New high resolution measurements of open and hidden charm production in proton-nucleus collisions at $\sqrt{s} = 110$ GeV with LHCb

Émilie Maurice on behalf of the LHCb collaboration

XXVI international conference on ultrarelativistic heavy-ion collisions,
Quark Matter, 7$^{\text{th}}$ February 2017

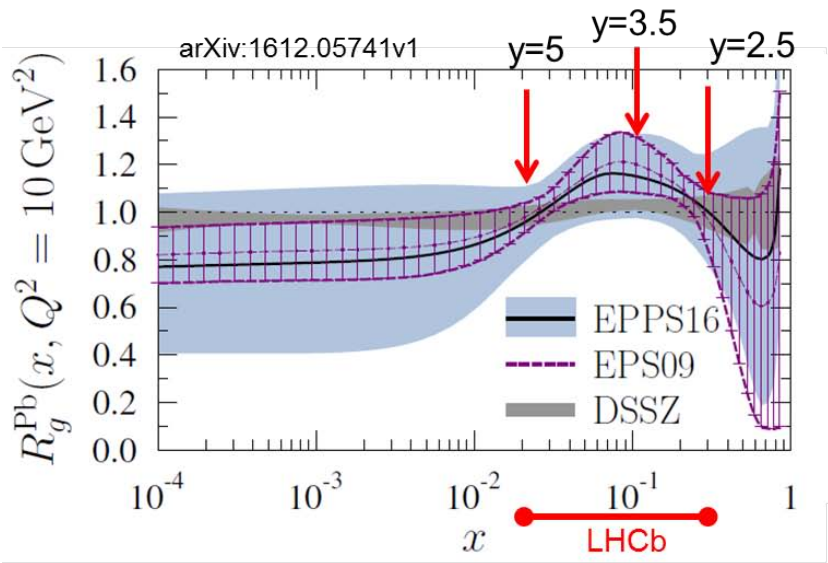
Fixed target proton-nucleus program at LHCb

LHCb designed for b, c physics; general purpose detector in the forward direction

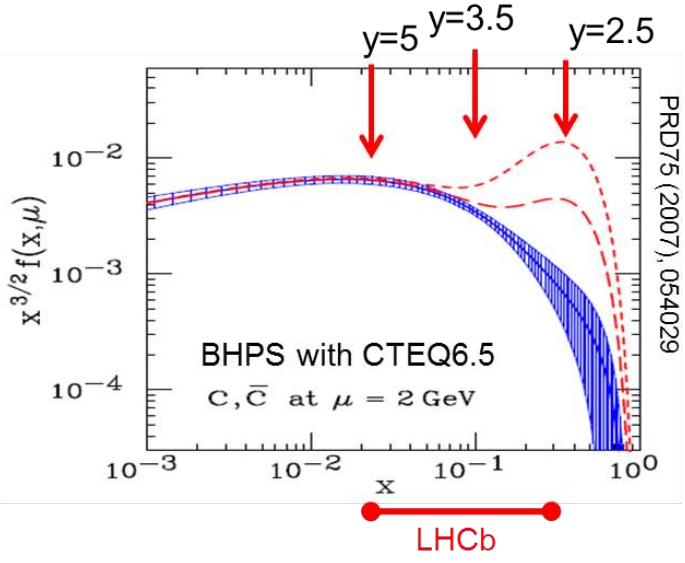
Unique oppportunity to perform fixed-target mode program at LHC:

- Forward measurement of open and hidden charm production ($J/\psi, D^0$...)
- Measurement down to low p_{T}
- Large rapidity coverage ($\sim$ 3 rapidity units) at large Bjorken-x

Access to nPDF anti-shadowing region



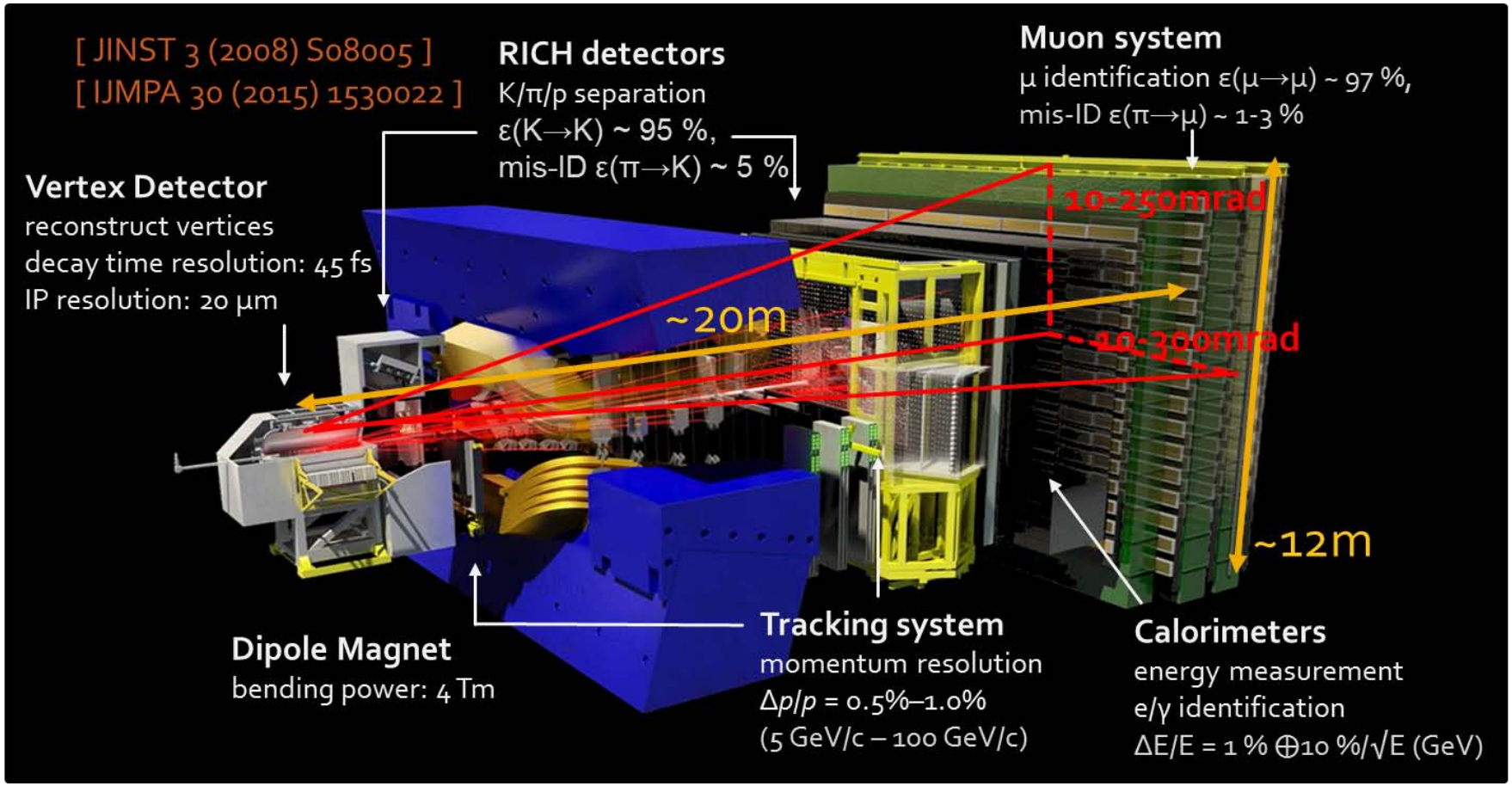
Access to intrinsic charm content in the nucleon



