Production of open charm and beauty states in p-Pb collisions with LHCb

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On the behalf of the LHCb collaboration

Outline

I. Physics motivation : from Pb-Pb to p-Pb collisions

II. The LHCb detector

III. Results for charm production in p-Pb:

- D^0 production at $\sqrt{s_{NN}} = 5.02$ TeV

- Λ_c^+ production at $\sqrt{s_{NN}} = 5.02$ TeV
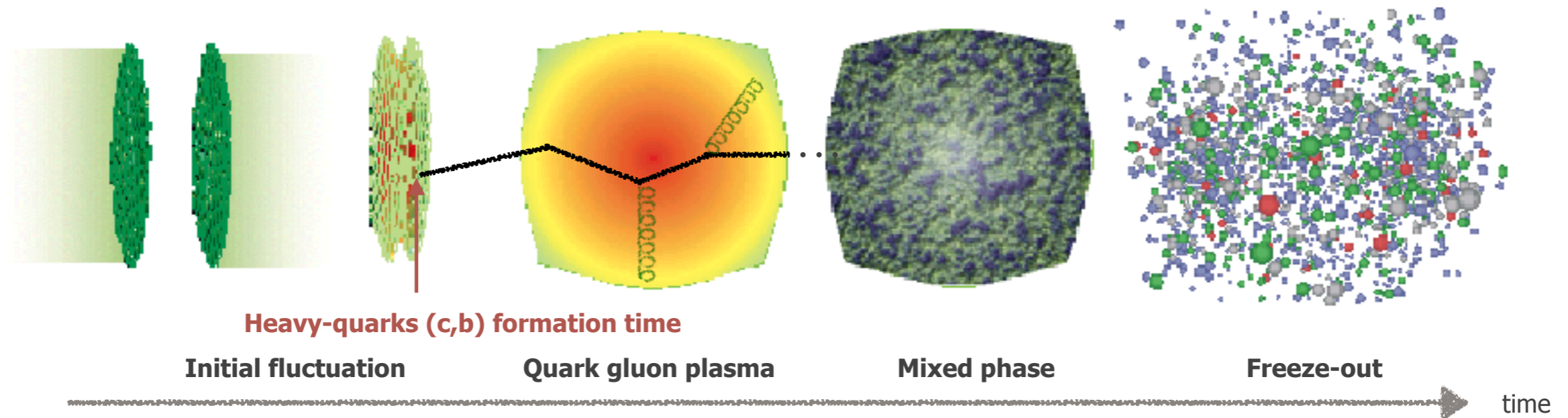
IV. Results for beauty production

- $\Upsilon(1S)$ production at $\sqrt{s_{NN}} = 5.02$ TeV

- Non-prompt charmonia production at $\sqrt{s_{NN}} = 5.02$ TeV
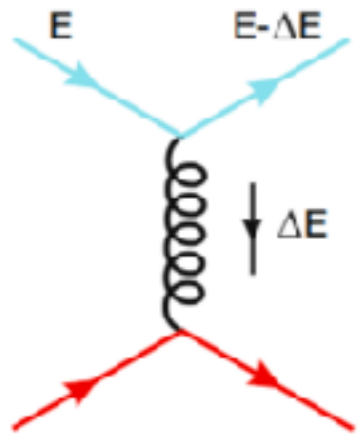
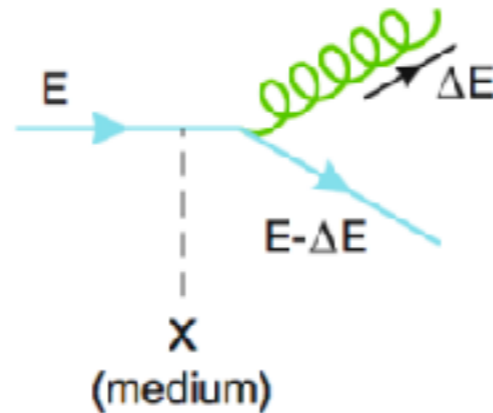❖ Conclusion and outlooks

Physics motivation

From Pb-Pb collisions ...

Heavy-quarks (c,b) formation time

| Initial fluctuation | Quark gluon plasma | Mixed phase | Freeze-out |

time

Physical processes

- • *Collision energy-loss*
- • *Dominate at low-p_T*

- • *Radiative energy-loss*
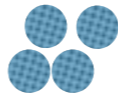- • *Dominate at higher p_T*

❖ Heavy-Quarks:

➡ produced at the earliest stage of the collision.

➡ Sensitive to the deconfined phase of hadronic matter.

❖ Possible quantity : $R_{AA} = \dfrac{Y_{AA}}{\langle T_{AA} \rangle \sigma_{pp}}$

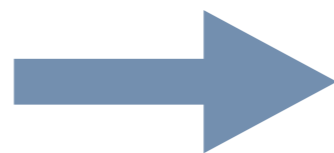❖ **Question : how to disentangle hot from cold-nuclear matter effets ?**

... to p-Pb collisions

❖ Cold nuclear matter effects :

  ➡ Shadowing, co-movers, parton energy loss etc.

