Charm production with SMOG at LHCb
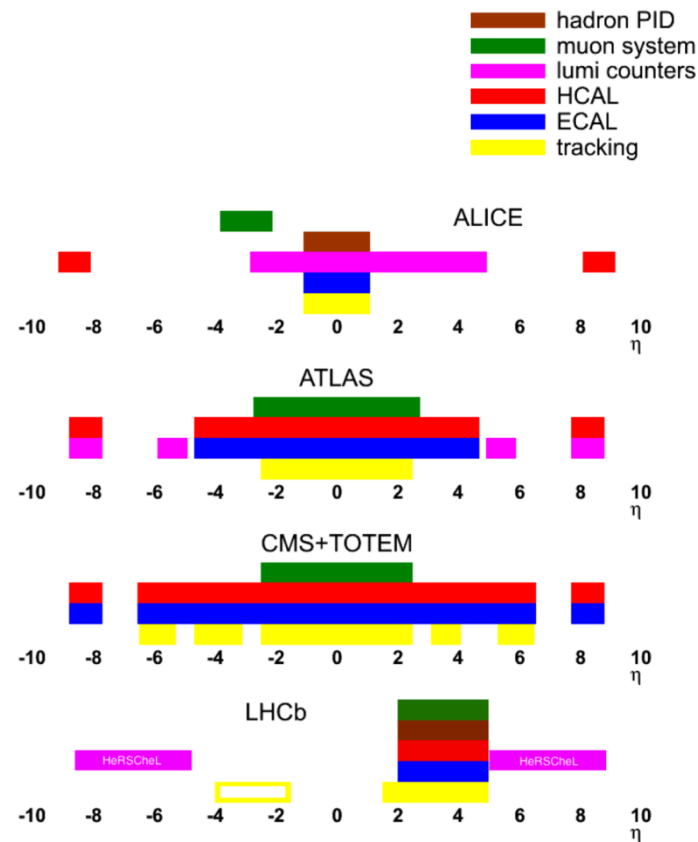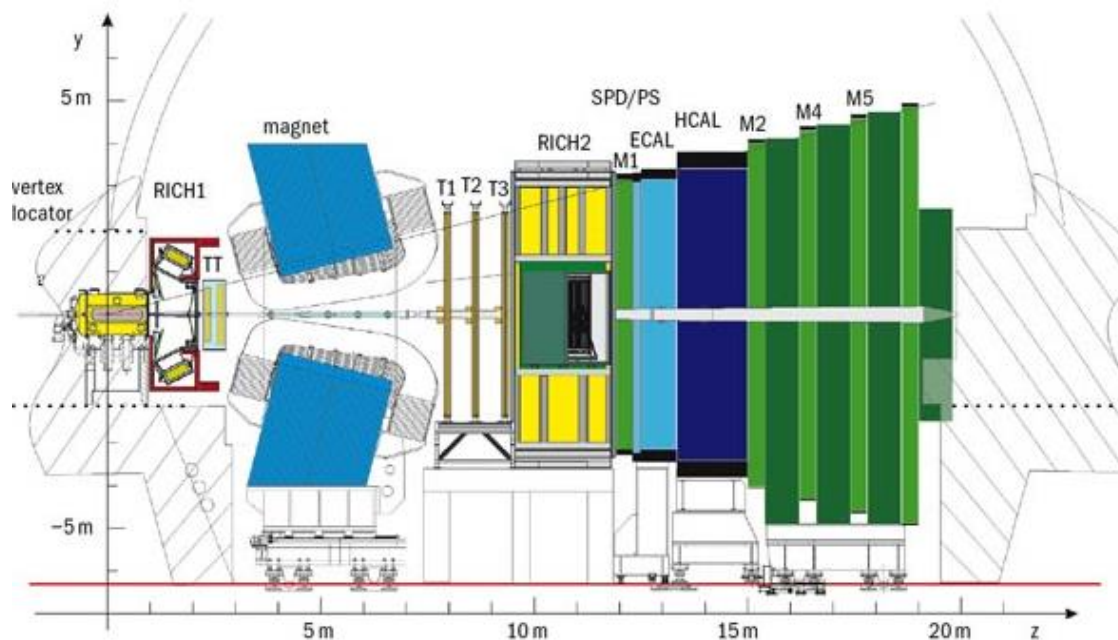
Running LHCb in a fixed-target mode

Heavy flavor production in Heavy Ion collisions

Frédéric Fleuret - LLR/LAL - LHCb

LHCb detector

- Designed for heavy flavor physics
- Single arm spectrometer, fully instrumented in 2 < y < 5

Excellent vertex, IP and decay time resolution
  $\sigma(IP) \approx 20\mu m$

Very good momentum resolution
  $\delta p/p \approx 0.5-1\%$ for $0 < p < 200$ GeV/c

Particle identification
  $\varepsilon_{K \to K} \approx 95\%$ for $\varepsilon_{\pi \to K} \approx 5\%$ up to 100 GeV/c
  $\varepsilon_{\mu \to \mu} \approx 97\%$ for $\varepsilon_{\pi \to \mu} \approx 1-3\%$

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

- **Injecting gas in LHCb Vertex Locator (VELO) region**

  – Primary role : luminosity measurement

  – Can be used as an **internal gas target**

  – Allows measurement of p-gas and ion-gas interactions
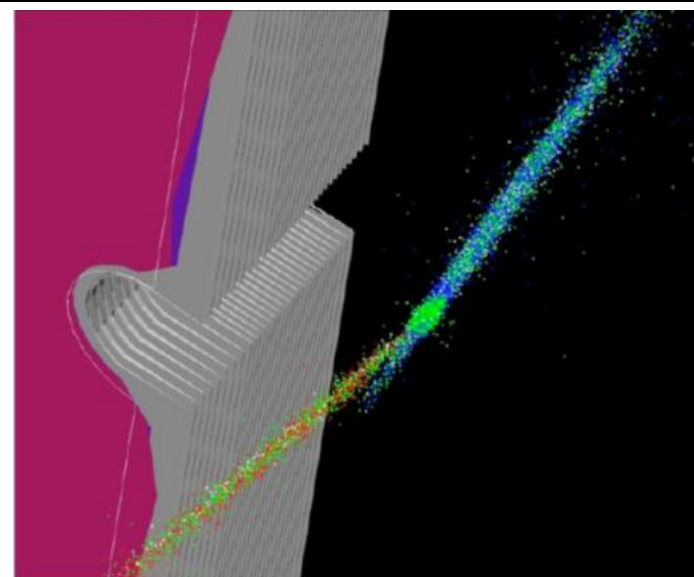
Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.

Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

beam

target

Gas injection
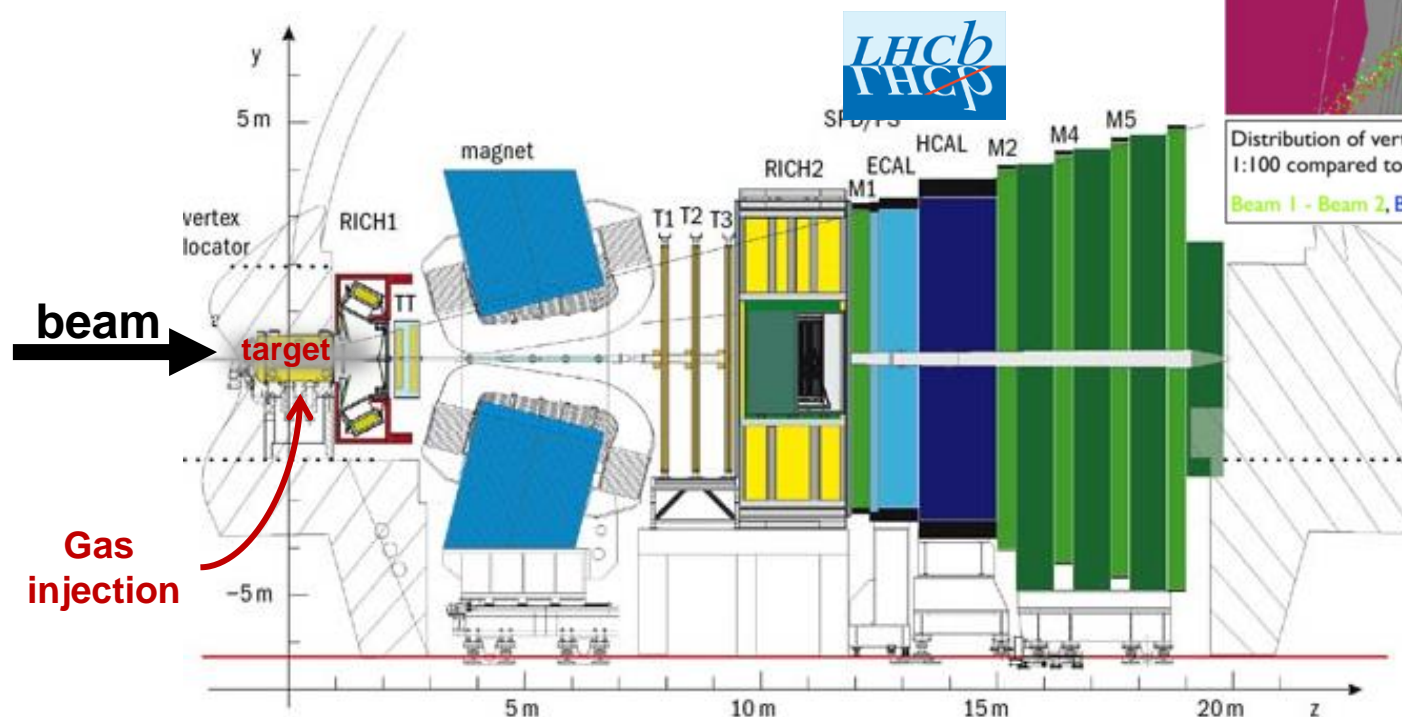
Noble gas only :
(very low chemical reactivity)

He, Ne, Ar, Kr, Xe
A = 4, 20, 40, 84, 131

Gaz pressure:
10^{-7} to 10^{-6} mbar

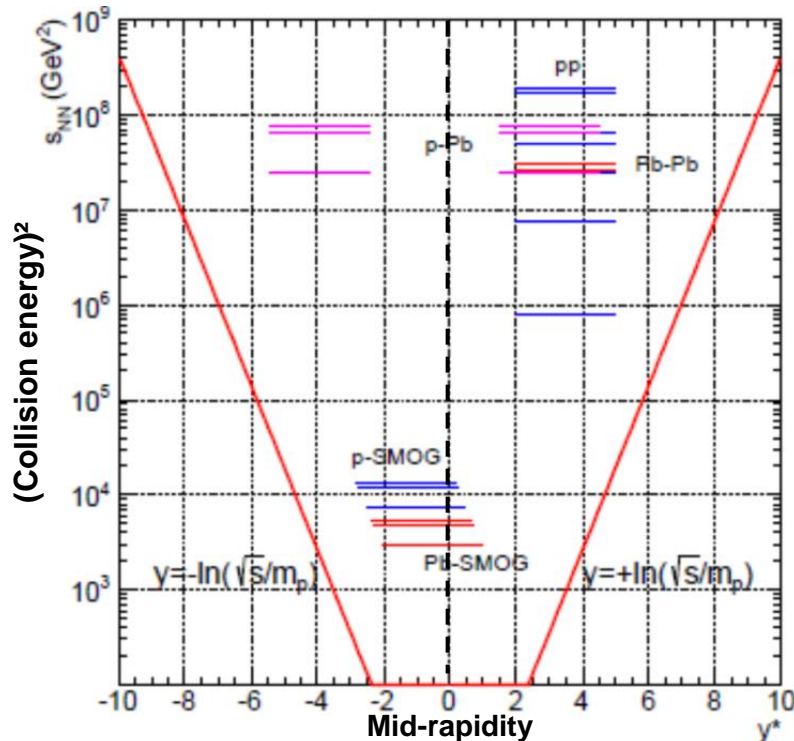$\sqrt{s_{NN}^{SPS}} \sim 20$ GeV

$\sqrt{s_{NN}^{RHIC}} = 200$ GeV

$\sqrt{s_{NN}^{LHC}} = 5$ TeV

$\sqrt{s_{NN}} = 90$ à 110 GeV

$\sqrt{s_{NN}} = 69$ GeV

p → Ar SMOG

Pb → Ar SMOG

LHCb rapidity coverage in the center-of-mass system

← Colliding mode (forward rapidity)

$E_{beam}(p)$	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.02 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

← Fixed-target mode (backward rapidity)

At $\sqrt{s_{NN}} = 110$ GeV $y^* = y_{lab} - 4.77$

Give access to the target large Bjorken-x region

Nucleus-Nucleus collisions

- **Physics case**
  - 2.75 TeV Pb beam on fixed target ➜ $\sqrt{s_{NN}}$~71 GeV (close to the 17 GeV regime reached at SPS)
    - Investigate the **color screening**
    - Thanks to **unique capabilities**, LHCb offers **new opportunities** in the charm sector: J/ψ, ψ', χ_c, D^0, $D^{+/-}$, D^*, Λ_c... *(in the 90's the NA50/SPS experiment measured only J/ψ and ψ' in PbPb @ 17 GeV)*

- **Accessing similar energy density regime (than SPS): operate PbAr@71 GeV**
  - Particle multiplicity is related to event centrality and center-of-mass energy
  - Particle multiplicity can be used to compare different A+B collisions at different $\sqrt{s_{NN}}$

| System \ centrality	60 – 100%	50 – 60%	40 – 50%	30 – 40%	20 – 30%	10 – 20 %	0 – 10%
PbNe – 71 GeV	108.6	254.4	392.5	588.0	814.5	1086.0	1494.9
PbAr – 71 GeV	**123.6**	**308.8**	**496.5**	**806.6**	**1228.3**	**1711.9**	**2372.7**
PbKr – 71 GeV	196.9	533.6	919.1	1451.2	2205.5	2986.6	4084.3
PbPb – 17 GeV	**124.2**	**331.6**	**605.9**	**919.6**	**1338.7**	**2035.8**	**2980.5**

SPS|◄─LHC→|

(based on EPOS-LHC-v3400)

  - PbAr @ 71 GeV multiplicity $\equiv$ PbPb@17 GeV multiplicity

 ➜ **PbAr @ 71 GeV and PbNe are a good starting points to compare with NA50 (SPS)**

- Serve as a **baseline** for nucleus-nucleus collisions

- **Specific proton-nucleus physics program:**
  - Nuclear parton distribution function (nPDF), nuclear absorption, …