Proton-nucleus collisions provide reference for heavy ions studies

LHCb detector

Single arm spectrometer in the forward region, fully instrumented in $2 < \eta < 5$



→ **LHCb can operate in fixed-target mode**

LHCb - SMOG

SMOG: System for Measuring Overlap with Gas

- Injecting noble gas (He, Ne, Ar, ...) in the Vertex Detector
- Primary role: beam-gas imaging for luminosity measurement

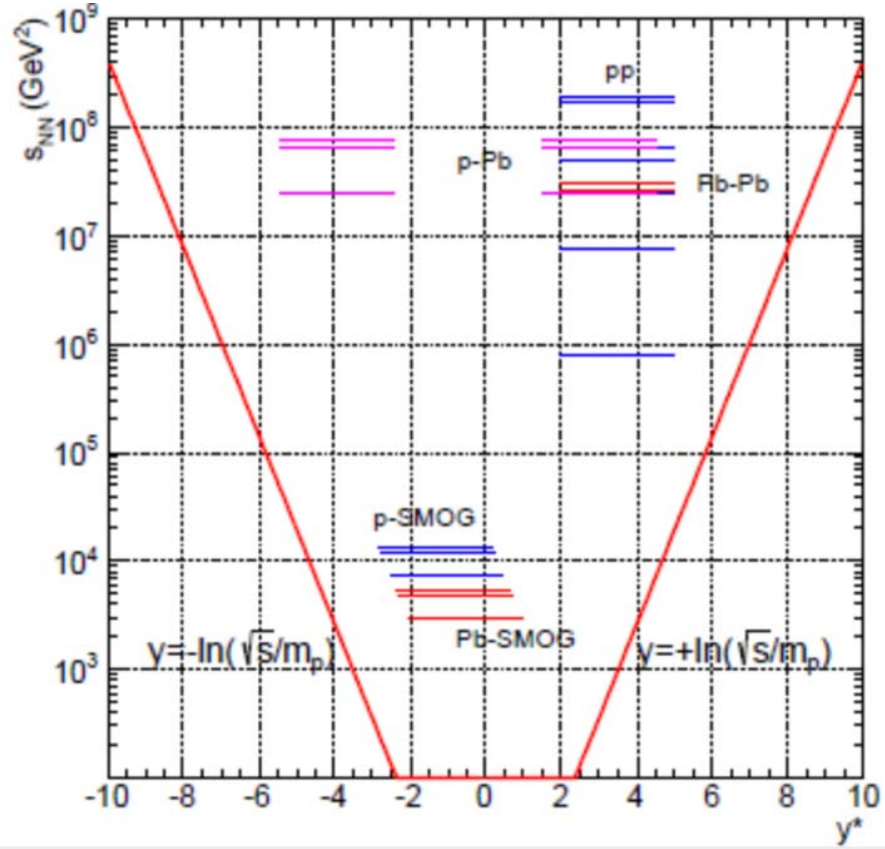
→ Can be used as an internal gas target ($\approx 10^{-7}$ mbar)

Fixed-target mode

- Parasitic to the collider mode
- Gas spreads in the beam pipe up to $\pm$20m around LHCb
- Use non-colliding bunches

Fixed-target specs

- With 2.5 to 7 TeV proton beams: $\sqrt{s_{NN}} \in [69, 115]$ GeV
- With 2.5 TeV Pb beams: $\sqrt{s_{NN}} = 69$ GeV
- Backward rapidity region $y^* = y - 4.77$



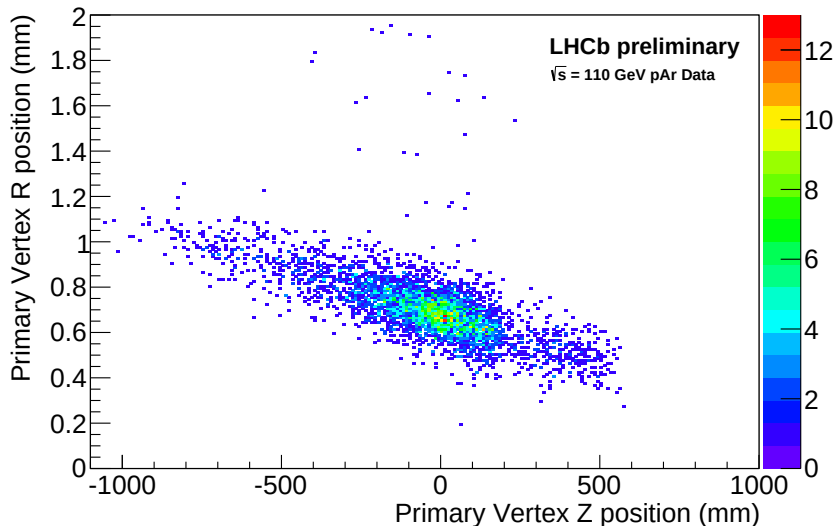
LHCb fixed-target mode: *p*Ar analysis

Study the J/ψ and D^0 production in *p*Ar collisions at $\sqrt{s_{NN}} = 110$ GeV
in rapidity and transverse momentum bins

