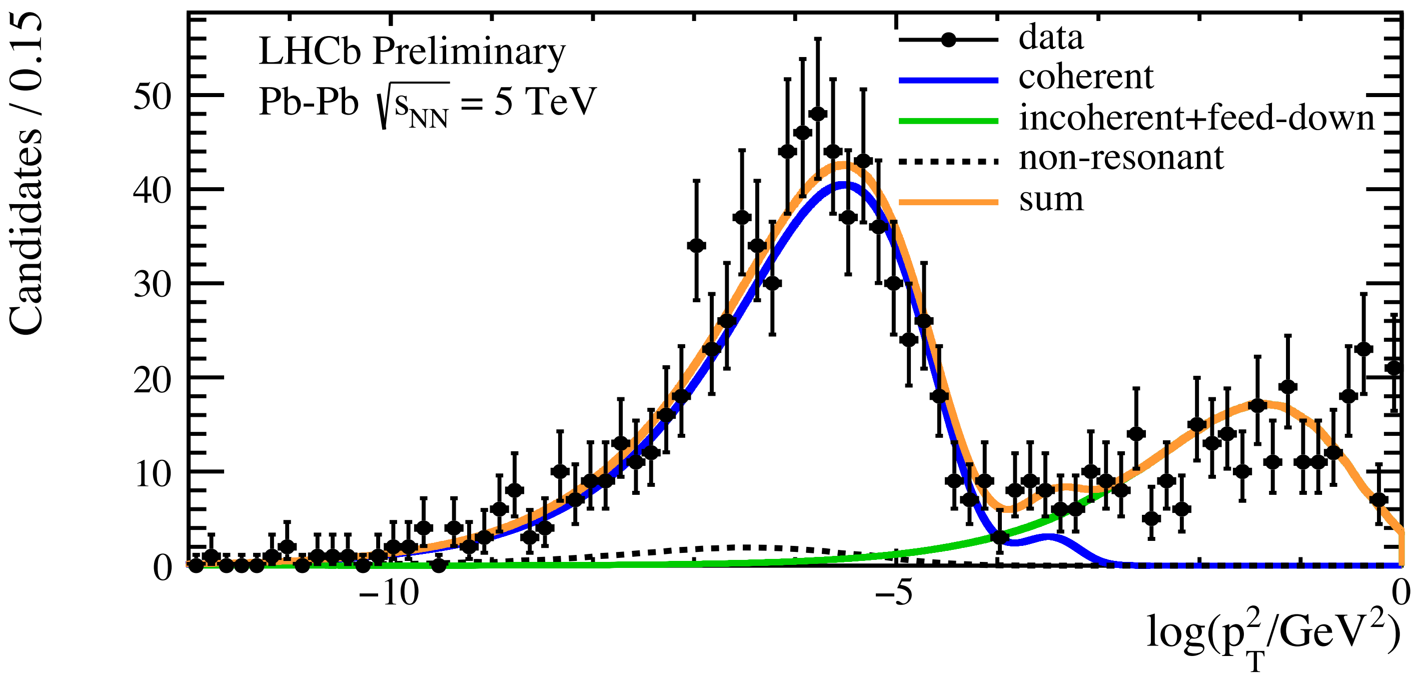
Ultra-Peripheral PbPb collisions: γ-probe of the nucleus

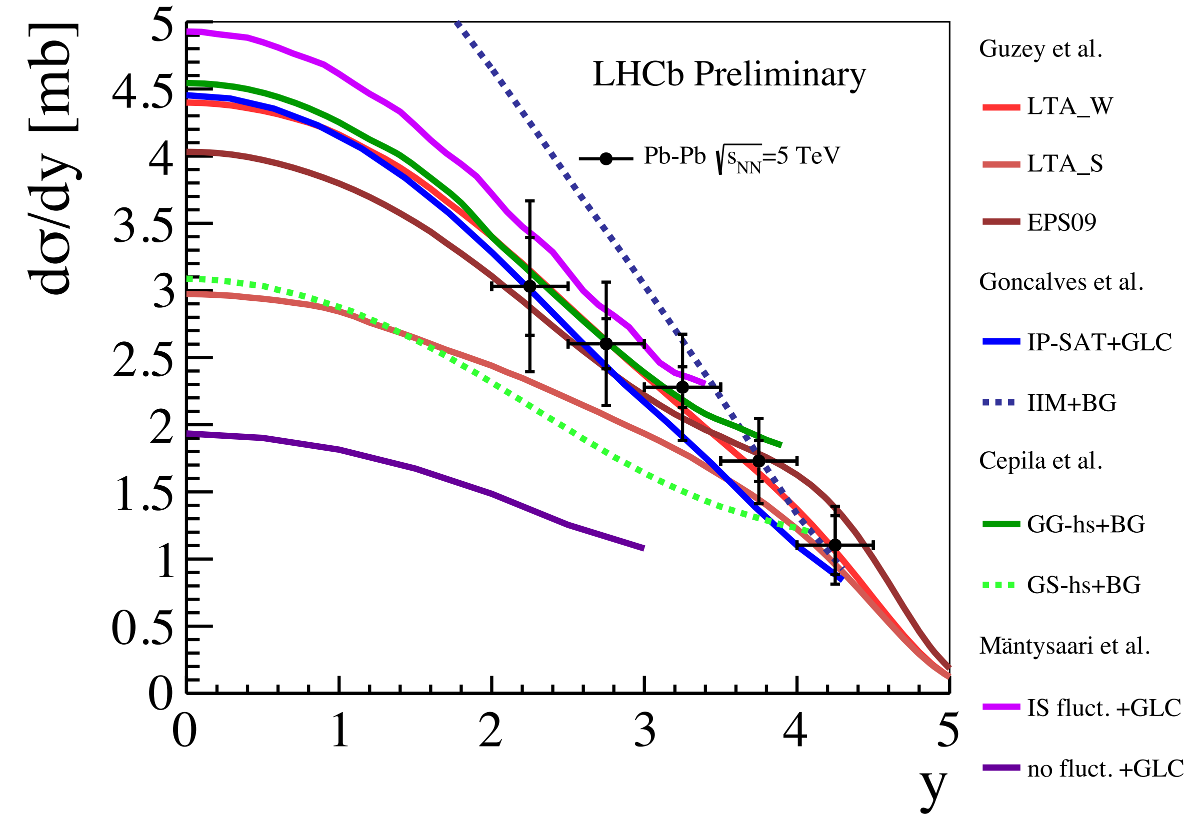


Large cross-sections due to the large e.m. field (photon flux grows with Z^2) of the 2 nuclei

- Exclusive vector meson production via γ-pomeron scattering
- Sensitive to generalised gluon distributions for Bjorken-x $\in 10^{-2}$ -10^{-5}
- For small $q\bar{q}$ at leading twist, leading ln(1/x), $t \to 0$: $\sigma \propto$ (gluon-PDF)^2
- LHCb well suited for exclusive production studies with Pb-beams: resolution, PID & very forward detector (HerSCheL)