- With SMOG, LHCb offers a large rapidity coverage (~3 rapidity units) at **large Bjorken-x x_2**
  - Give access to **nPDF anti-shadowing** region and **intrinsic charm** content in the nucleon
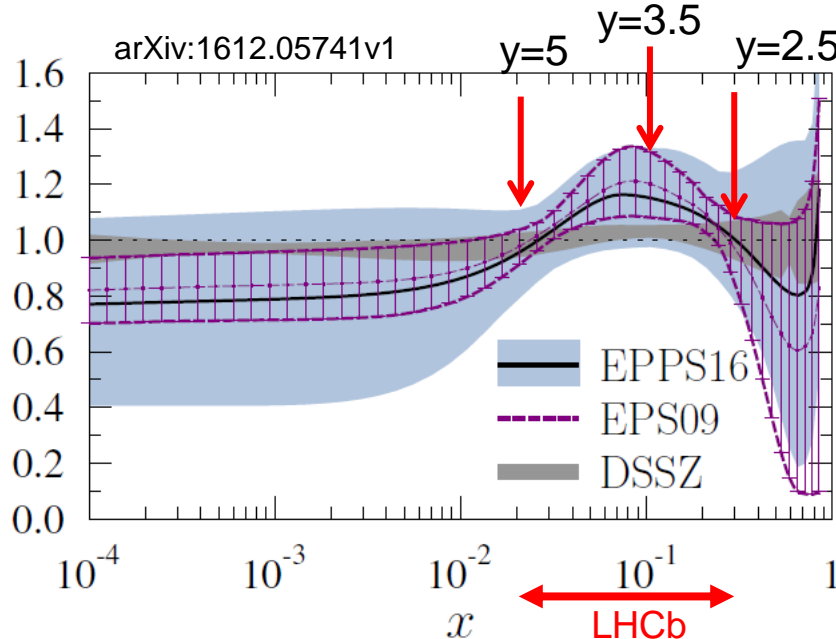
Bjorken-x = fraction of the nucleon momentum carried by a parton
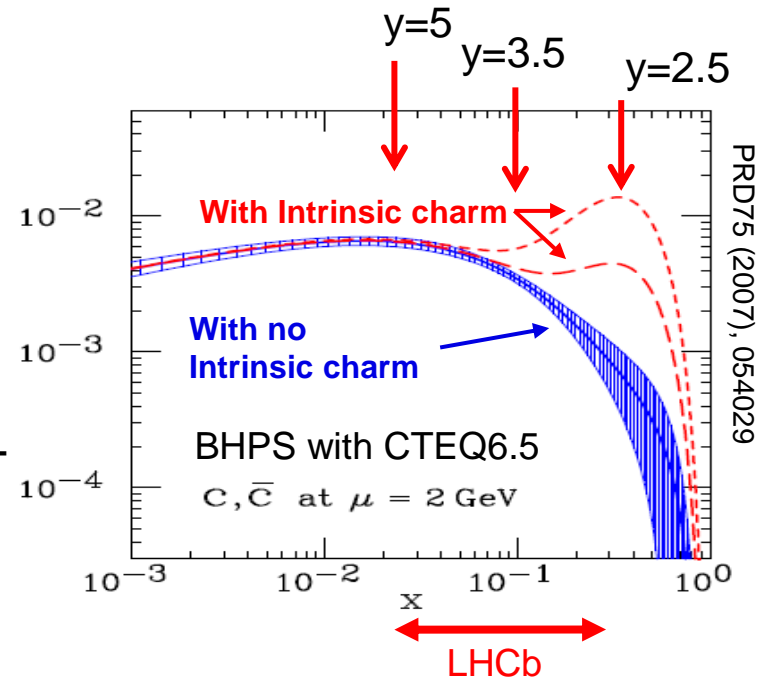
- **pAr collisions @ 110 GeV (oct. 2015)**

$$R = \sqrt{X^2 + Y^2}$$

(R,Z) position of the Primary Vertex
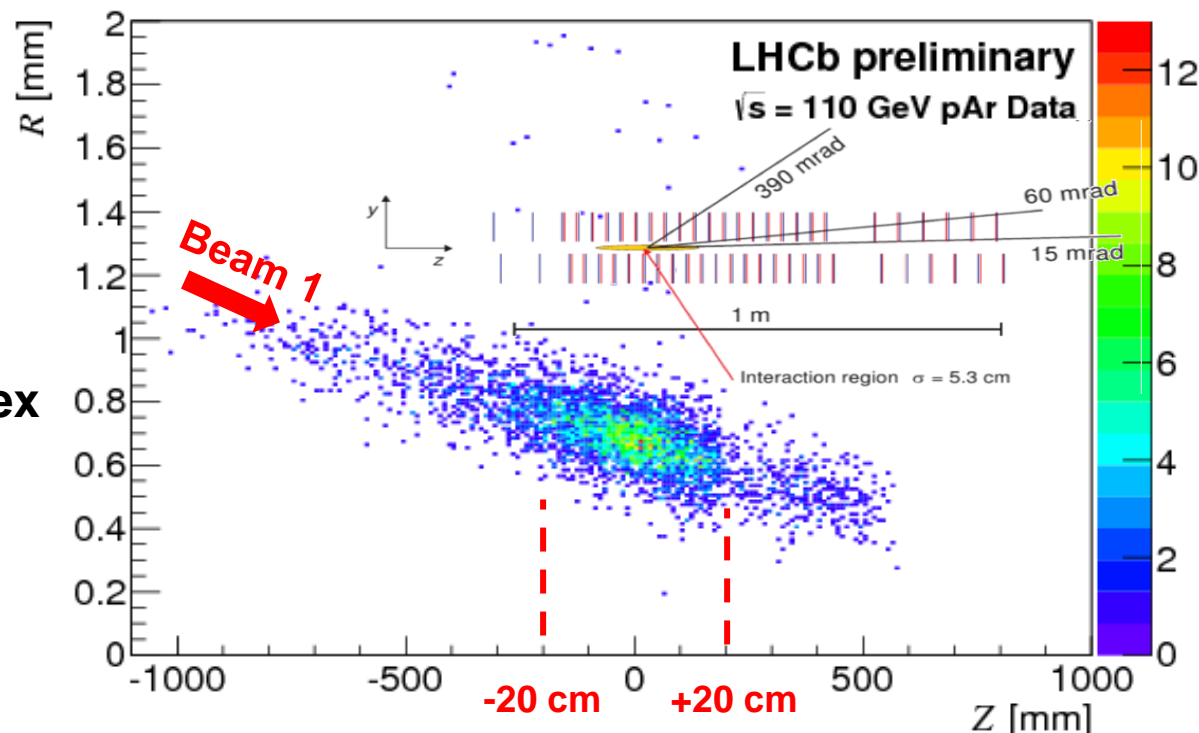
- – **17h** of pAr collisions with **685 non-colliding bunches**: **~4×10²² Protons** On Target
- – Select events with Beam 1 only at interaction point
- – Apply topological cuts to remove possible residual proton-proton collisions (ghost charge)
- – **Select events with Z_{vertex} inside VELO** $Z_{vertex} \in$ [-20 cm, 20 cm]
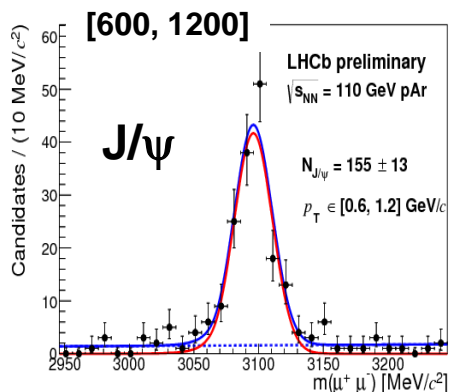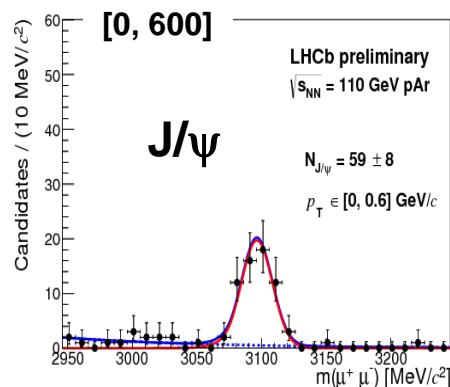
- **J/ψ and D^0 signal**