LHCb-CONF-2017-001

First measurement of heavy-flavour production with LHCb in fixed-target mode

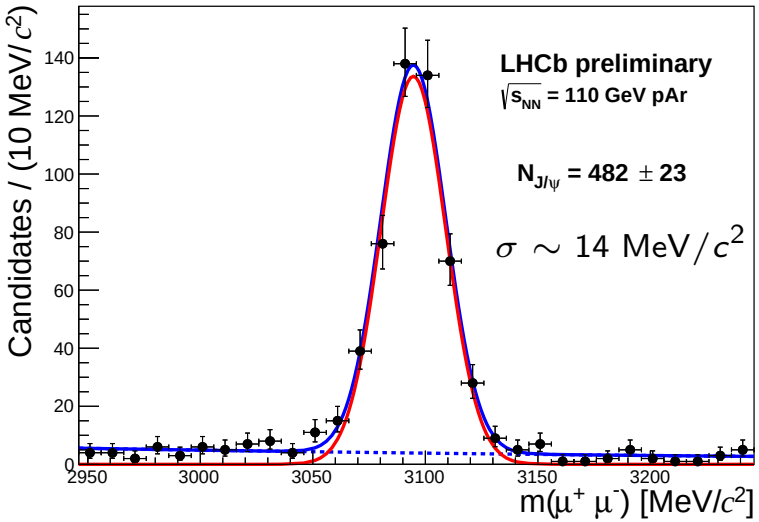
- 6.5 TeV proton beam on argon gaseous target $\approx 10^{-7}$ mbar
- During $\sim$ 17h, $\sim 4 \times 10^{22}$ protons on target
- Reconstructed collision vertices extended over $\sim$1m

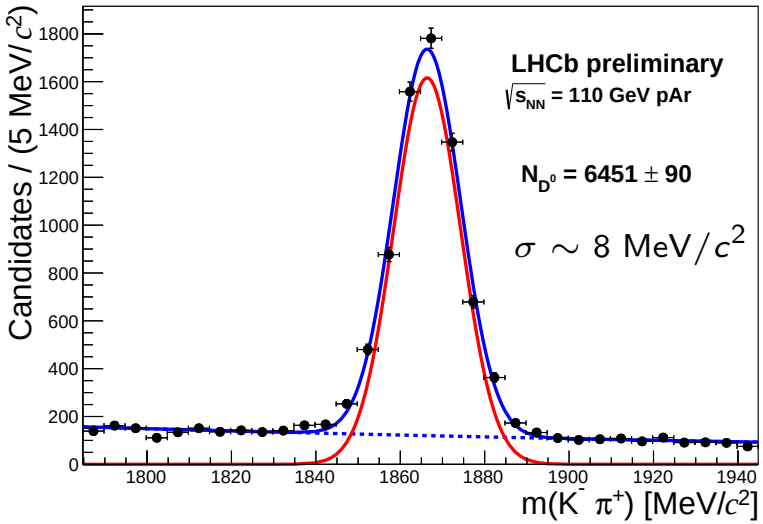


Signal extraction

Select events with Z_{vertex} inside the Vertex Detector, $Z_{vertex} \in [-200, +200]$ mm

J/ψ and D^0 signal are extracted using Crystal Ball functions



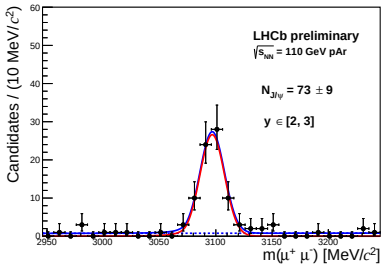
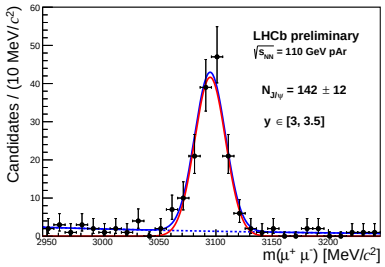
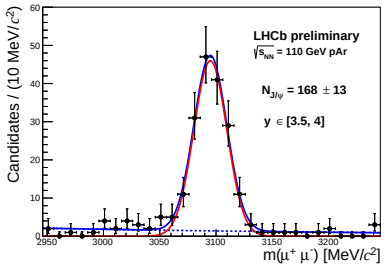
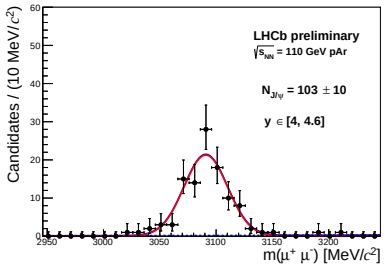
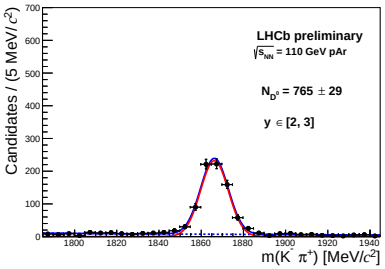
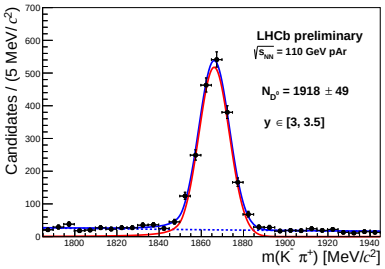
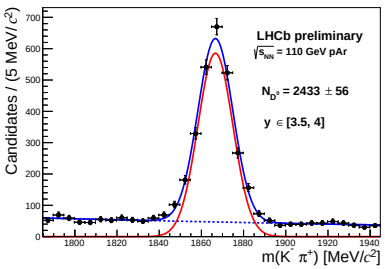
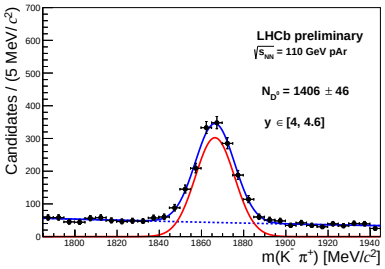