  ➡ Studied with very different formalisms.

❖ Comparing charm and beauty productions allows to test and constraint model predictions.

❖ The nuclear modification factor :

Signal extraction

$$R_{pA} = \frac{\sigma_{pA}}{A \cdot \sigma_{pp}} \quad \Longrightarrow \quad \frac{\mathrm{d}^2\sigma_{xx}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} = \frac{N_{xx}(D^0 \to K^{\pm}\pi^{\mp})}{\mathscr{L} \cdot \epsilon_{tot} \cdot Br(D^0 \to K^{\pm}\pi^{\mp}) \cdot \Delta\mathrm{d}p_{\mathrm{T}} \cdot \Delta\mathrm{d}y}$$

Luminosity   *Efficiency*   *Branching ratio*
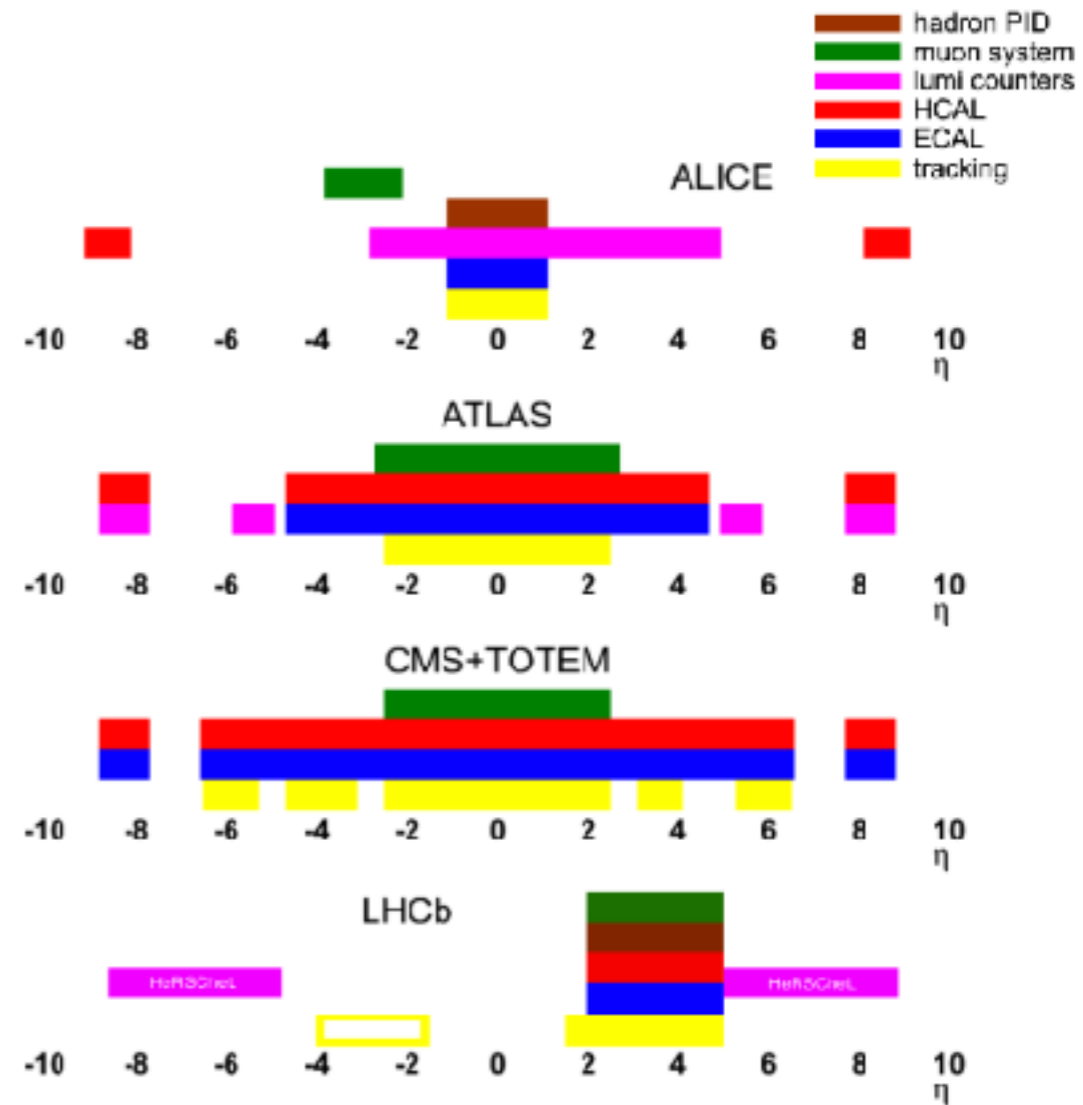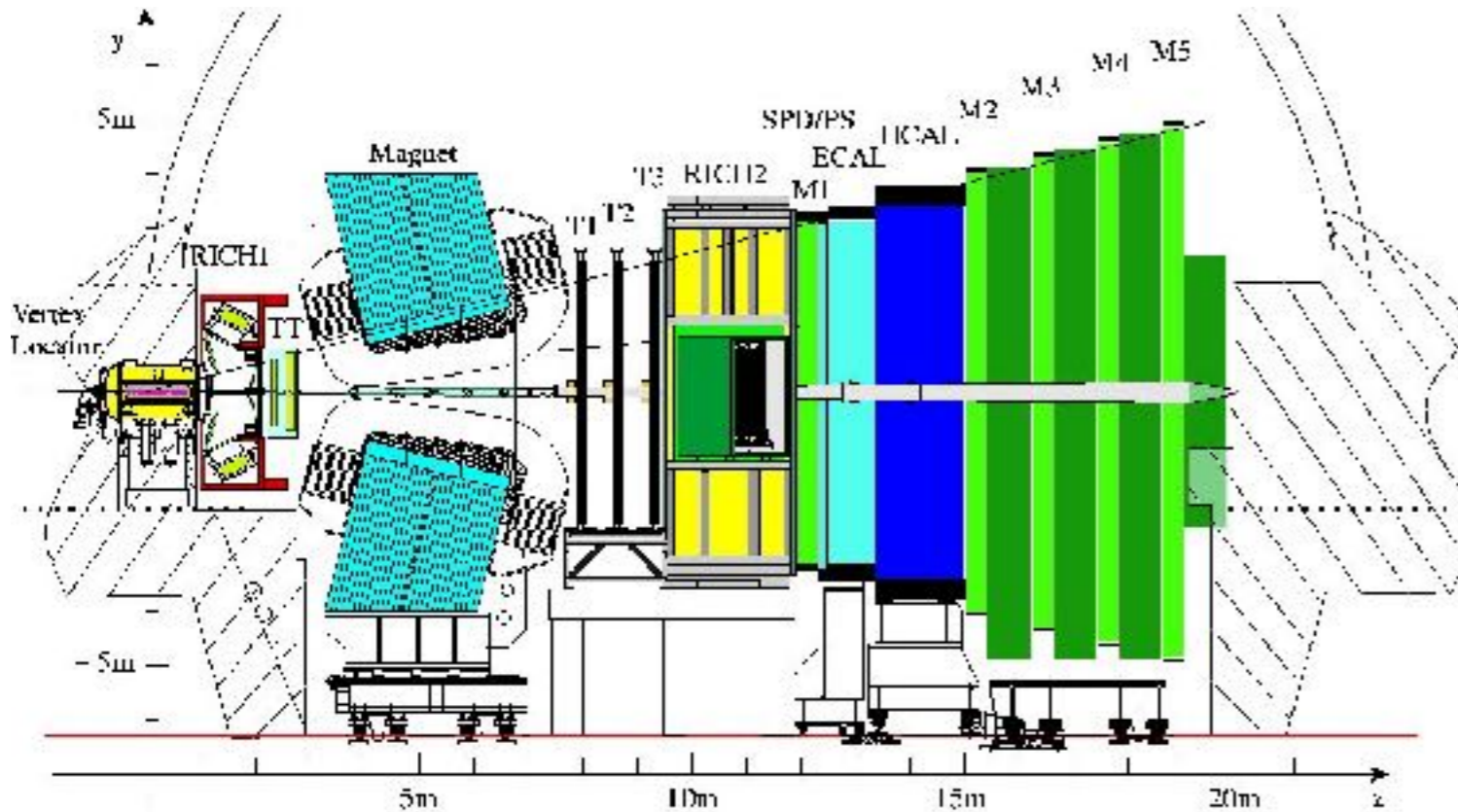
Generic definition