  – Overall data (17h) : ~500 J/ψ ~6500 D^0
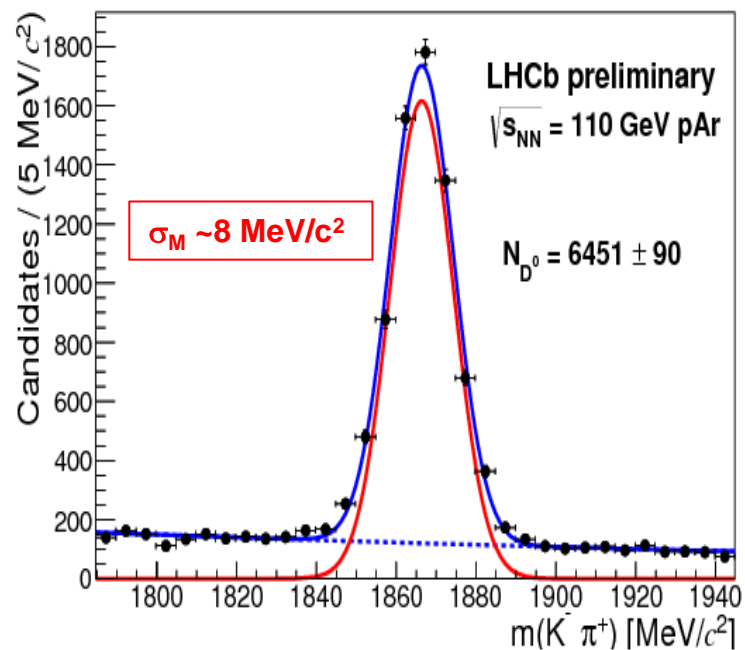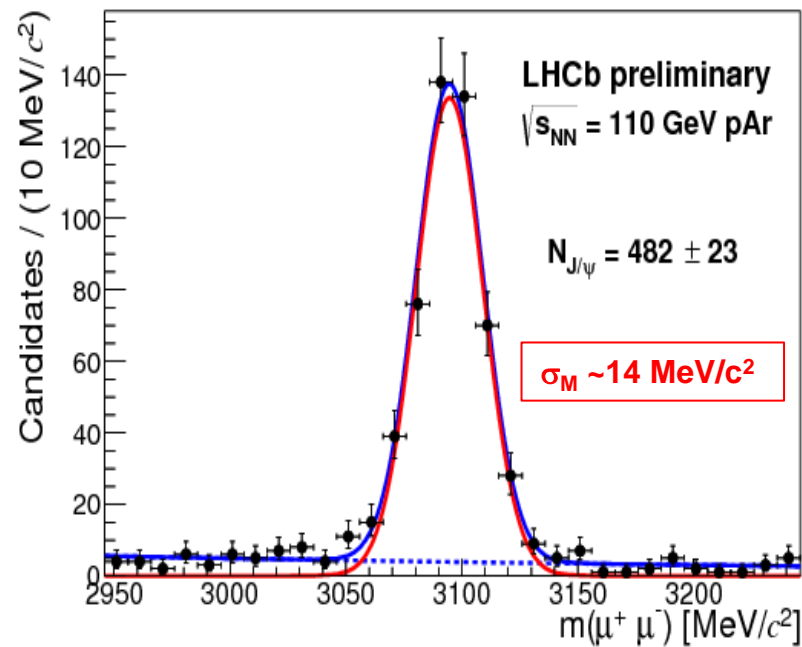
  – Very clear signal, very small background

- **4 p_T bins $\in$ [0, 600] – [600, 1200] – [1200, 1800] – [1800, 8000] MeV/c**
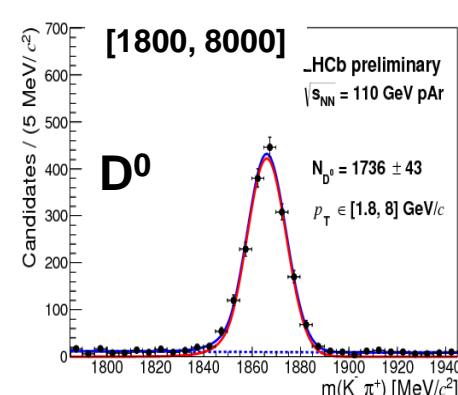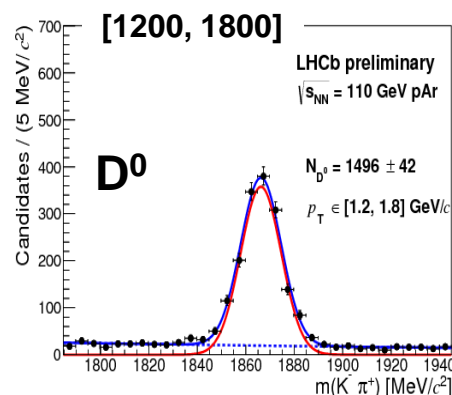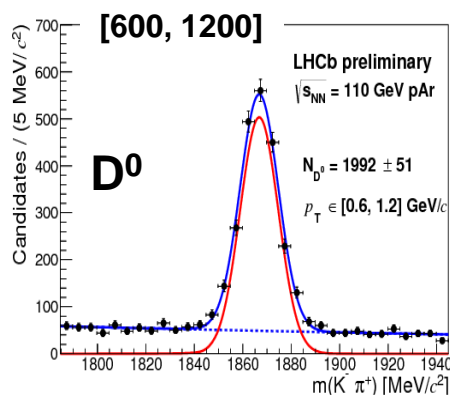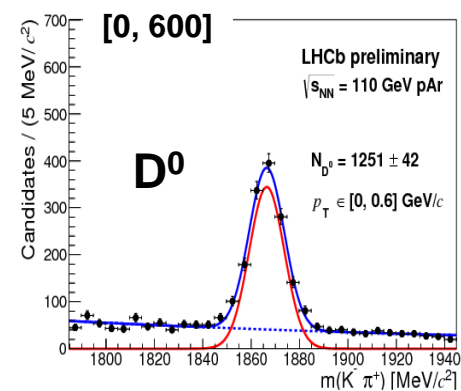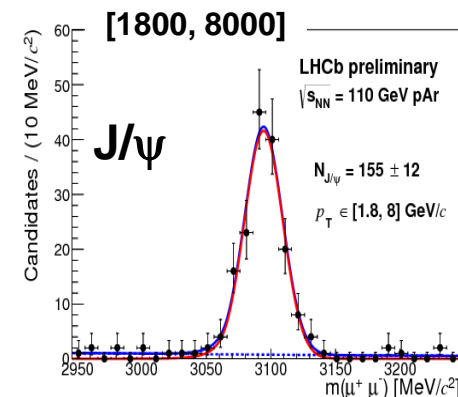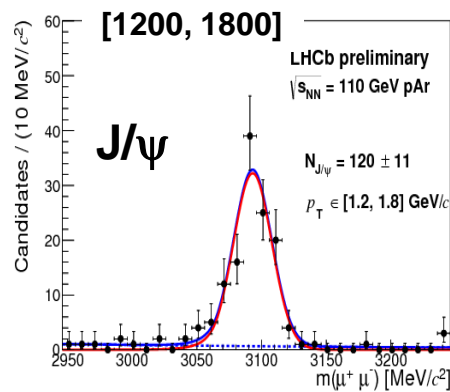
- **4 rapidity bins : [2, 3] – [3, 3.5] – [3.5, 4] – [4, 4.6]**