$\sim 500\ J/\psi \to \mu^+\mu^-$

$\sim 6\,500\ D^0 \to K^\mp\pi^\pm$

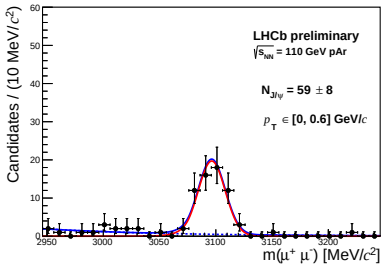
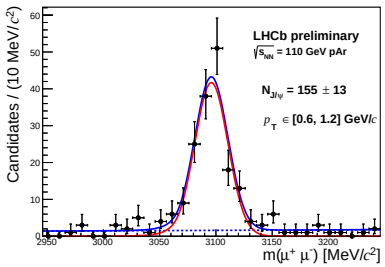
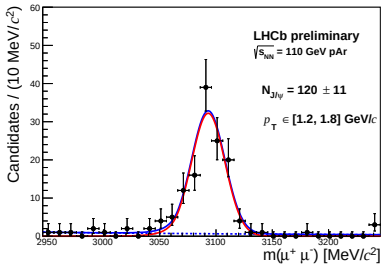
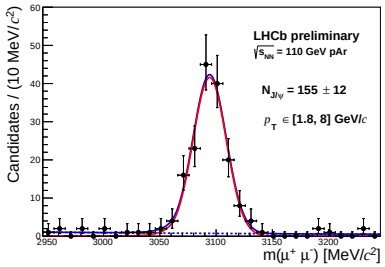
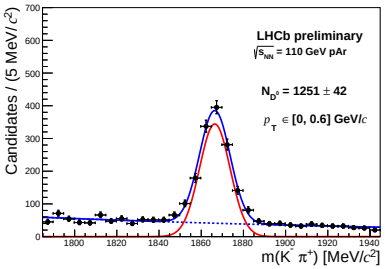
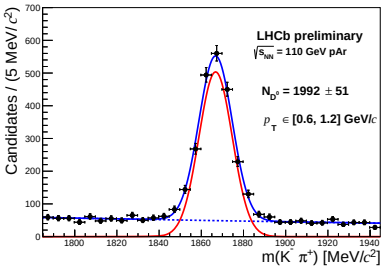
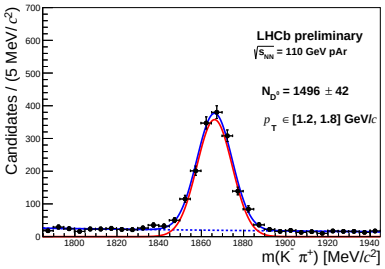
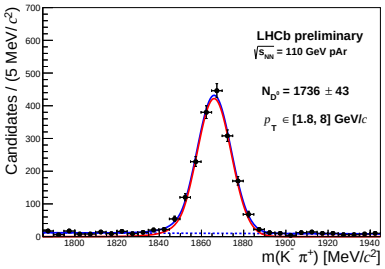
Differential production: rapidity

J/ψ and D^0 signal extracted independently in 4 rapidity bins

	$y \in [2, 3]$	$y \in [3, 3.5]$	$y \in [3.5, 4]$	$y \in [4, 4.6]$
J/ψ				
D^0				

Differential production: transverse momentum

J/ψ and D^0 signal extracted independently in 4 transverse momentum bins

	[0, 0.6] GeV/c	[0.6, 1.2] GeV/c	[1.2, 1.8] GeV/c	[1.8, 8] GeV/c
J/ψ				
D^0				

Yield corrections and uncertainties

$$N^k = \frac{N_k^{measured}}{\epsilon^k} \quad \text{with } k = J/\psi, D^0$$

$N_k^{measured}$ extracted from mass fits are corrected for different efficiencies:

$$\epsilon^k = \epsilon^k_{acc} \times \epsilon^k_{trig} \times \epsilon^k_{sel} \times \epsilon^k_{reco} \times \epsilon^k_{PID}$$

geometrical acceptance, trigger, selection, reconstruction, particle identification

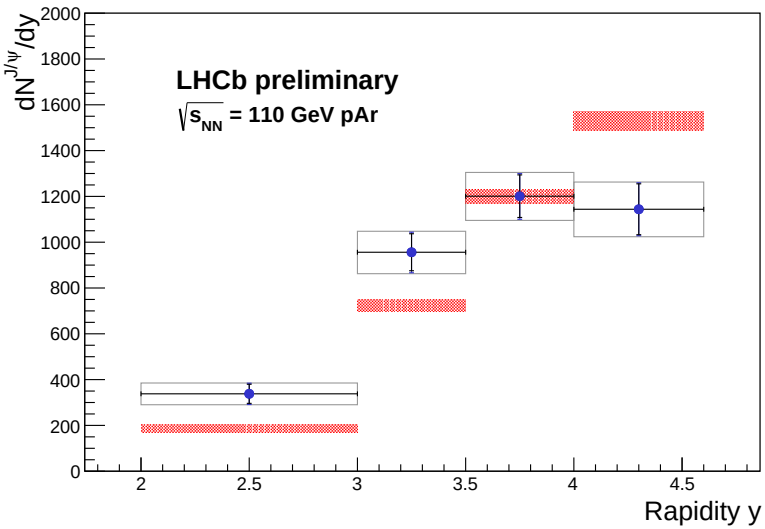
Corrections are computed using *p*Ar simulation samples and *pp* 13 TeV data

Source of uncertainties	J/ψ y	J/ψ p_T	D^0 y	D^0 p_T
Corr. between bins				
Signal selection	1.4%	1.4%	2.2%	2.2%
Signal extraction	2.3%	2.3%	2.3%	2.7%
Uncorr. between bins				
MC sample	(1.2 – 2.6)%	(0.9 – 1.4)%	(1.0 – 1.9)%	(1.0 – 1.5)%
Tracking	(2.2 – 3.7)%	(2.2 – 2.9)%	(2.7 – 3.4)%	(2.8 – 3.6)%
PID	(0.2 – 2.7)%	(0.1 – 2.0)%	(4.1 – 8.8)%	(4.8 – 6.9)%
Stat. uncertainties	(7.7 – 12.5)%	(7.8 – 13.6)%	(0.7 – 3.7)%	(0.6 – 3.4)%