Experimental cross section

The LHCb detector

The LHCb detector

LHCb : **single arm spectrometer** **fully instrumented** in pseudo-rapidity range **2 < η < 5**

- σ(IP) ≈ 20 μm
- δp/p ≈ 0.5–1% for p < 200 GeV/c
- $\varepsilon_{K \to K} \approx 95\%$ for $\varepsilon_{\pi \to K} \approx 5\%$ up to 100 GeV/c
- $\varepsilon_{\mu \to \mu} \approx 97\%$ for $\varepsilon_{\pi \to \mu} \approx 1\text{-}3\%$ 10.1142/S0217751X15300227

Some assets :
- Excellent vertex and decay-time resolution.
- Very good momentum resolution.
- Good particle identification.

The LHCb detector

LHCb : **single arm spectrometer fully instrumented** in pseudo-rapidity range **2 < η < 5**
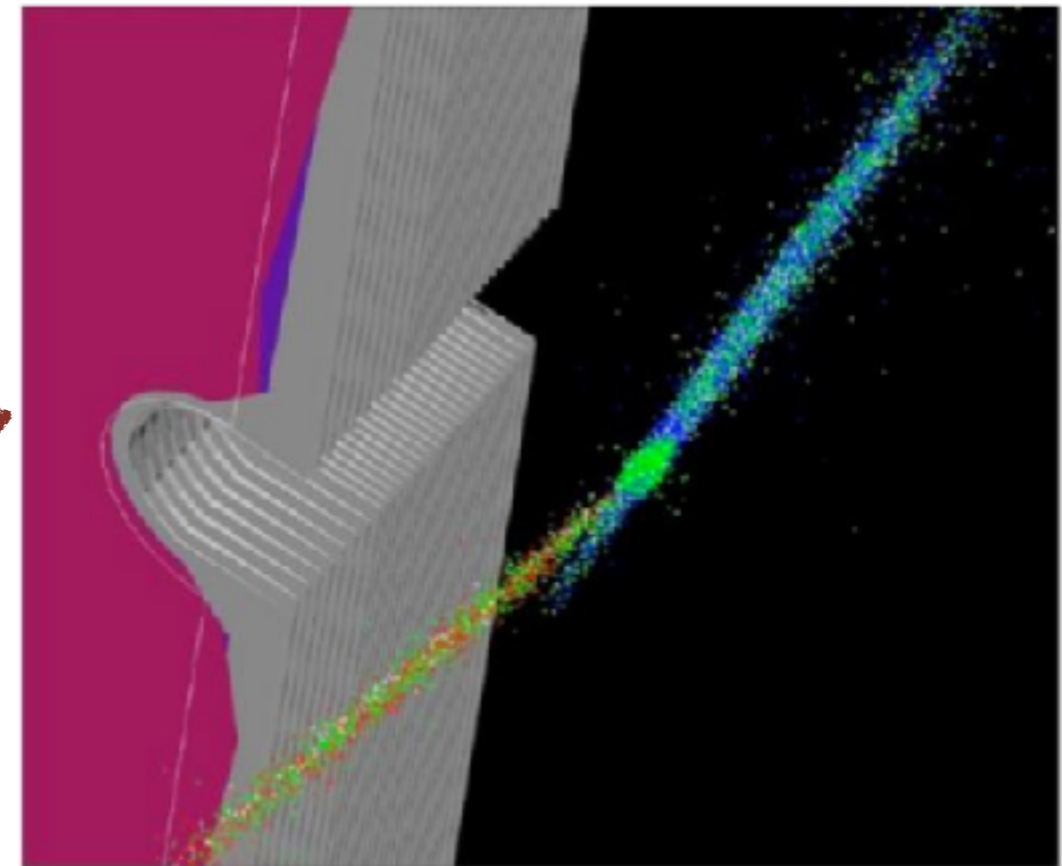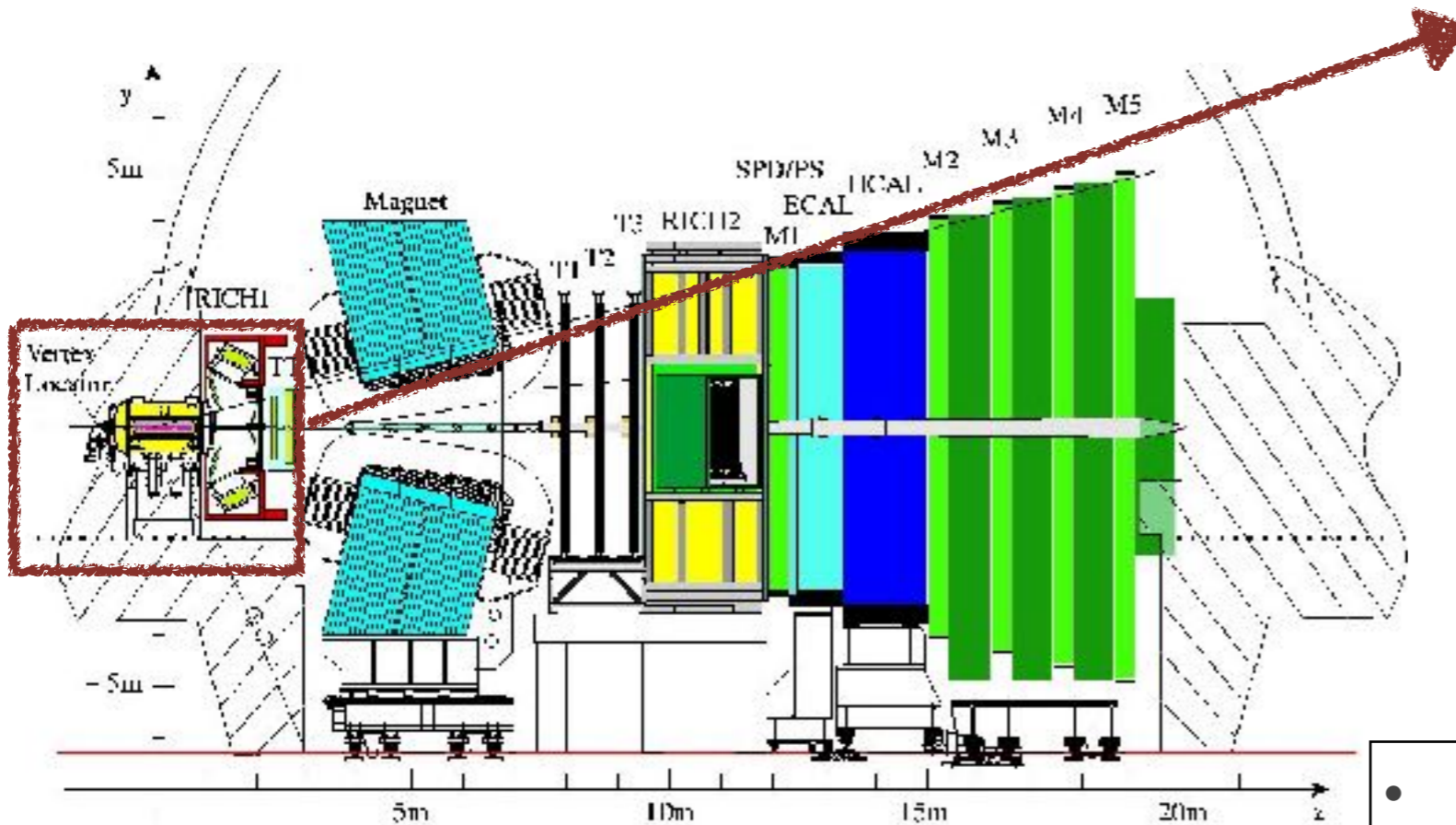
Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.
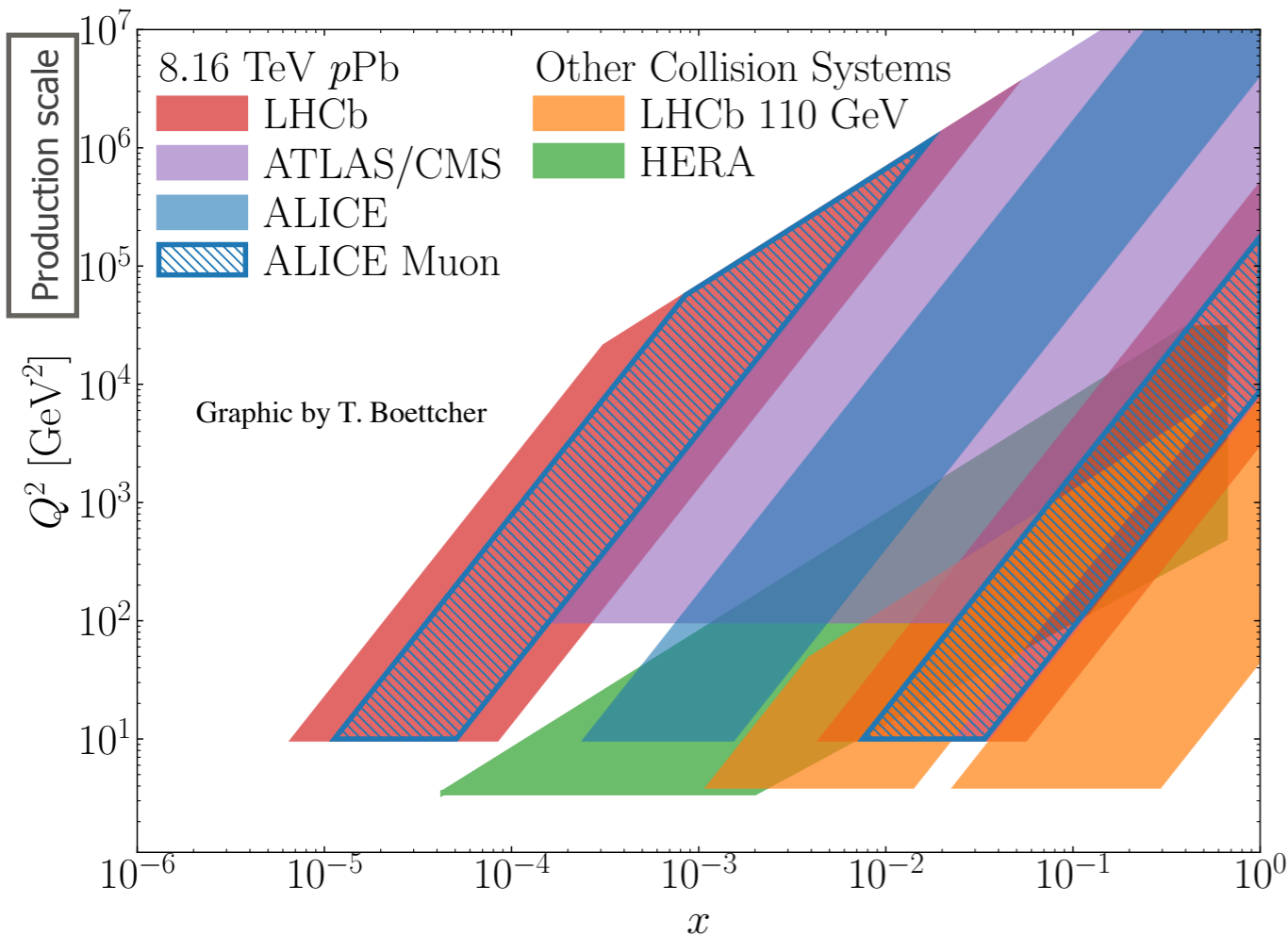
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