Yield corrections and uncertainties
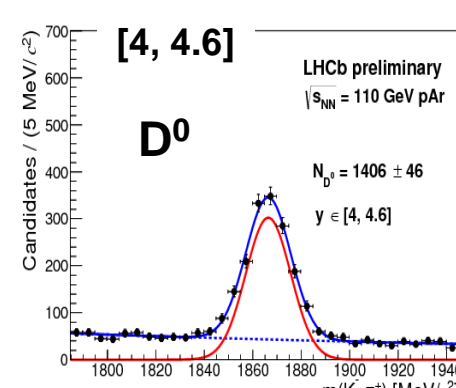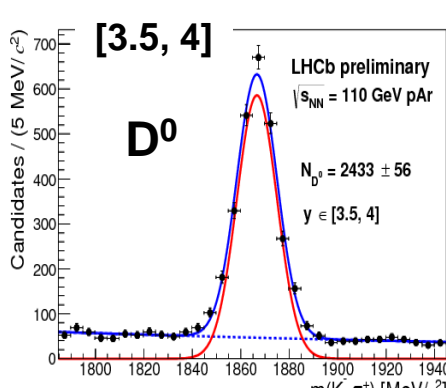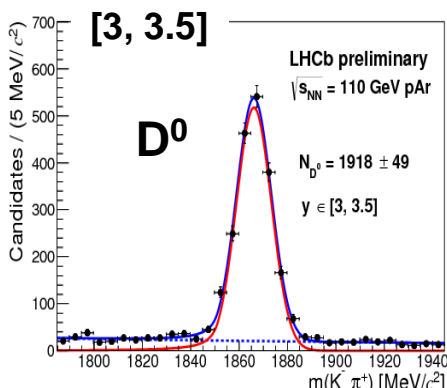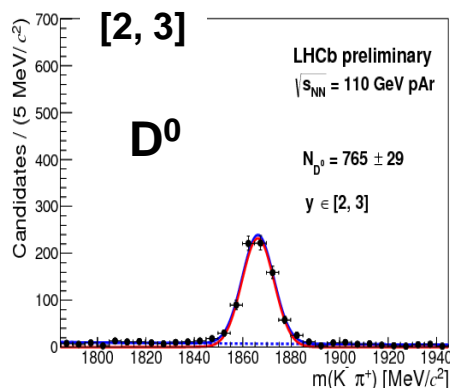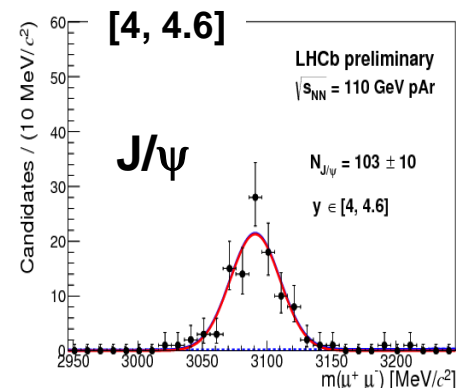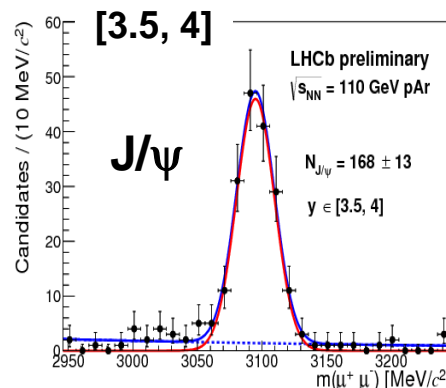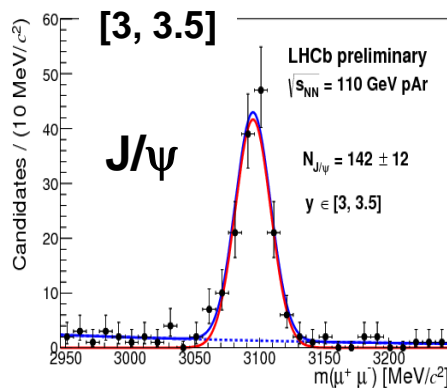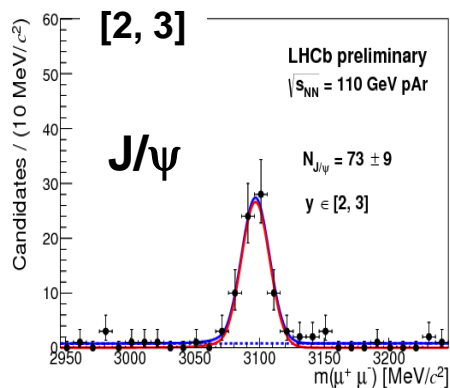
$$Y = \frac{Y^{measured}}{\varepsilon}$$

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

$$\varepsilon = \varepsilon_{acc} \times \varepsilon_{trig} \times \varepsilon_{sel} \times \varepsilon_{reco} \times \varepsilon_{PID}$$

*geometrical acceptance, trigger, selection, reconstruction, particle identification*

Corrections are computed using pAr 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
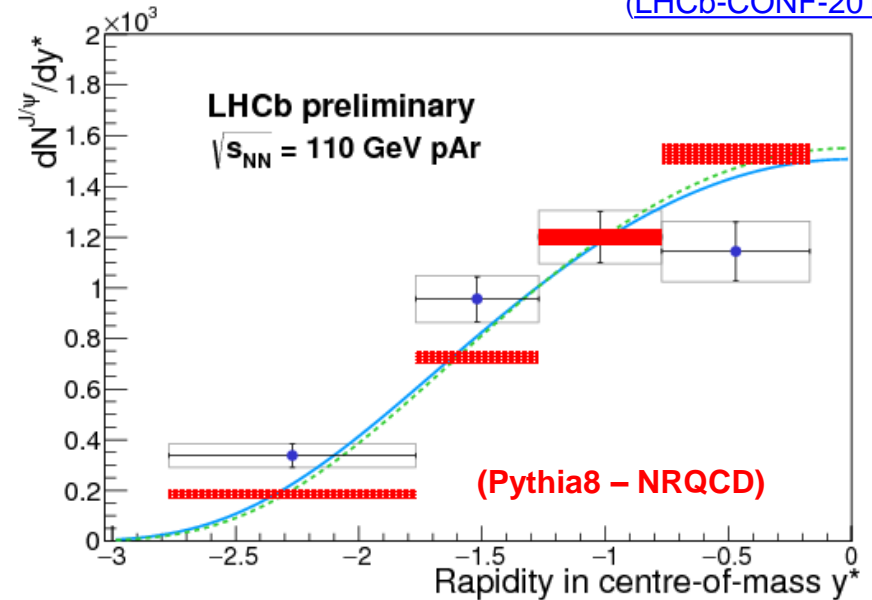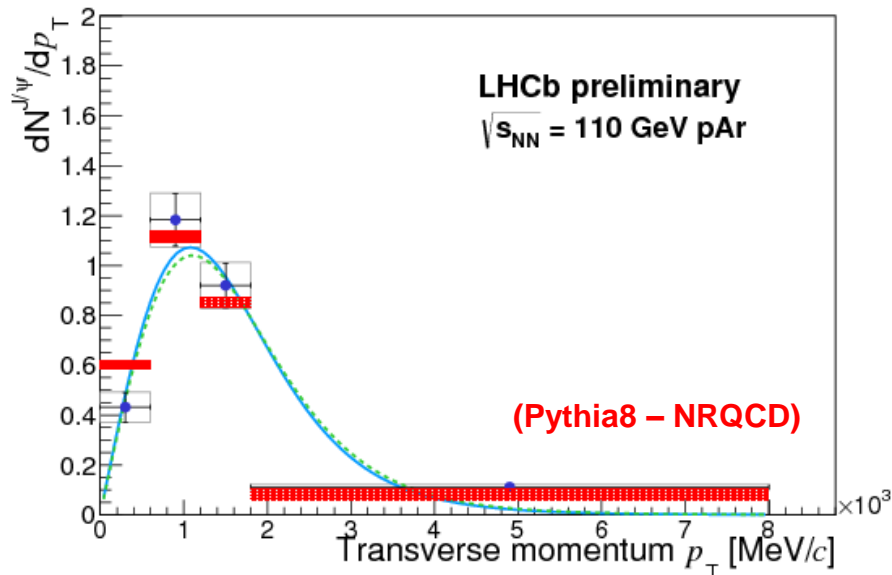
(LHCb-CONF-2017-001)