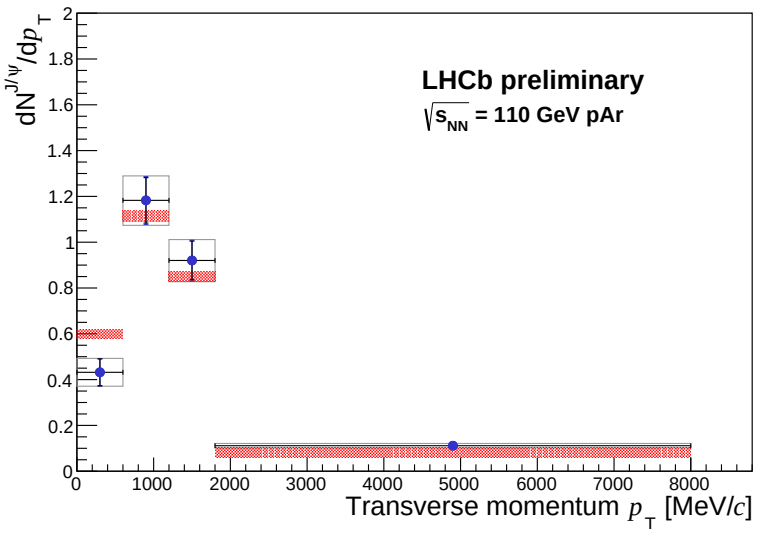
J/ψ uncertainties are dominated by statistical uncertainties

J/ψ corrected yields

Rapidity y



Transverse momentum p_{T}



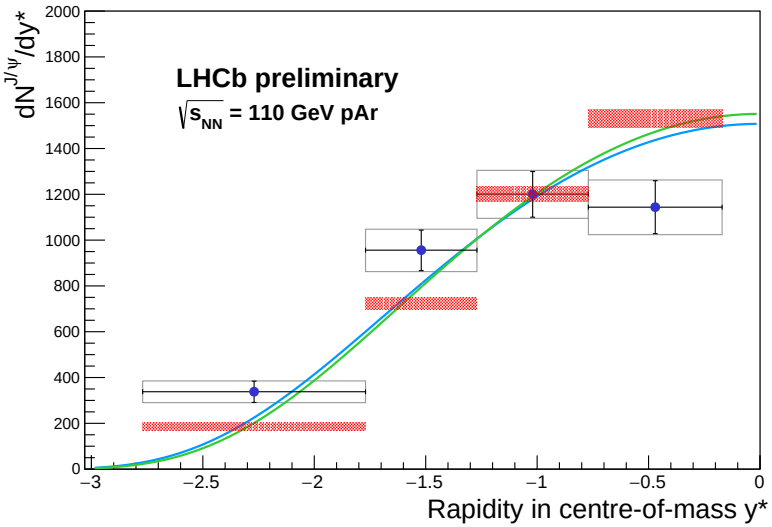
- Blue points: data $\frac{dN^{J/\psi}}{dy}, \frac{dN^{J/\psi}}{dp_{\mathrm{T}}}$
- Vertical lines: stat. uncertainties (black), uncorrelated syst. uncertainties (blue)
- Box: Quadratic sum of statistical, uncorrelated and correlated syst. uncertainties
- Red area: Monte Carlo (PYTHIA8-CT09MCS/NRQCD) normalized to data, uncertainties are statistical

J/ψ: comparison with phenomenological parametrizations

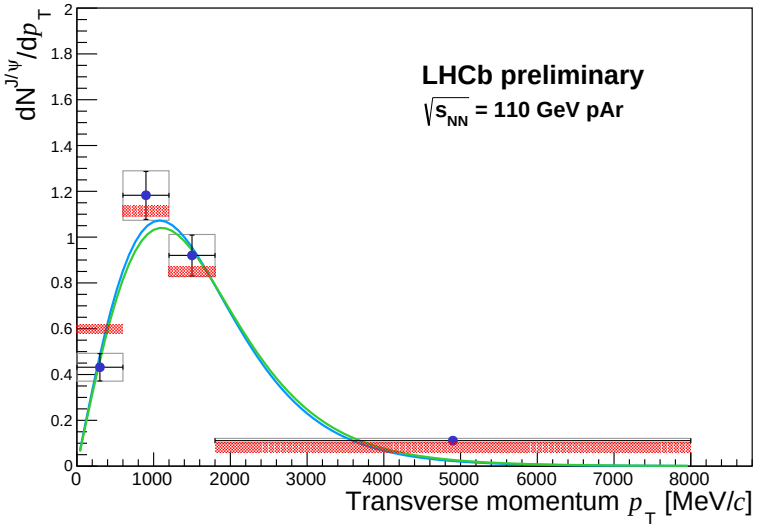
Based on

Arleo, F. & Peigné, S. J. High Energ. Phys. (2013) 2013: 122.
Arleo, F. et al. J. High Energ. Phys. (2013) 2013: 155.

Rapidity in cms: $y^* = y - 4.77$



Transverse momentum p_T

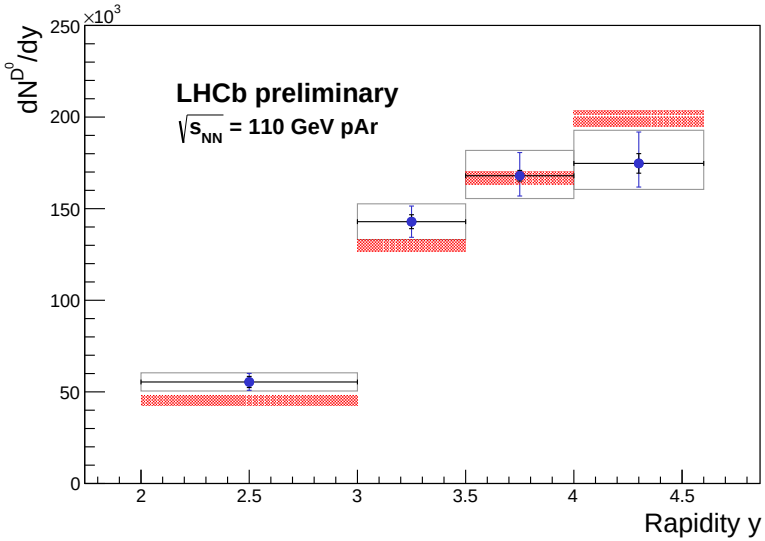


Phenomenological parameters based on linear and logarithmic interpolations between 41.5 GeV and 200 GeV measurements