UPC for J/ψ in PbPb collisions at 5.02 TeV

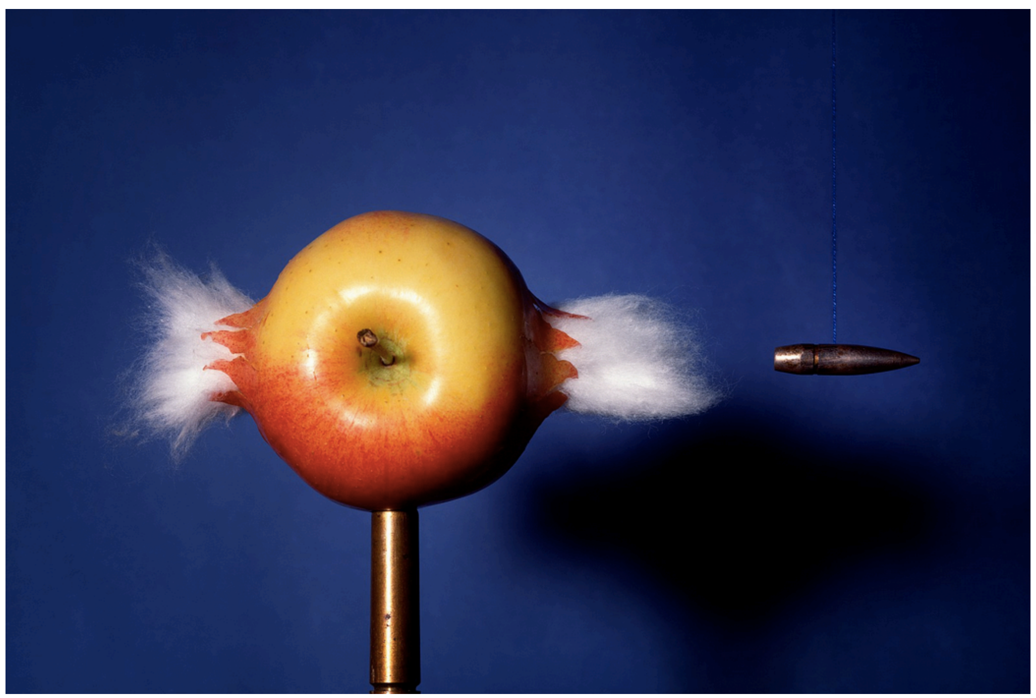


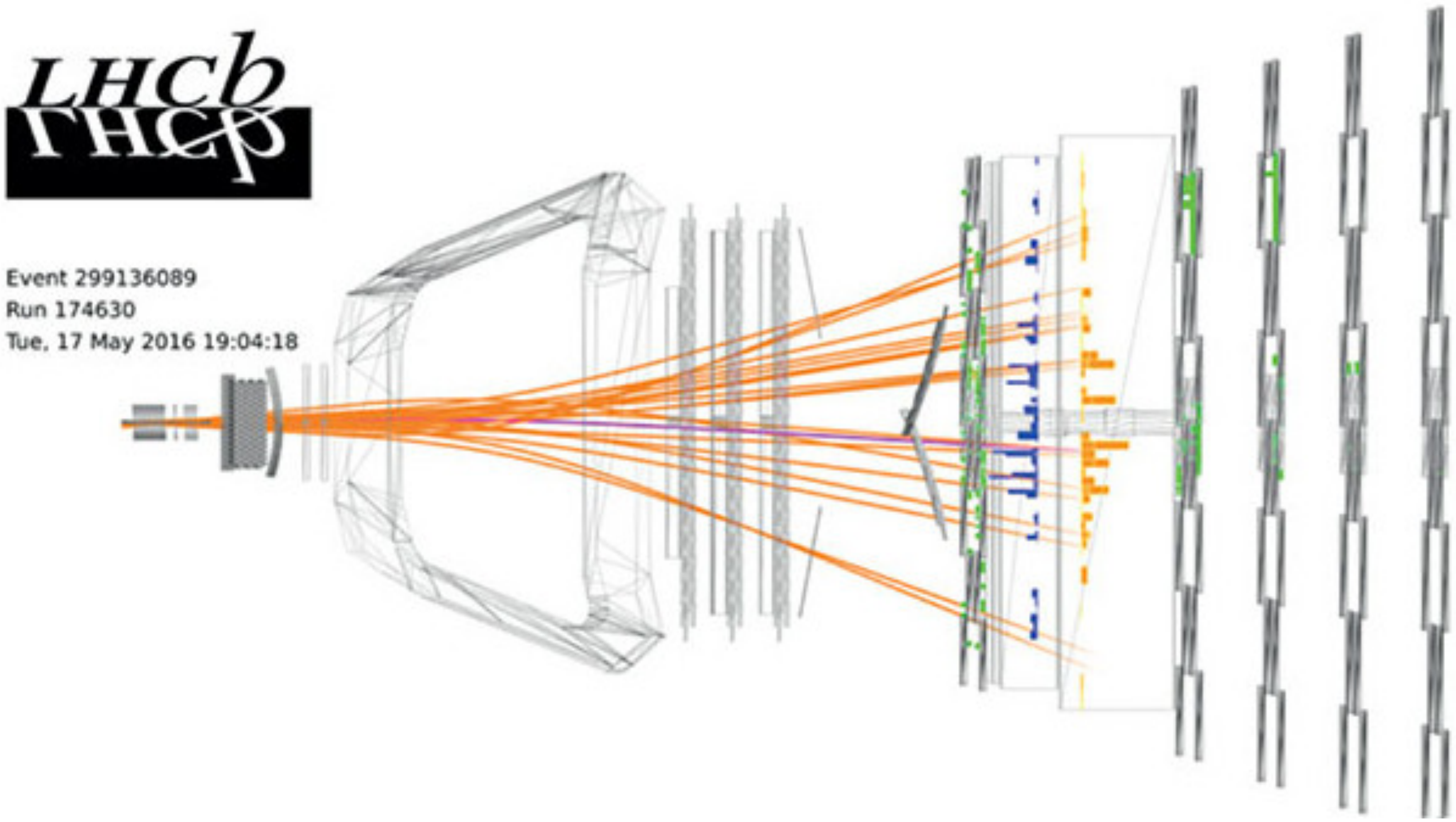


LHCb-CONF-2018-003

- Coherent (whole nucleus) J/ψ production can be well separated from incoherent (γ-nucleons) part
- Coherent photo production cross section sensitive to nPDF
- Covered rapidity range and precision can well constrain the models (2018 data taking gives a big boost)
- Mantysaari model without subnucleonic fluctuations disfavoured —> crucial input for HI