- **J/ψ transverse momentum and rapidity distributions**
  - Box = quadractic sum of all uncertainties
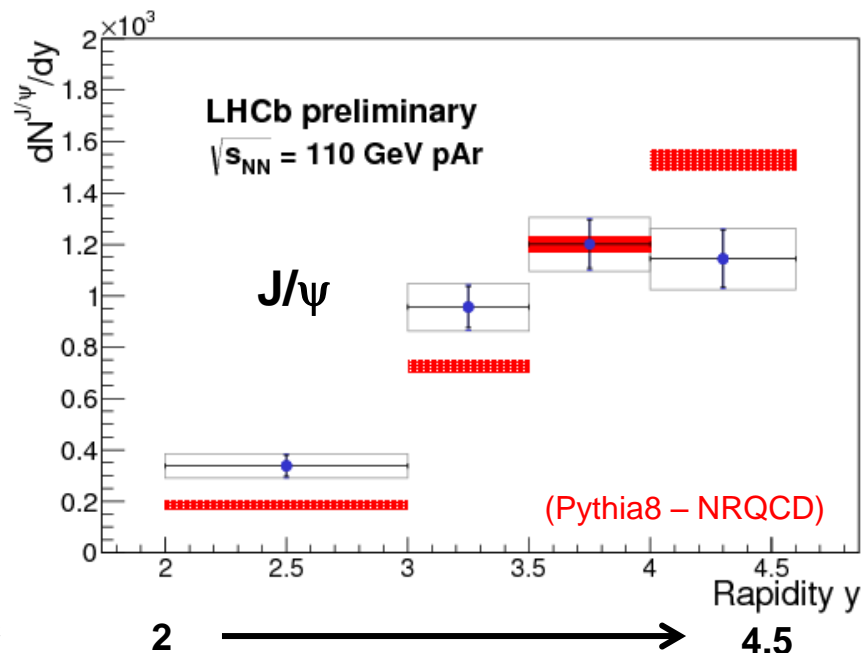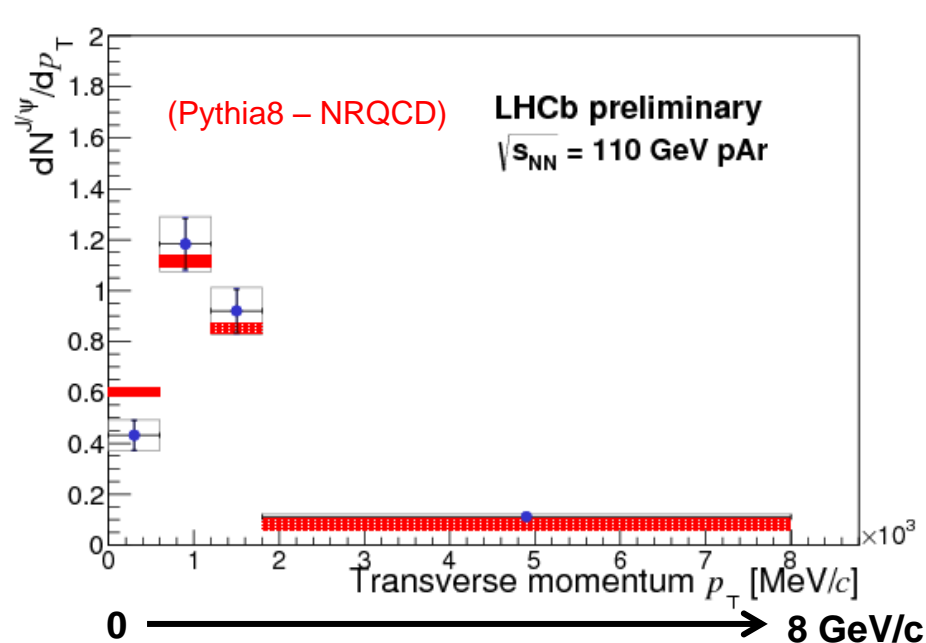
- Red boxes = MC
  - Pythia8-CT09MCS/NRQCD
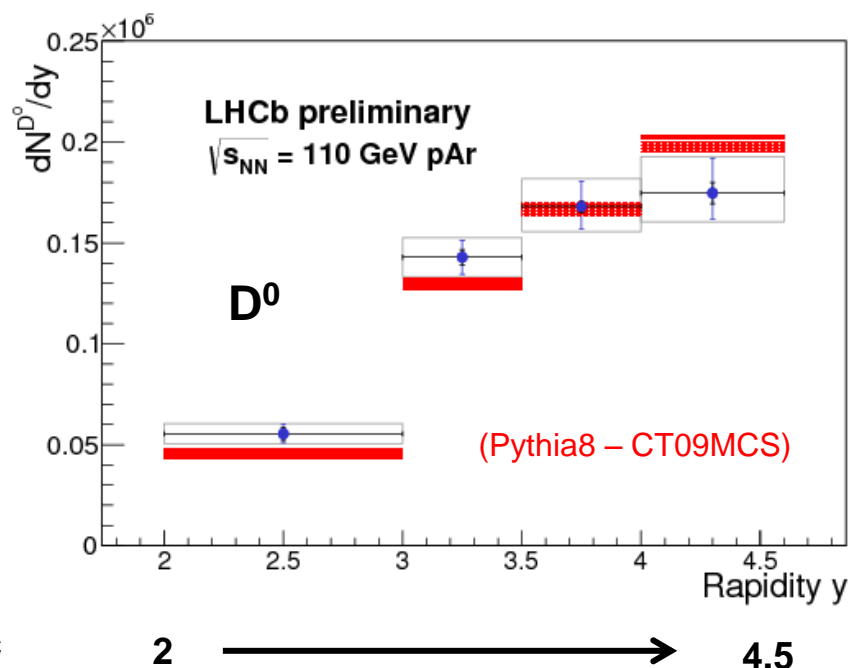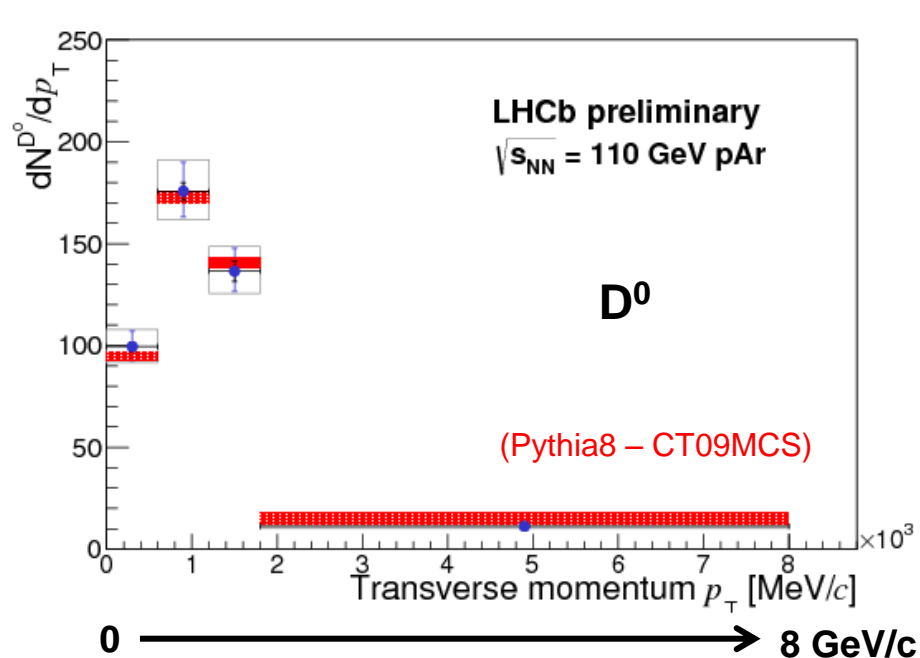 - Overall MC yields normalized to overal data yields

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

- **Phenomenological parametrizations based on**
  - Arleo, F. and Peigné, S. J. High Energ. Phys. (2013) 2013:122
  - Arleo, F. et al., J. High Energ. Phys. (2013) 2013: 155
  - *MC and phenomenological distributions are normalized to data*

- **Phenomenological parameters**
  - extracted from linear (blue plain curve) and logarithmic (green dashed curve) interpolations between 41.5 GeV and 200 GeV measurements