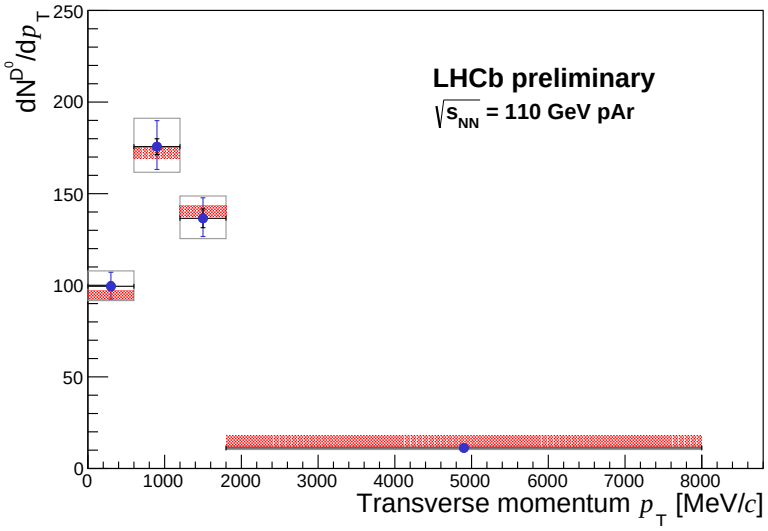
→ No strong difference observed within uncertainties

D^0 corrected yields

Rapidity y



Transverse momentum p_{T}

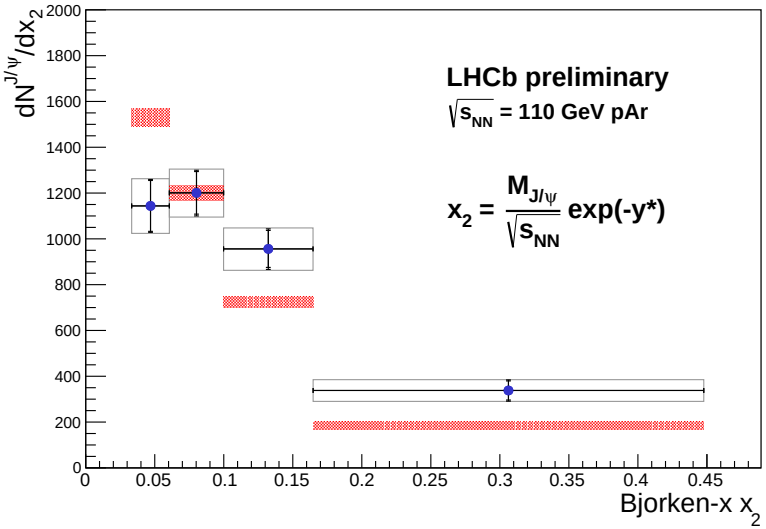


- Blue points: data $\frac{dN^{D^0}}{dy}, \frac{dN^{D^0}}{dp_{\mathrm{T}}}$
- Vertical lines: stat. uncertainties (black), uncorrelated syst. uncertainties (blue)
- Box: Quadratic sum of statistical, uncorrelated and correlated syst. uncertainties
- Red area: Monte Carlo (PYTHIA8-CT09MCS) normalized to data, uncertainties are statistical

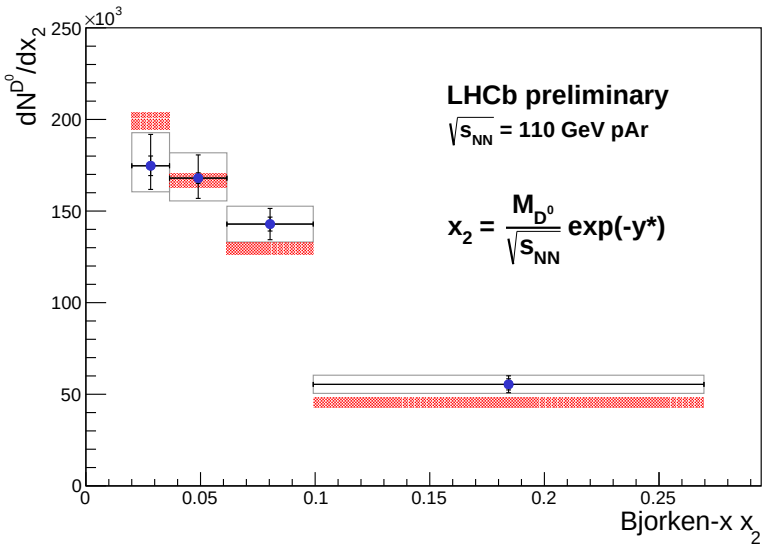
Bjorken-x distribution

$$x_2 = \frac{M}{\sqrt{s_{NN}}} exp(-y^*)$$

J/ψ



D^0



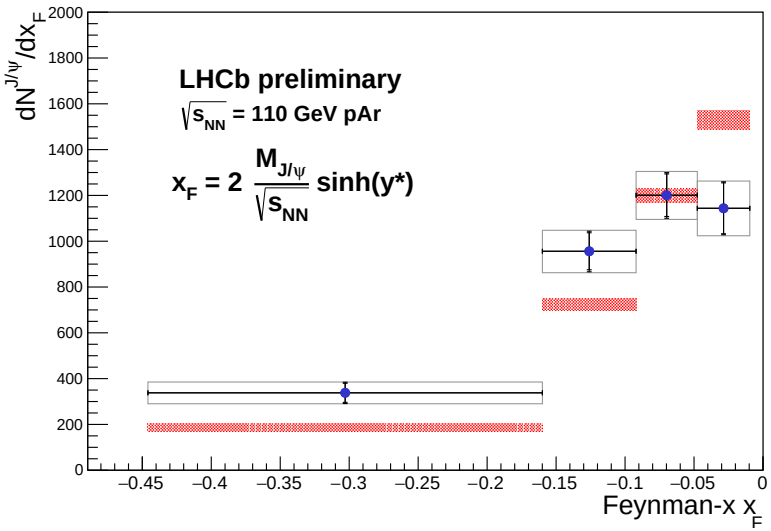
Coverage: $x_2^{J/\psi} \in [0.03, 0.45]$ $x_2^{D^0} \in [0.02, 0.27]$