Can operate in fixed-target !

- Fixed-target mode: **unique at LHC !**
  - Injecting gas in the LHCb VErtex LOcator (VELO) tank
  - **Noble gas only** : He, Ne, Ar, Kr, Xe
- **Nice follow-up/completion of p-Pb studies.**

Probing the nucleus with LHCb

Example of gluon nPDF

Graphic by T. Boettcher

8.16 TeV pPb
- LHCb
- ATLAS/CMS
- ALICE
- ALICE Muon

Other Collision Systems
- LHCb 110 GeV
- HERA

Production scale

Q^2 [GeV^2]

x

EPPS16
nCTEQ15

$R_g^{Pb}(x, Q^2 = 10\,\text{GeV}^2)$

Eur.Phys.J. C77 (2017) no.3, 163

Bjorken-x = fraction of the nucleon momentum carried by a parton

LHCb can contribute to probe the large and low Bjorken-x regions

LHCb physics program

* Other talks this week:

  → **Shanzen Chen** - Quarkonia production in pPb collisions with LHCb (07/05/18)

    - J/ψ production in p-Pb at $\sqrt{s_{NN}}$ = 8.16 TeV

  → **Jihyun Bhom** - pA collisions in fixed-target mode at LHCb (07/07/18)

    - J/ψ production in p-Ar and p-He collisions

    - D^0 production in p-Ar and p-He collisions

$E_{beam}(p)$	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

Syst.	Year	$\sqrt{s_{NN}}$	Lumi.	
p-Pb/Pb-p	2013	5.02 TeV	1.6 nb⁻¹	
Pb-Pb	2015	5.02 TeV	10 μb⁻¹	
p-Pb/Pb-p	2016	8.16 TeV	34 nb⁻¹	21×2013
Xe-Xe	2017	5.44 TeV	0.4 μb⁻¹	
Pb-Pb	2018	5.02 TeV	≈ 10 μb⁻¹	

Results for charm productions

D⁰ production in p-Pb@5.02 TeV

JHEP 10 (2017) 090

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rapidity in the CMS y^*
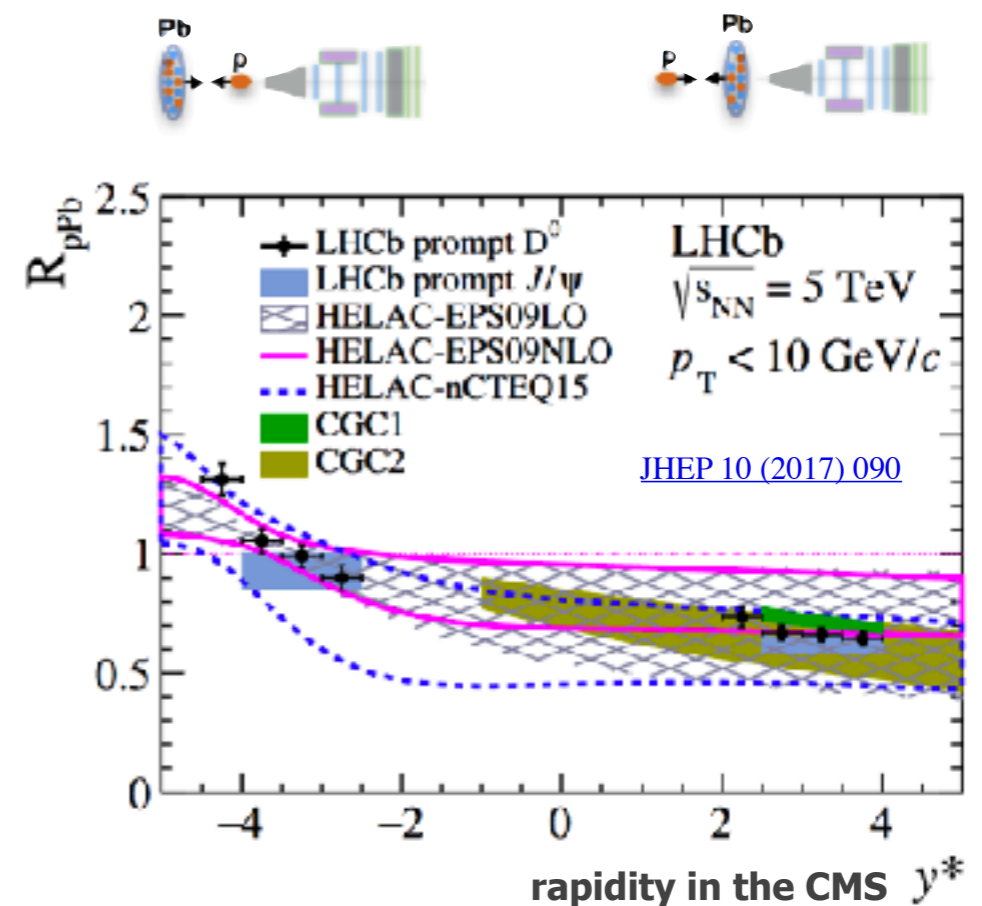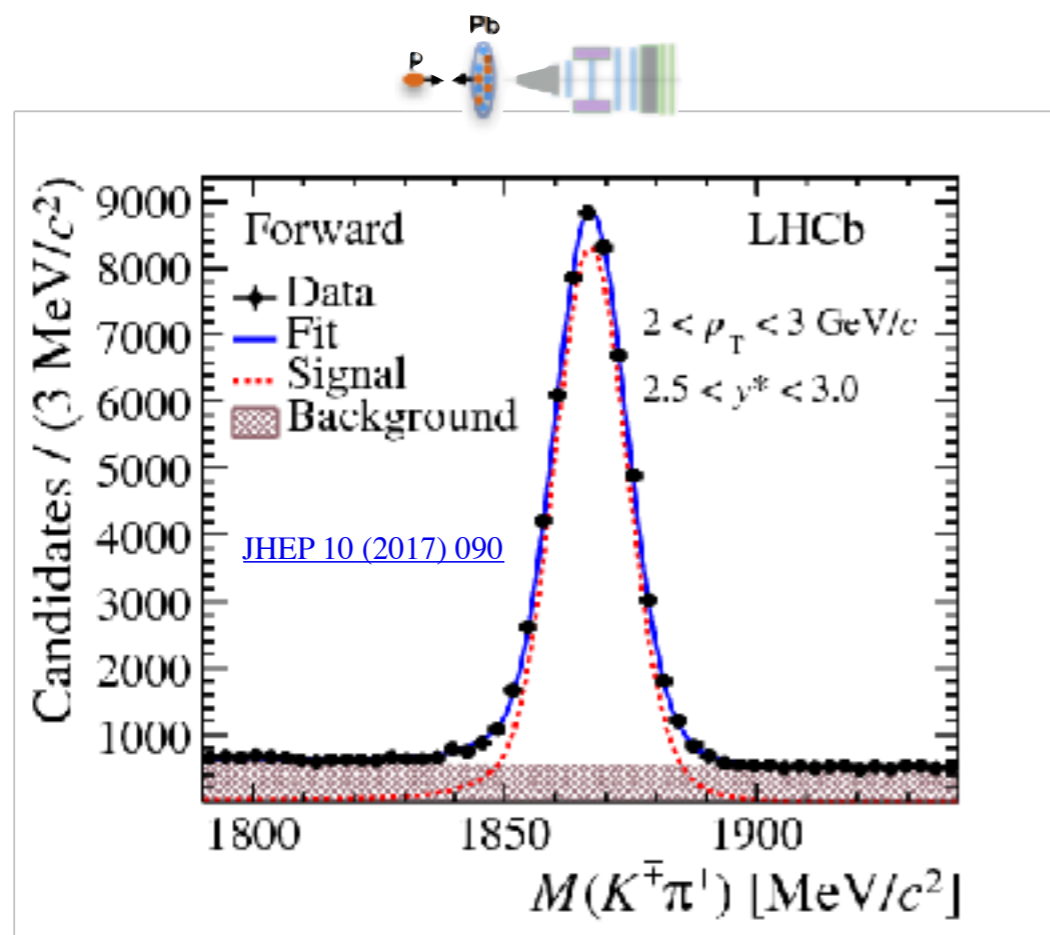
❖ Forward rapidity region :