- **No strong difference observed within uncertainties**

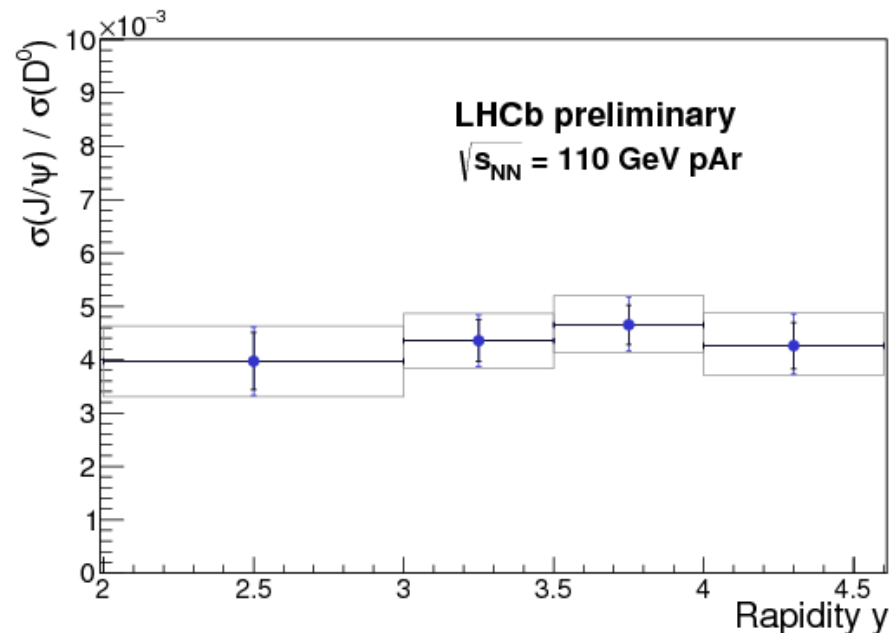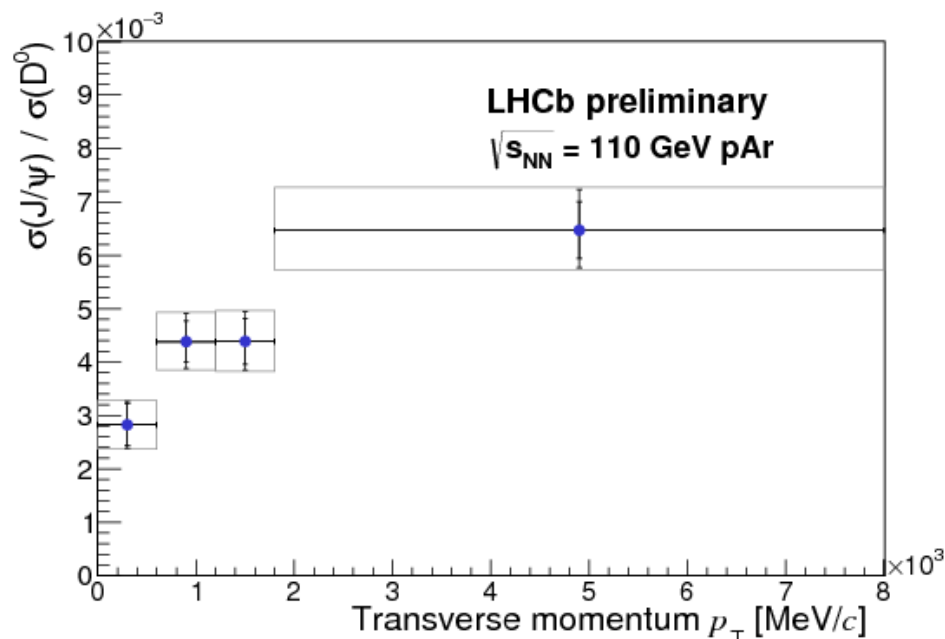- **D⁰ transverse momentum and rapidity distributions**
  - Box = quadractic sum of all uncertainties

- Red boxes = MC
  - Pythia8-CT09MCS
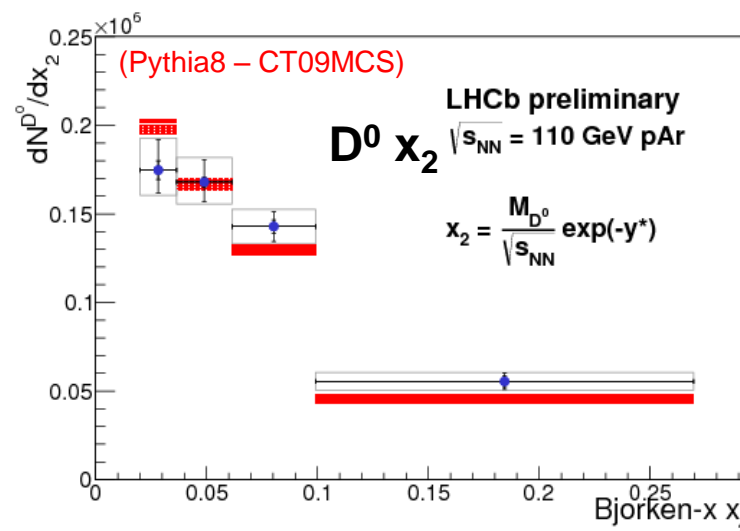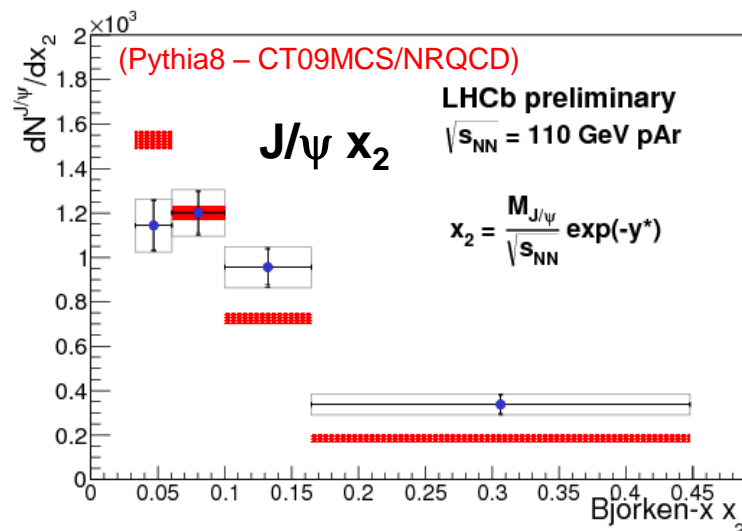 - Overall MC yields normalized to overal data yields

- **J/ψ / D⁰ cross section ratio *vs.* p_T and rapidity**

- Luminosity cancel out in the cross section ratio $\left(\dfrac{\sigma(J/\psi)}{\sigma(D^0)} = \dfrac{Y(J/\psi)}{\mathcal{L}} \times \dfrac{\mathcal{L}}{Y(D^0)} \right)$

- **No significant dependence** of $\sigma(J/\psi)/\sigma(D^0)$ with **rapidity**
- $\sigma(J/\psi)/\sigma(D^0)$ **ratio increases** with **transverse momentum**

- ***Need theoretical predictions !***

- **Definition used in this analysis:** $x_2 = \dfrac{M}{\sqrt{s_{NN}}} e^{-y^*}$ (Rapidity in CMS: $y^* = y - 4.77$)

  - Overall MC yields normalized to overal data yields

(Pythia8 – CT09MCS/NRQCD)

J/ψ x_2

LHCb preliminary
$\sqrt{s_{NN}} = 110$ GeV pAr

$x_2 = \dfrac{M_{J/\psi}}{\sqrt{s_{NN}}} \exp(-y^*)$

(Pythia8 – CT09MCS)