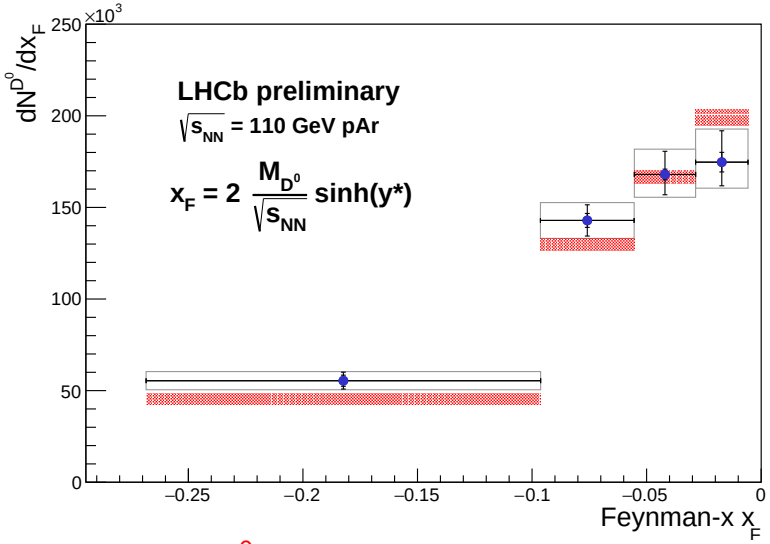
- Blue points: data
- Vertical lines: stat. uncertainties (black), uncorrelated syst. uncertainties (blue)
- Box: Quadratic sum of statistical, uncorrelated and correlated syst. uncertainties
- Red area: Monte Carlo (PYTHIA8-CT09MCS) normalized to data, uncertainties are statistical

Feynman-x distribution

$$x_F = x_1 - x_2 = 2\frac{M}{\sqrt{s_{NN}}} sinh(y^*)$$

J/ψ D^0



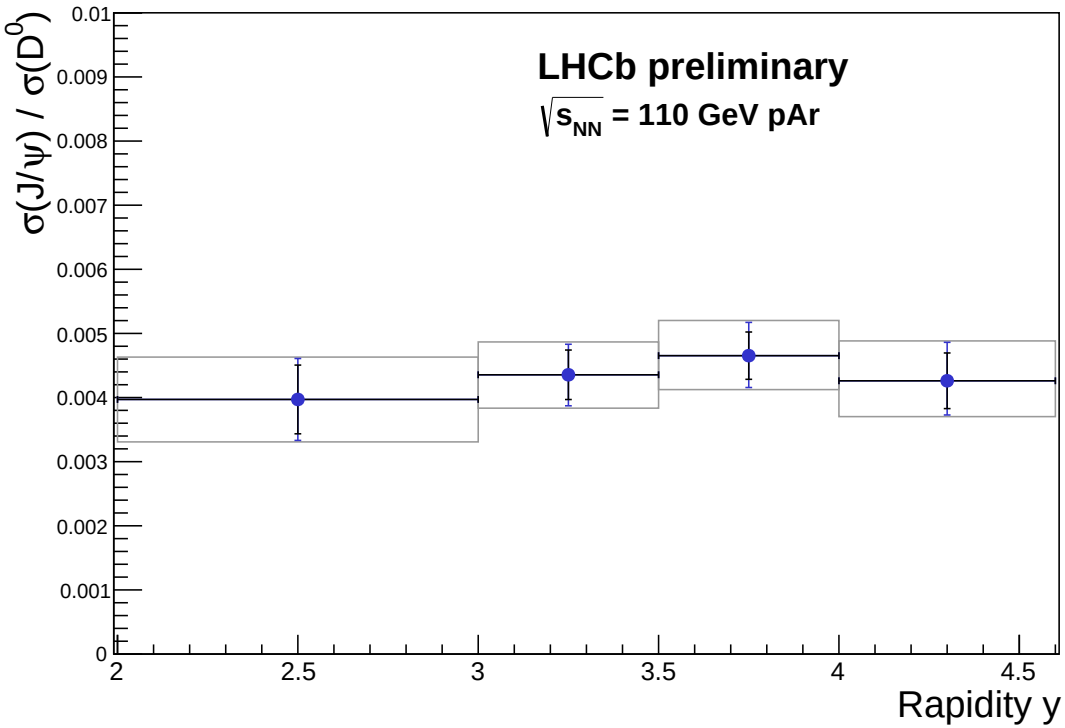


Coverage: $x_F^{J/\psi} \in [-0.45, -0.01]$ $x_F^{D^0} \in [-0.27, -0.01]$

- Blue points: data
- Vertical lines: stat. uncertainties (black), uncorrelated syst. uncertainties (blue)
- Box: Quadratic sum of statistical, uncorrelated and correlated syst. uncertainties
- Red area: Monte Carlo (PYTHIA8-CT09MCS) normalized to data, uncertainties are statistical

Comparison between J/ψ and D^0 cross sections

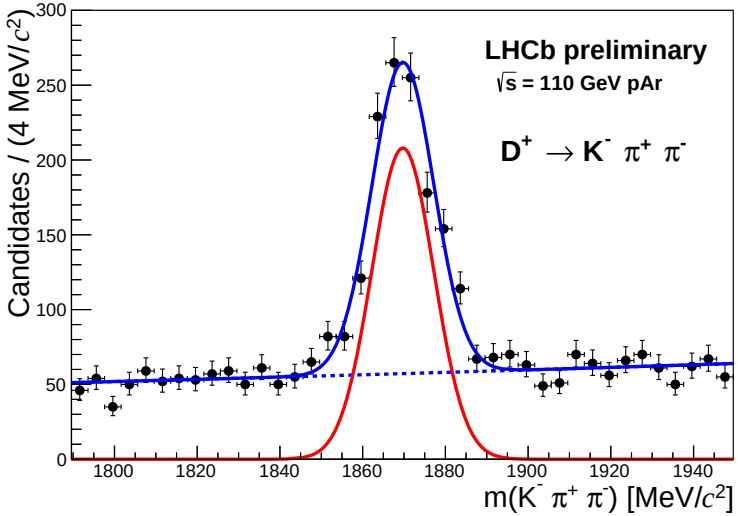
$$\frac{\sigma(J/\psi)}{\sigma(D^0)} = \frac{N^{J/\psi}}{N^{D^0}} \times \frac{BR(D^0 \to K^{\mp}\pi^{\pm})}{BR(J/\psi \to \mu^+\mu^-)}$$