  ➡ **Significant D⁰ suppression** w.r.t pp yield

  ➡ **Good description** of the data by model predictions.

❖ Backward rapidity :

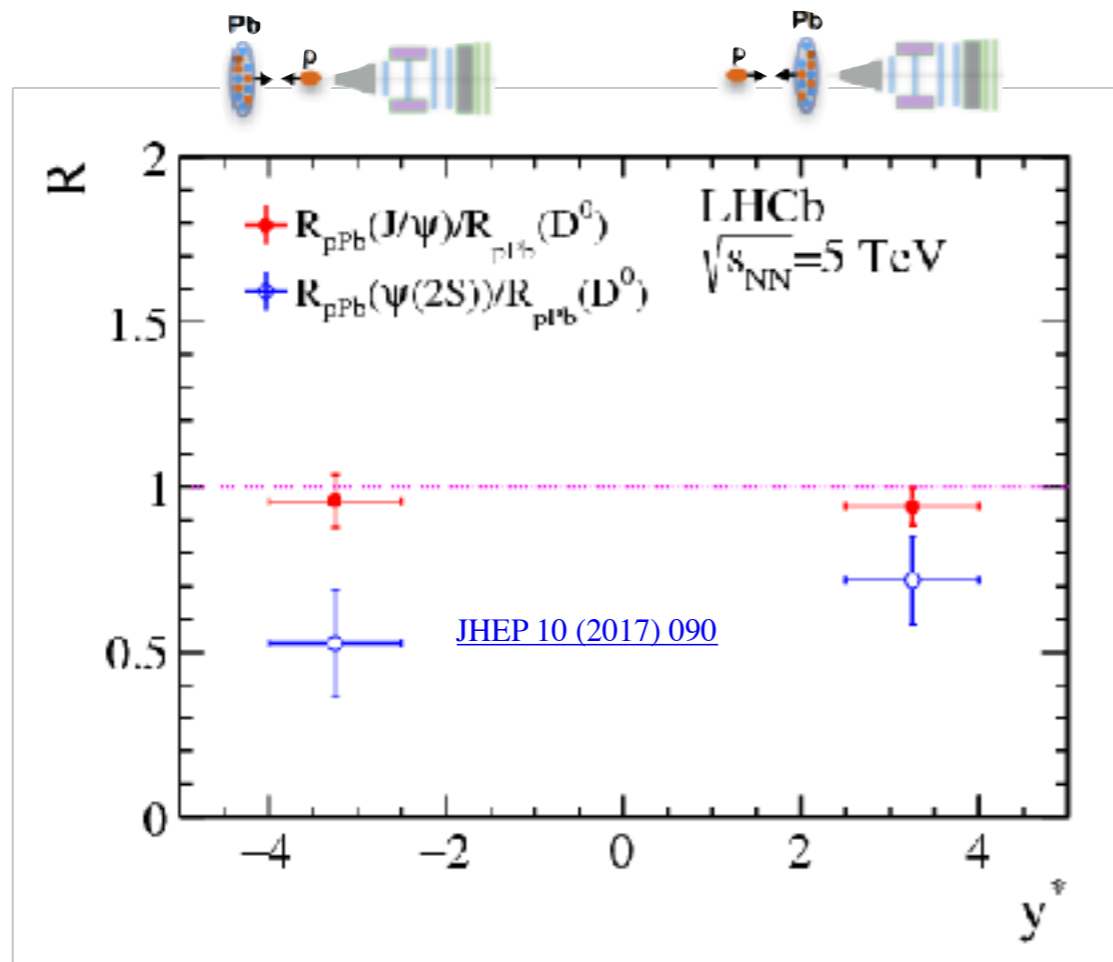 ➡ **Small enhancement** w.r.t pp yield **compatible** with theory predictions.