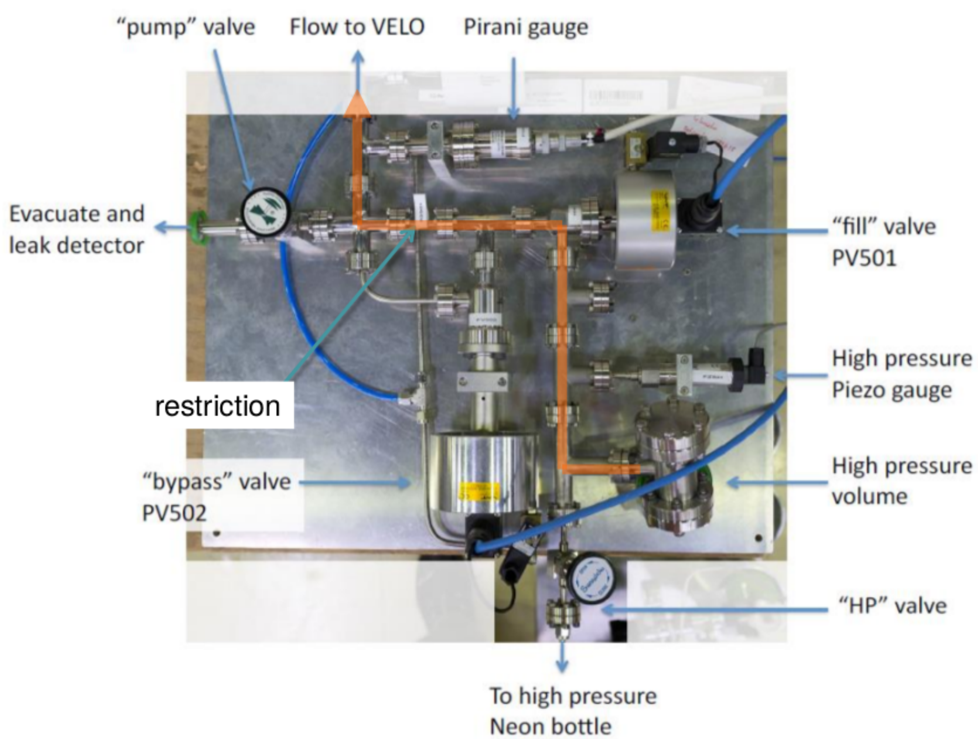
LHCb is the only experiment able to run both in collider and in fixed-target mode



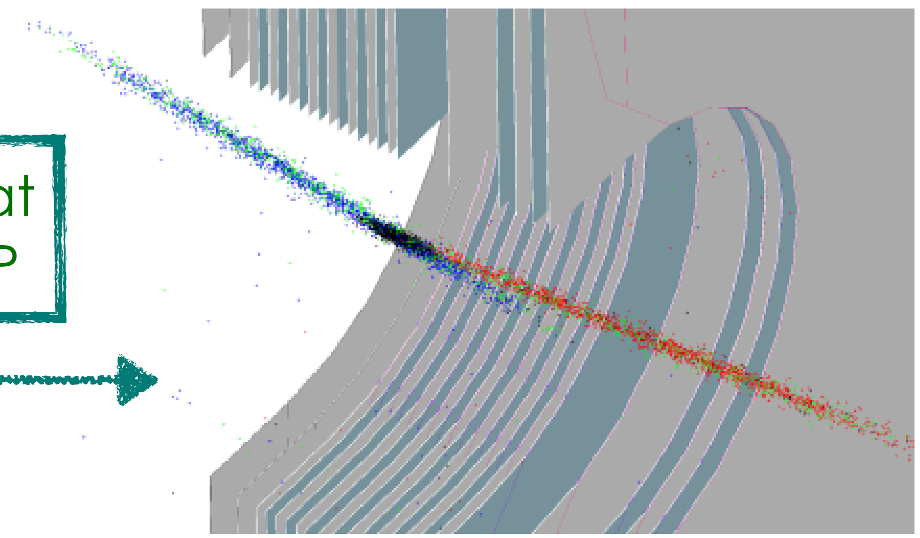


SMOG, a successful idea and a pseudo-target

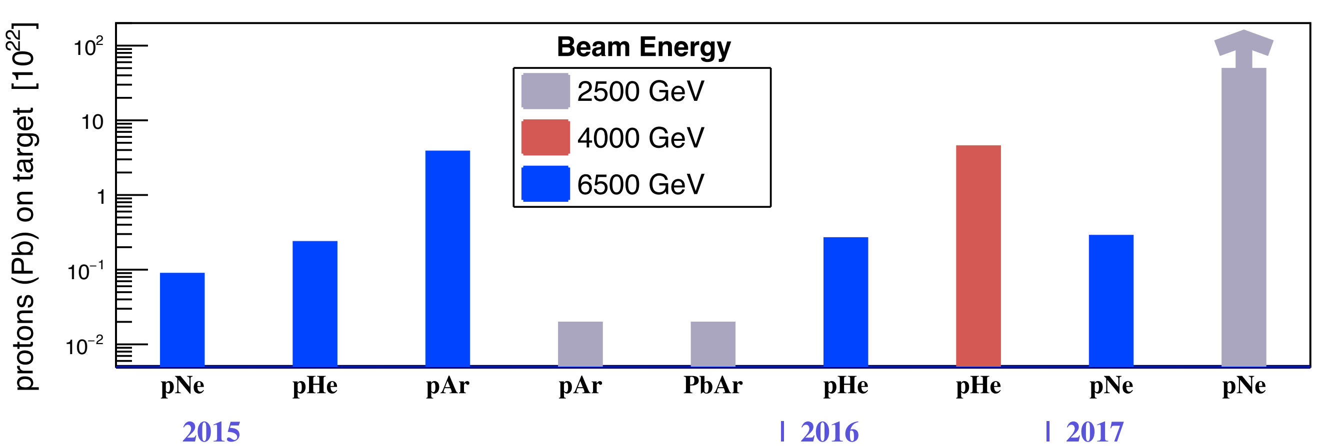
System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a "pseudo-target" producing interesting results