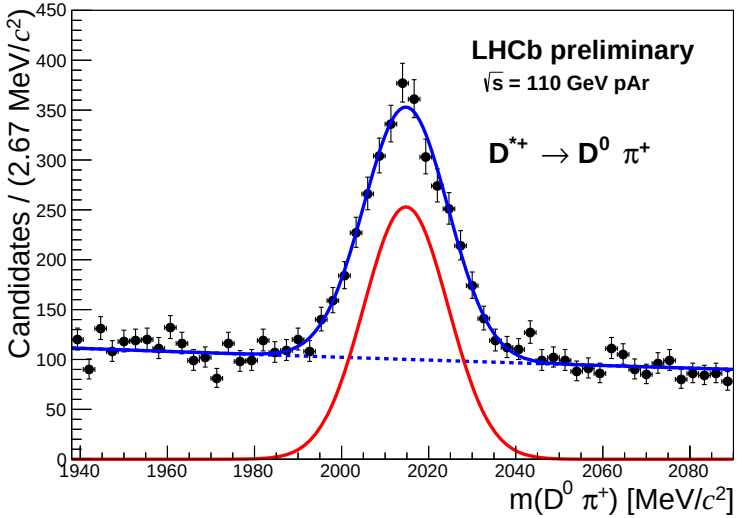


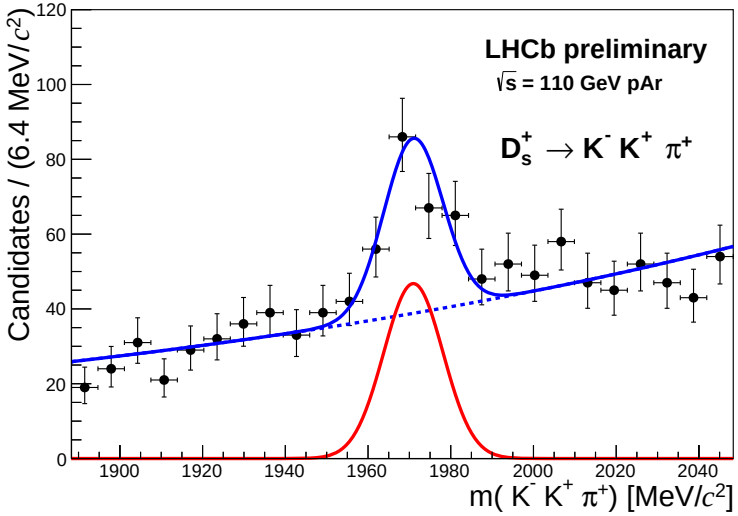
→ No strong difference observed between J/ψ and D^0 production

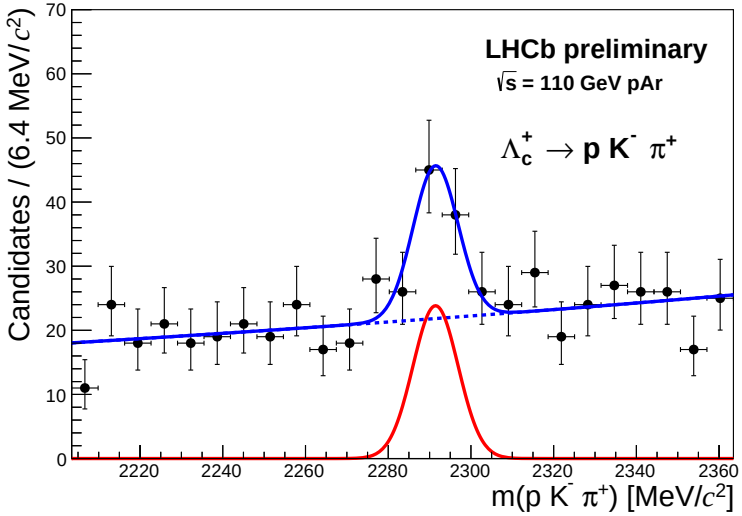
Looking for theoretical predictions

High resolution performance also for D^+, D^{*+}, D_s^+, Λ_c^+









Conclusion

First measurement of heavy-flavour production in LHCb fixed-target mode

- Studied J/ψ and D^0 production in pAr collisions at $\sqrt{s} = 110$ GeV
- Collected after selection overall ~ 500 J/ψ and ~ 6500 D^0
- LHCb is able to access nPDF anti-shadowing region and intrinsic charm content in the nucleon

Observe no strong difference between J/ψ and D^0 production

LHCb can also:

- Measure $D^+, D^{*+}, D_s^+, \Lambda_c^+$ hadrons
- Perform analysis of $\psi(2S), \chi_c$ with future larger data samples

Outlook:

- Work on luminosity for cross-section measurements
- Investigate pHe, pNe, PbAr data
- Take additional fixed-target data in 2017

Back up

SMOG data taking

2015:

- pHe: $\sim$ 8h, $\sqrt{s_{NN}} = 110$ GeV, protons on target $\sim 2 \times 10^{21}$
- pNe: $\sim$ 20h, $\sqrt{s_{NN}} = 110$ GeV, protons on target $\sim 1 \times 10^{21}$
- pAr: $\sim$ 18h, $\sqrt{s_{NN}} = 110$ GeV, protons on target $\sim 4 \times 10^{22}$
- pAr: $\sim$ 11h, $\sqrt{s_{NN}} = 69$ GeV, protons on target $\sim 2 \times 10^{20}$
- PbAr: $\sim$ 100h, $\sqrt{s_{NN}} = 69$ GeV, nuclei on target $\sim 2 \times 10^{20}$

2016:

- pHe: $\sim$ 18h, $\sqrt{s_{NN}} = 110$ GeV, protons on target $\sim 3 \times 10^{21}$
- pHe: $\sim$ 87h, $\sqrt{s_{NN}} = 87$ GeV, protons on target $\sim 4 \times 10^{22}$