D^0 x_2

LHCb preliminary
$\sqrt{s_{NN}} = 110$ GeV pAr
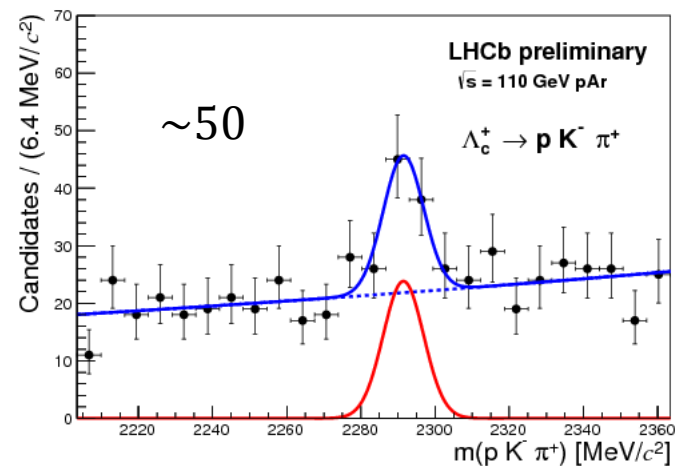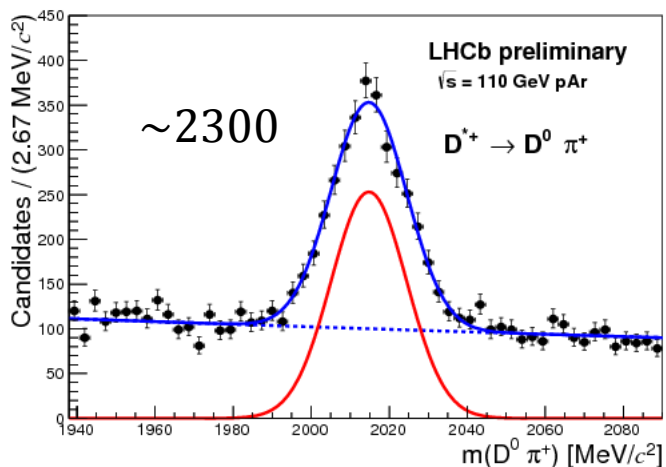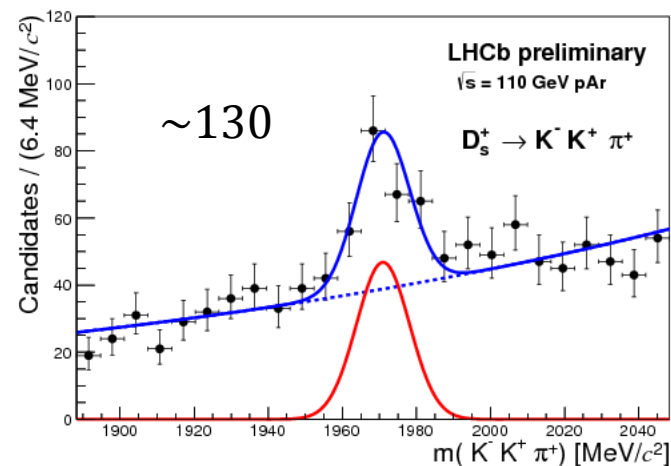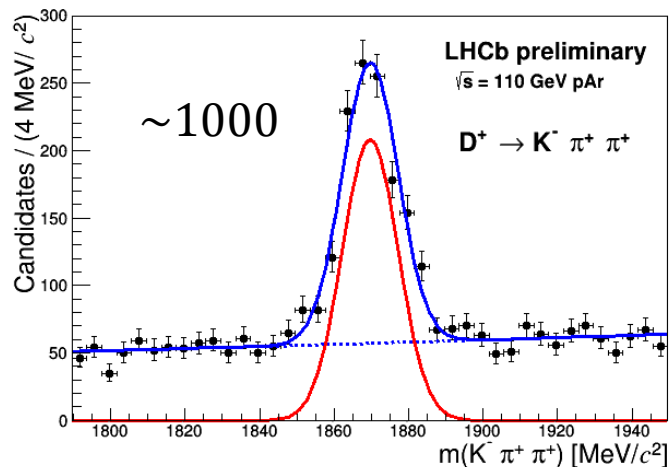
$x_2 = \dfrac{M_{D^0}}{\sqrt{s_{NN}}} \exp(-y^*)$

- Bjorken-x range covered by the data
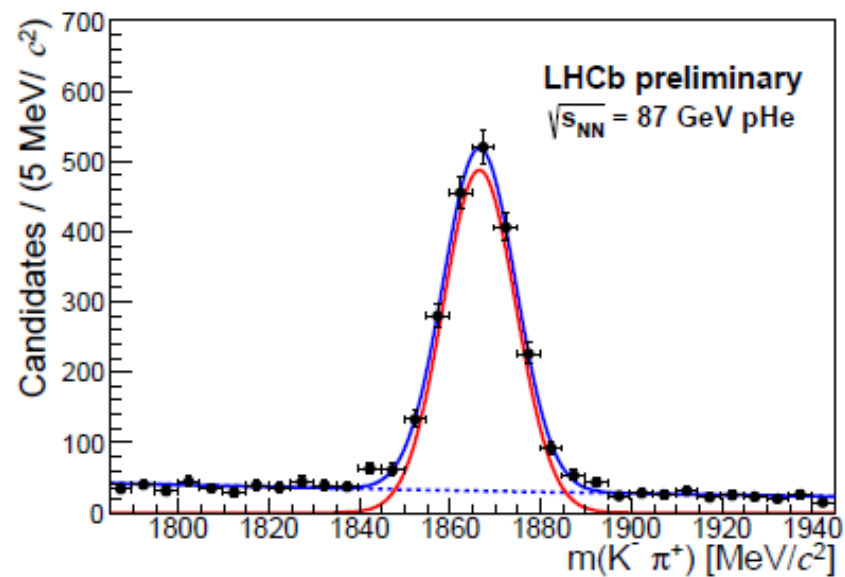 - J/ψ $x_2 \in [0.03, 0.45]$
  - D^0 $x_2 \in [0.02, 0.27]$

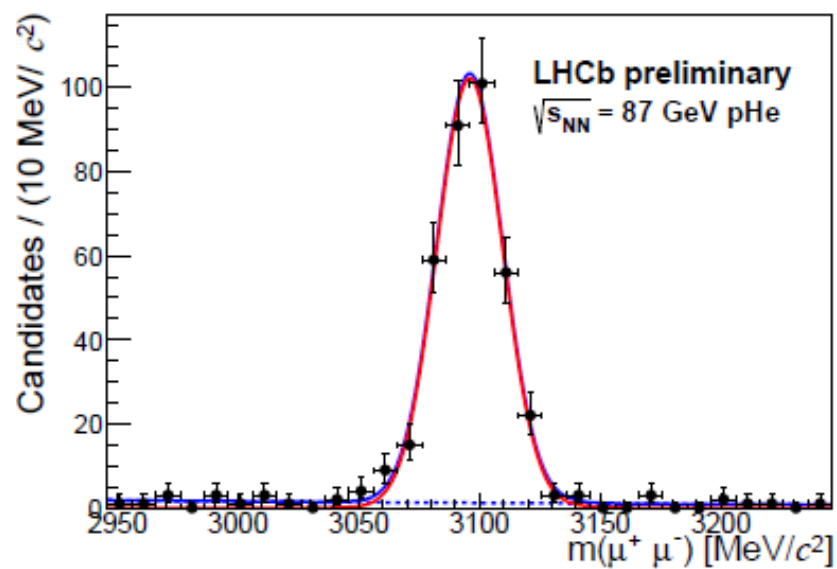- **Access Intrinsic charm regime**
- *Need theoretical predictions !*

0.02   0.27

With no
Intrinsic charm

BHPS with CTEQ6.5

$C, \bar{C}$ at $\mu = 2$ GeV

PRD75 (2007), 054029
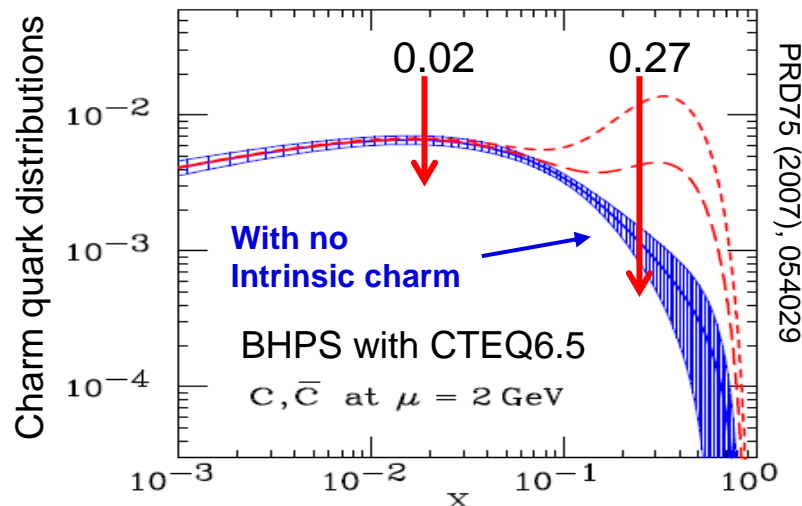
- **Other possible measurements: signals extracted from these pAr data**

2016 – pHe@87 GeV: J/ψ and D⁰ signal

- **1st measurement of heavy flavor production in fixed-target mode**
  - Measured ~500 J/ψ and 6500 D^0, other charm hadrons observed
  - *Demonstrate the feasibility of the program*

- **Ongoing analysis**
  - Finalize **pAr@110 GeV J/Ψ/D^0** analysis
  - perform **pHe@87 GeV J/Ψ/D^0** analysis

- **Next data taking**
  - 8 days (~150h) of **pNe @ 70 GeV** : 5 TeV 2017 winter run ➡ First ψ' and χ_c's
  - **PbNe @ 70 GeV** long run during winter 2018 Pb run