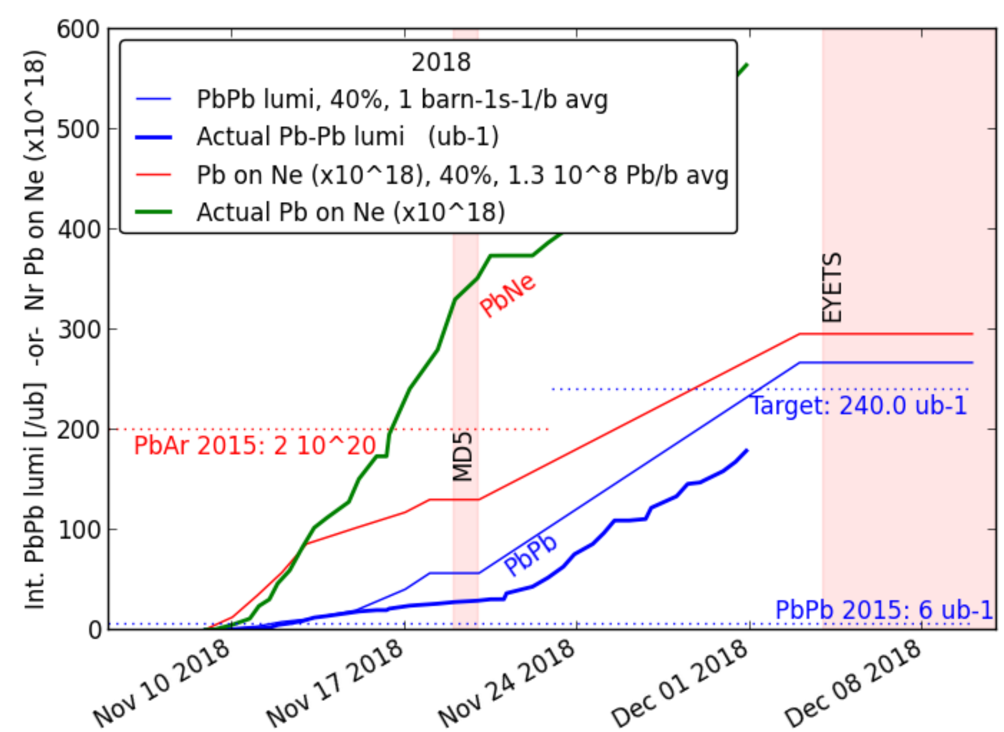


gas injection at
the nominal IP



Data taking SMOG 2015-2017





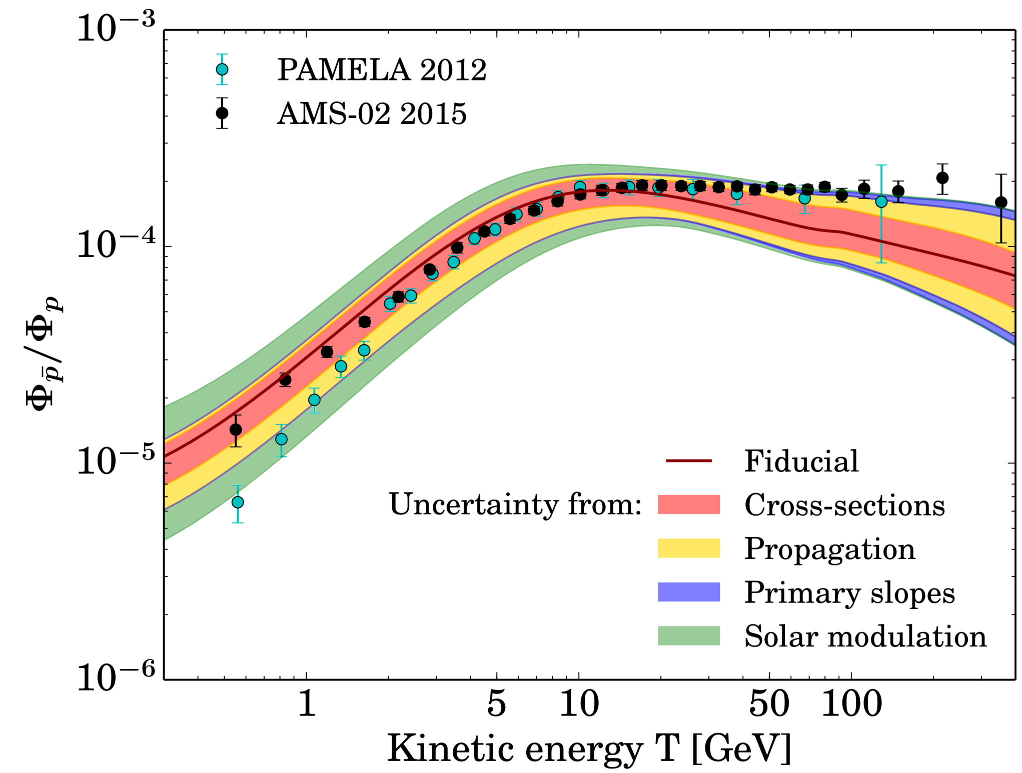
A very successful data taking just concluded

Cosmic Antiprotons

- Precision AMS-02 measurements of $\bar{p}/p$ ratio in cosmic rays at high energies is an indirect search for Dark Matter (PRL 117, 091103 (2016))

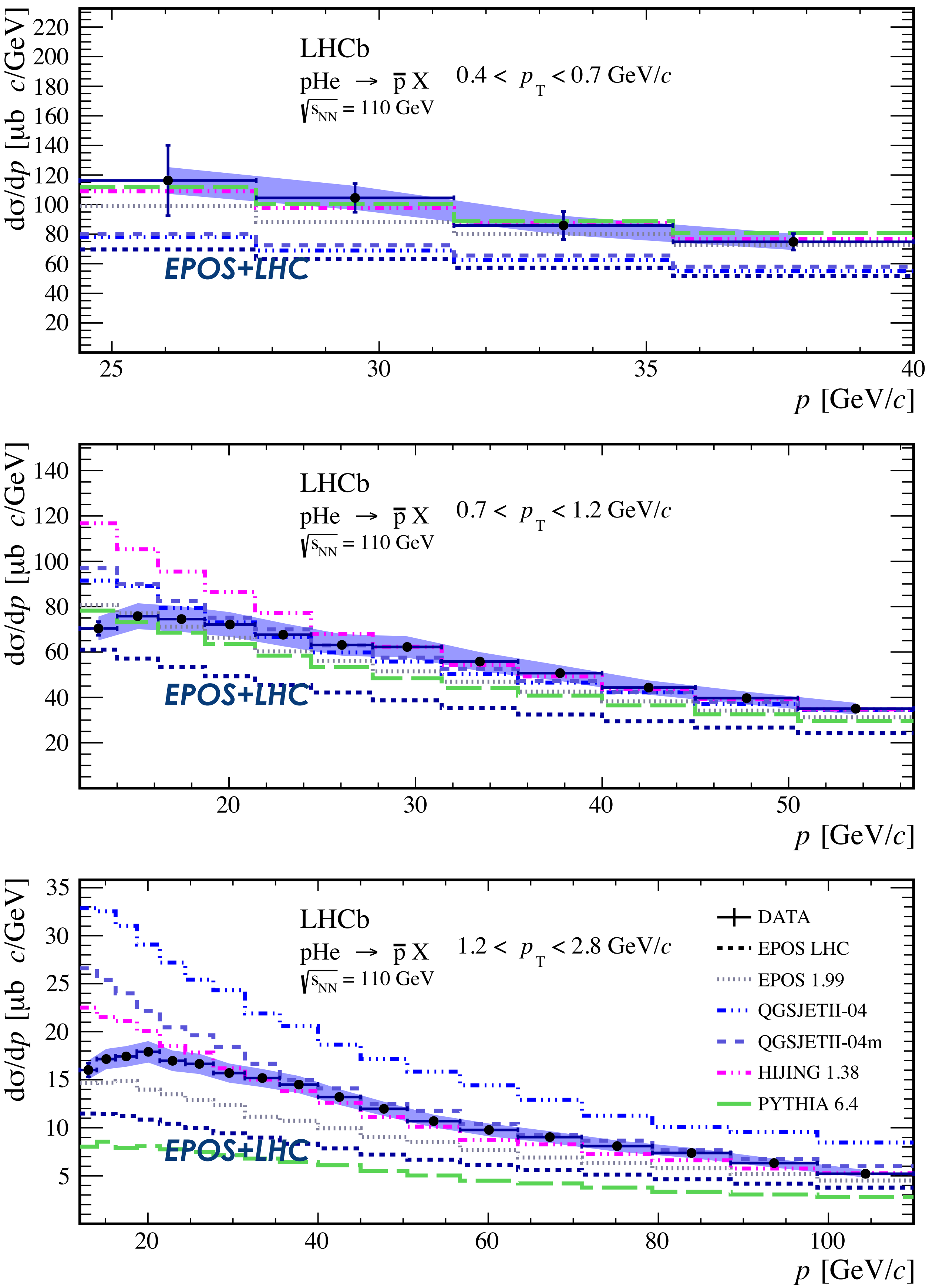
- Data hint for a possible excess, and milder energy dependence than expected

- Prediction for $\bar{p}/p$ ratio from spallation of primary cosmic rays on interstellar medium (H and He) is presently limited by uncertainties on $\bar{p}$ production cross-sections



- Large uncertainties (~ factor 2) on cross-sections from models of hadronic interactions
- Empirical parameterizations mostly based on SPS pp data, but no previous measurement of $\bar{p}$ production in p-He
- Scaling violations at $\sqrt{s_{NN}}$~100 GeV is poorly constrained

The LHC energy scale and LHCb +SMOG is very well suited to this measurement



Phys. Rev. Lett. 121 (2018), 222001 (arXiv:1808.06127)

- Uncertainties are smaller than model spread
- EPOS+LHC_tuning underestimate the $\bar{p}$-production
- … but then the visible inelastic cross section is compatible with EPOS-LHC:

$$\sigma_{\rm vis}^{\rm LHCb}/\sigma_{\rm vis}^{\rm EPOS-LHC} = 1.08 \pm 0.07 \pm 0.03$$

—> discrepancy: $\bar{p}$ yield/event

Fundamental contribution able to shrink the background uncertainties in dark matter searches in space

Natural pHe extensions:

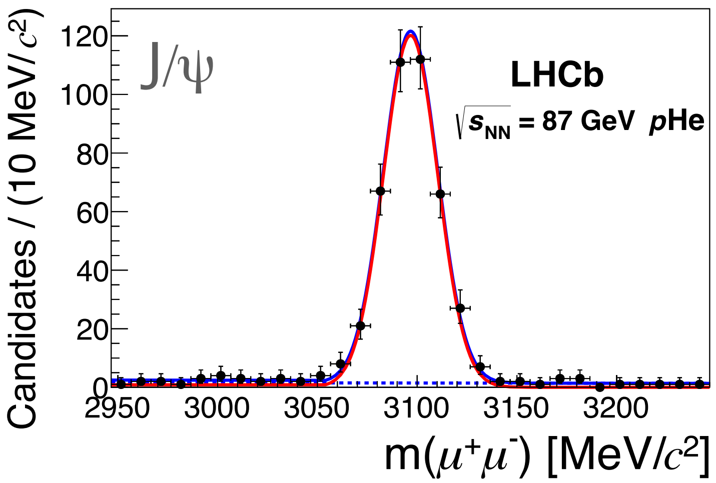
- inclusive $\bar{p}$ from hyperon decays

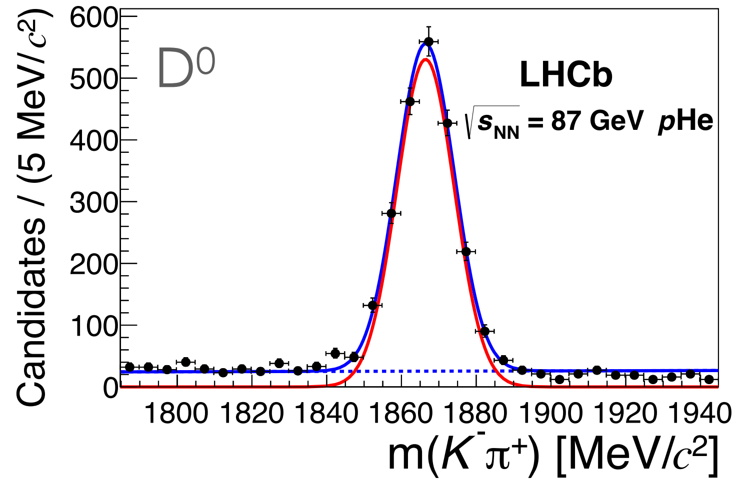
-charged π,K,p spectra

-$\sqrt{s_{NN}}$=87 GeV data

Charm production in fixed targets

Submitted to PRL (arXiv:1810.07907)

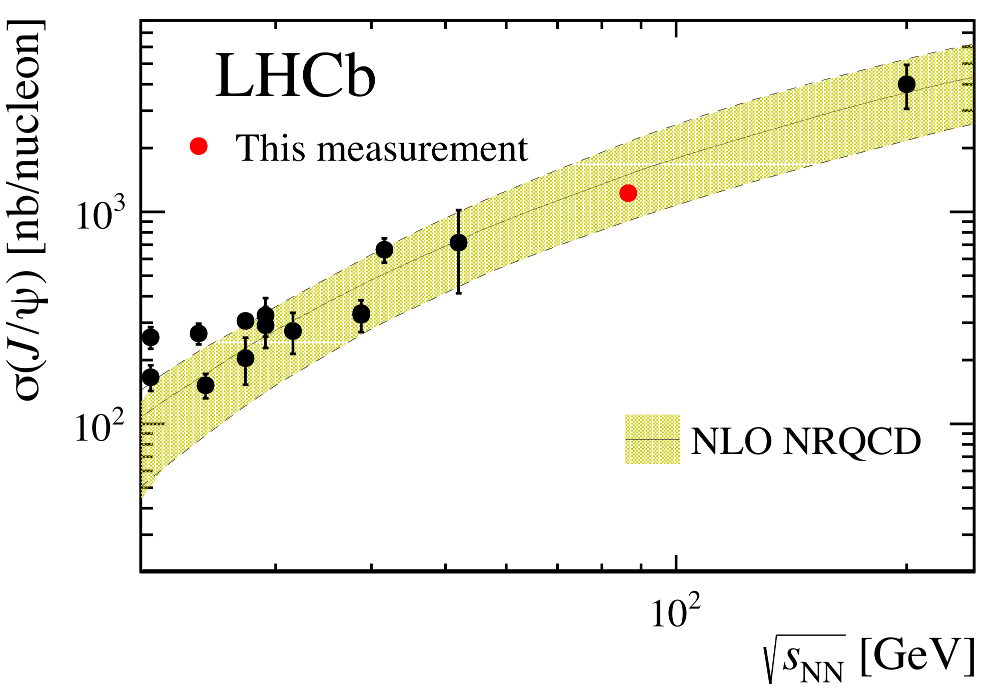


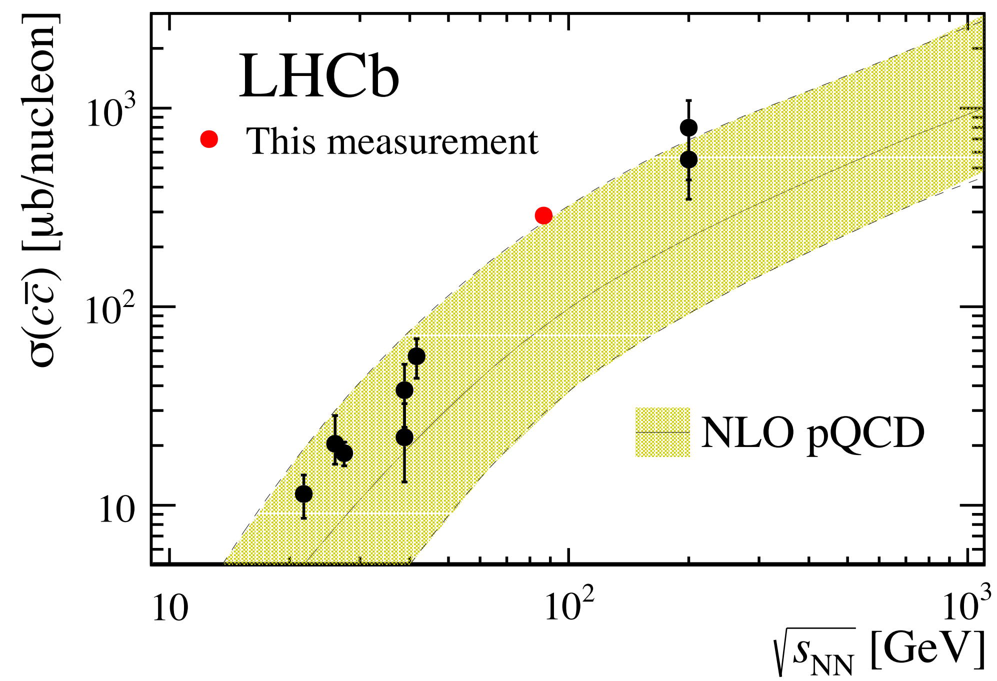


First LHCb charm samples from:

pHe@69 GeV (7.6 ± 0.5 nb^{-1}) and

pAr@110 GeV (few nb^{-1})





First determination of $c\bar{c}$ cross-section at this energy scale

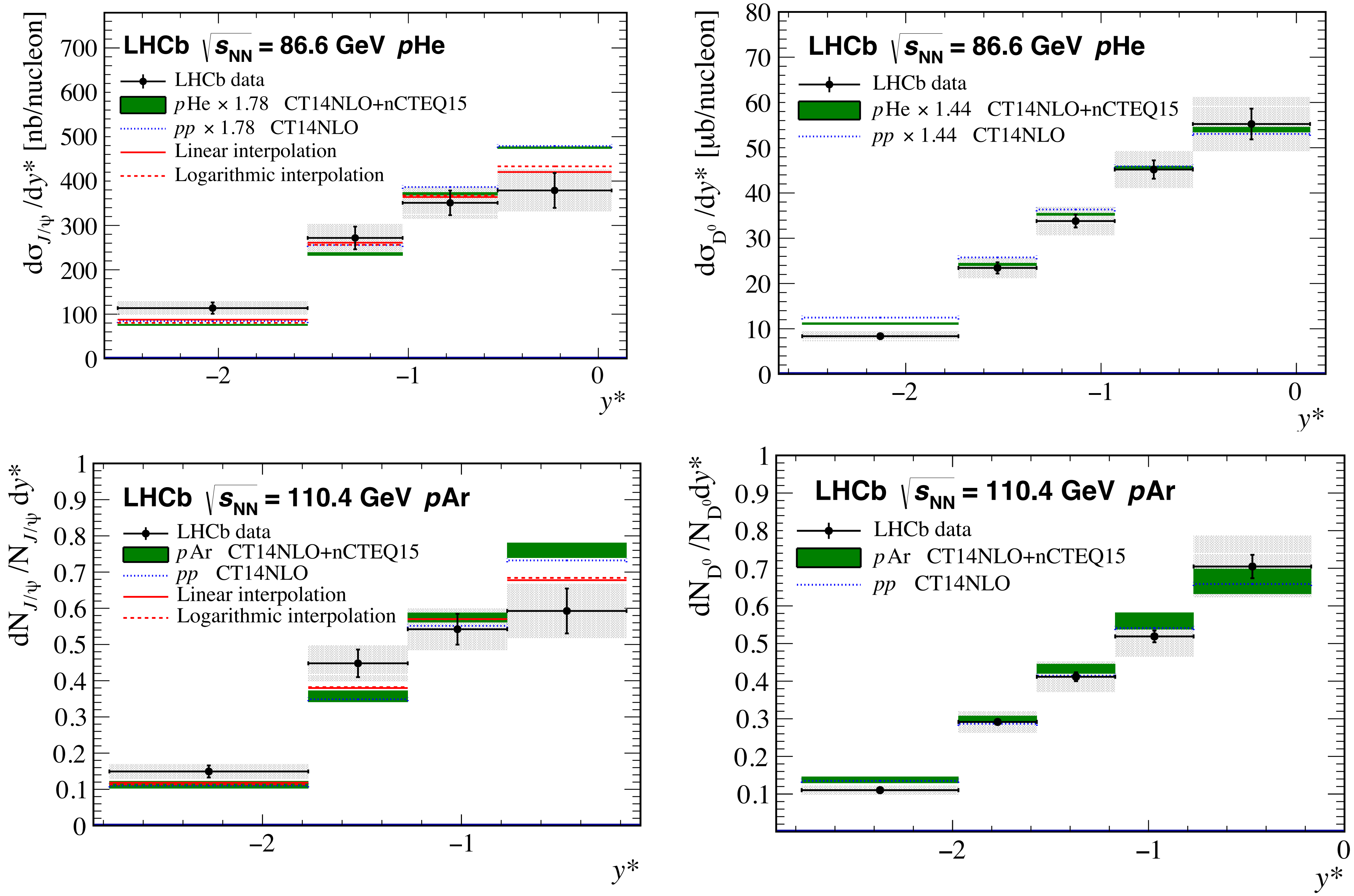
LHCb results in good agreement with NLO NRQCD fit (J/ψ, left) and NLO pQCD predictions (cc, right) and other measurements

Submitted to PRL (arXiv:1810.07907)

J/ψ D^0

He

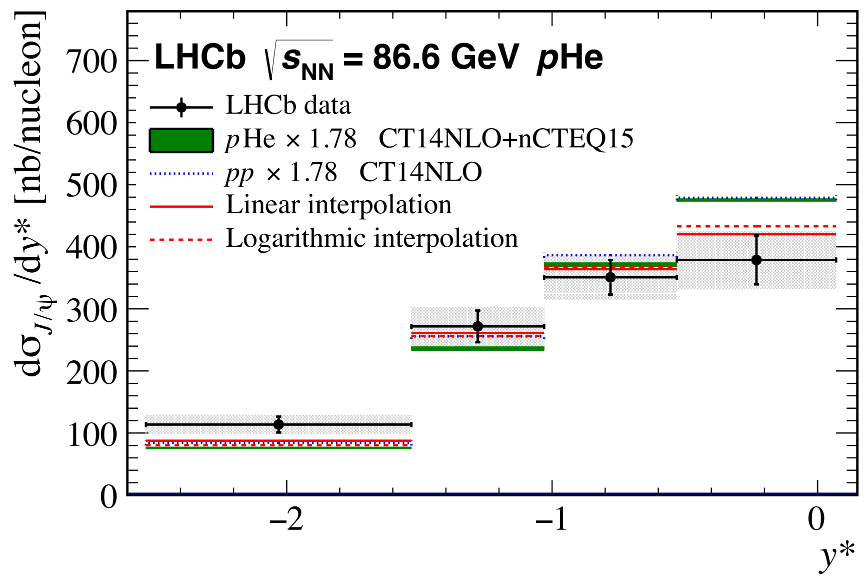
Ar

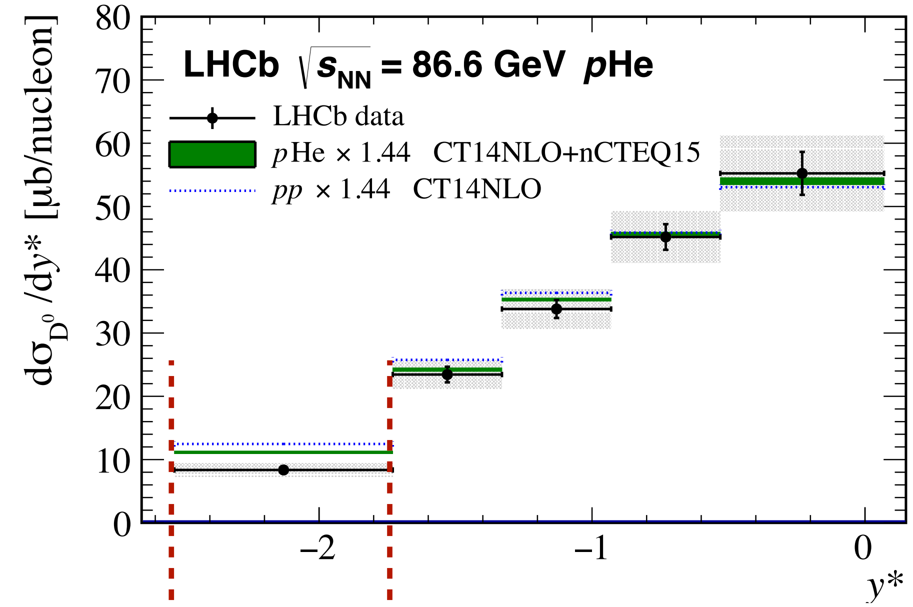


- Good agreement of phenomenological predictions with y*-shape, poor in p_T (not shown here) … gluon dominance?
- HELAC-ONIA, designed and tuned for collider data, underestimate the J/ψ (D^0) pHe-cross section by a factor 1.78 (1.44)

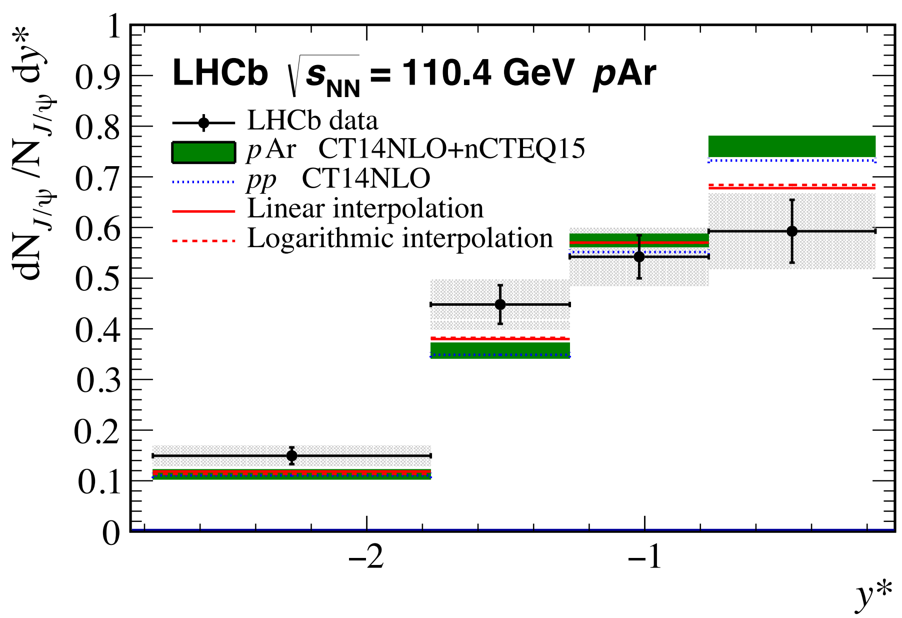
J/ψ D^0 Submitted to PRL (arXiv:1810.07907)

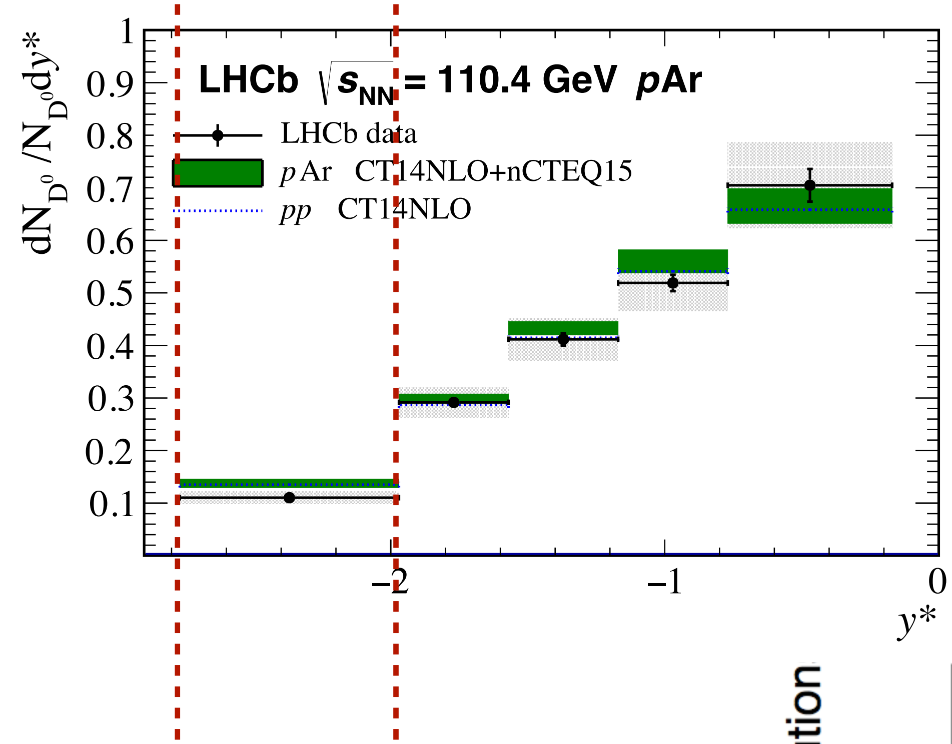
He





Ar

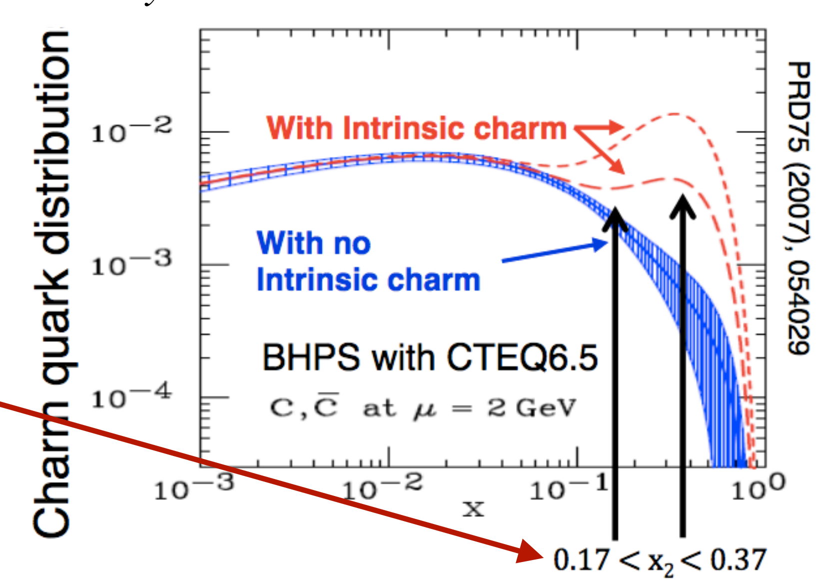




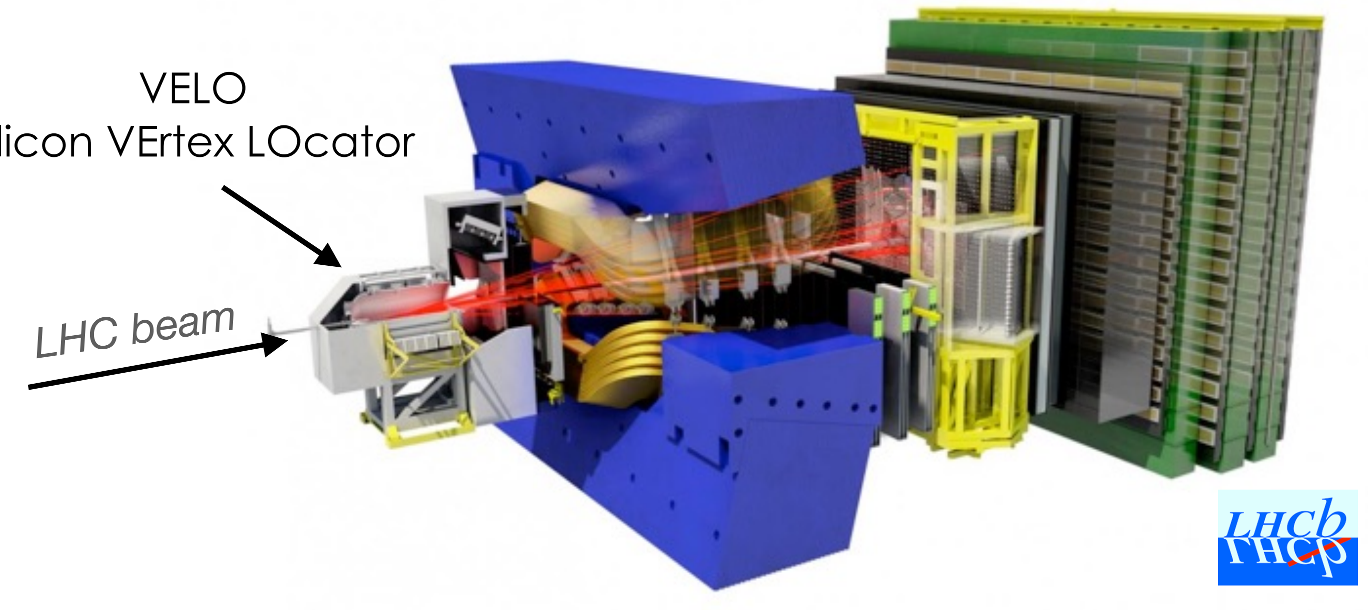
$-2.53 < y^* < -1.73$

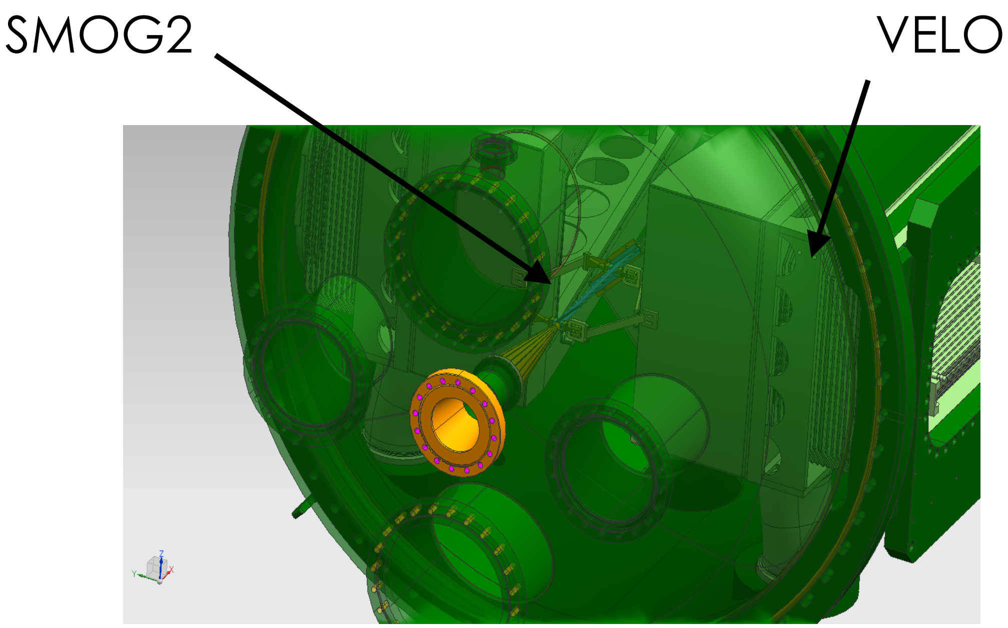
$0.17 < x_2 < 0.37$

- HELAC-ONIA does not contain intrinsic charm contribution
- No evidence for sizeable valence-like intrinsic charm contribution

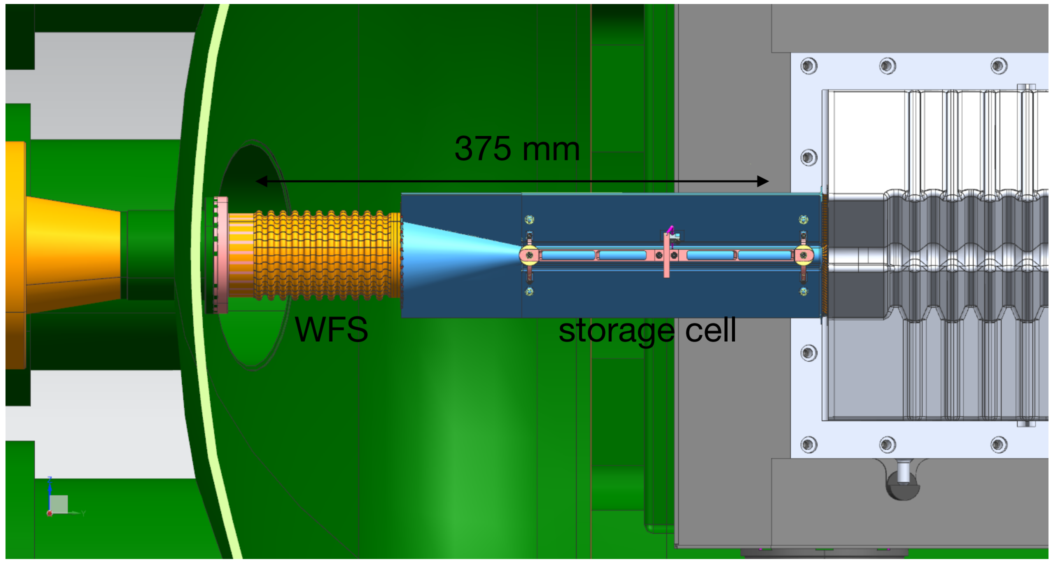


A real storage cell - **SMOG2** - will be installed during the LHC LS2 and start taking data from 2021





inside the LHC primary vacuum



Internal side view

- Increase of the luminosity by up to 2 orders of magnitude using the same gas load as SMOG
- Injection of $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$
- New Gas Feed System will give a strong improvement on the luminosity determination
- Well defined interaction region upstream the nominal IP: strong background reduction and also the possibility to run in parallel with pp collisions

Conclusions

- LHCb developed a lively and fast growing heavy-ion program, with very specific capabilities and unique acceptance at a hadron collider
- Much more data from Run 2 to be analyzed and substantial development of the program in the next future with an upgraded spectrometer and a real storage cell

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- Much more data from Run 2 to be analyzed and substantial development of the program in the next future with an upgraded spectrometer and a real storage cell

Heavy-Ion and Fixed-Target collisions at LHCb offer a unique opportunity for *a laboratory for QCD and astroparticle* in unexplored kinematic regions