❖ Put constraints on nPDF parametrization (see arXiv:1712.07024)

Theory papers :
- nPDFS: Eur. Phys. J.C 77 (2017) 1
- Energy-loss : JHEP 03(2013)122
- CGC1 : Phys. Rev. D 91(2015) 114005
- CGC2 : arXiv:1706.06728

ψ-to-D⁰ production in p-Pb@5.02 TeV
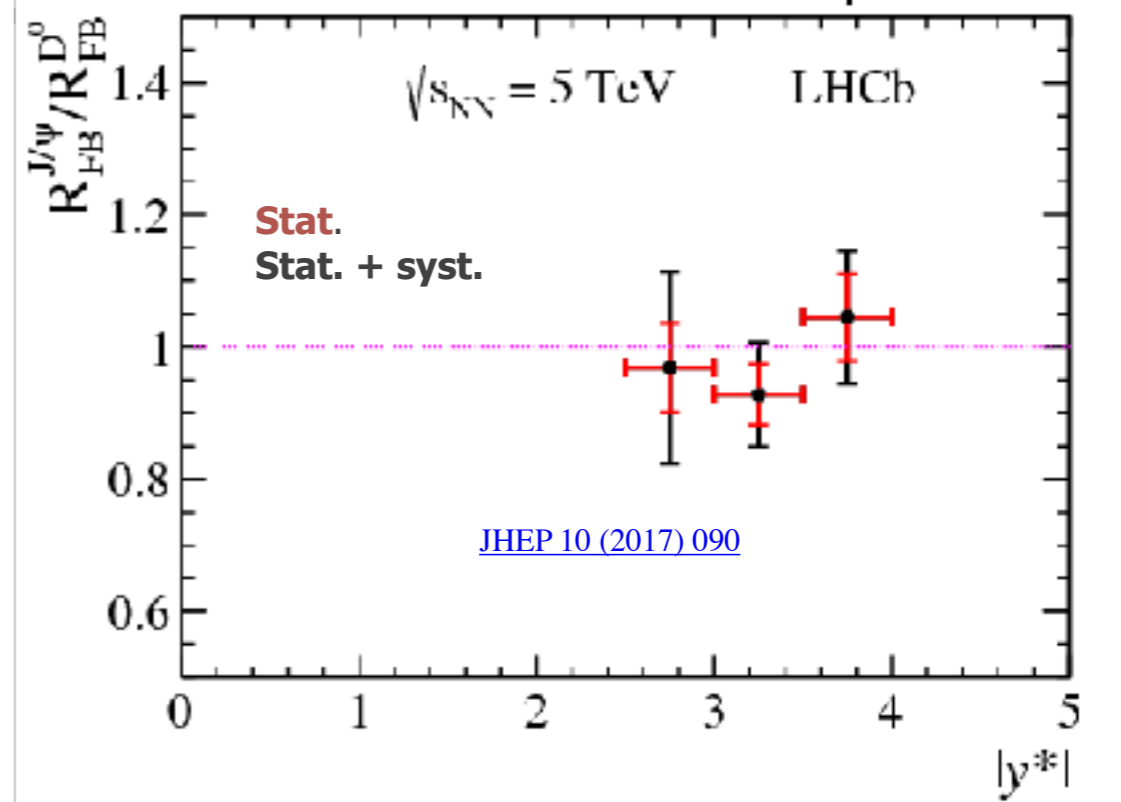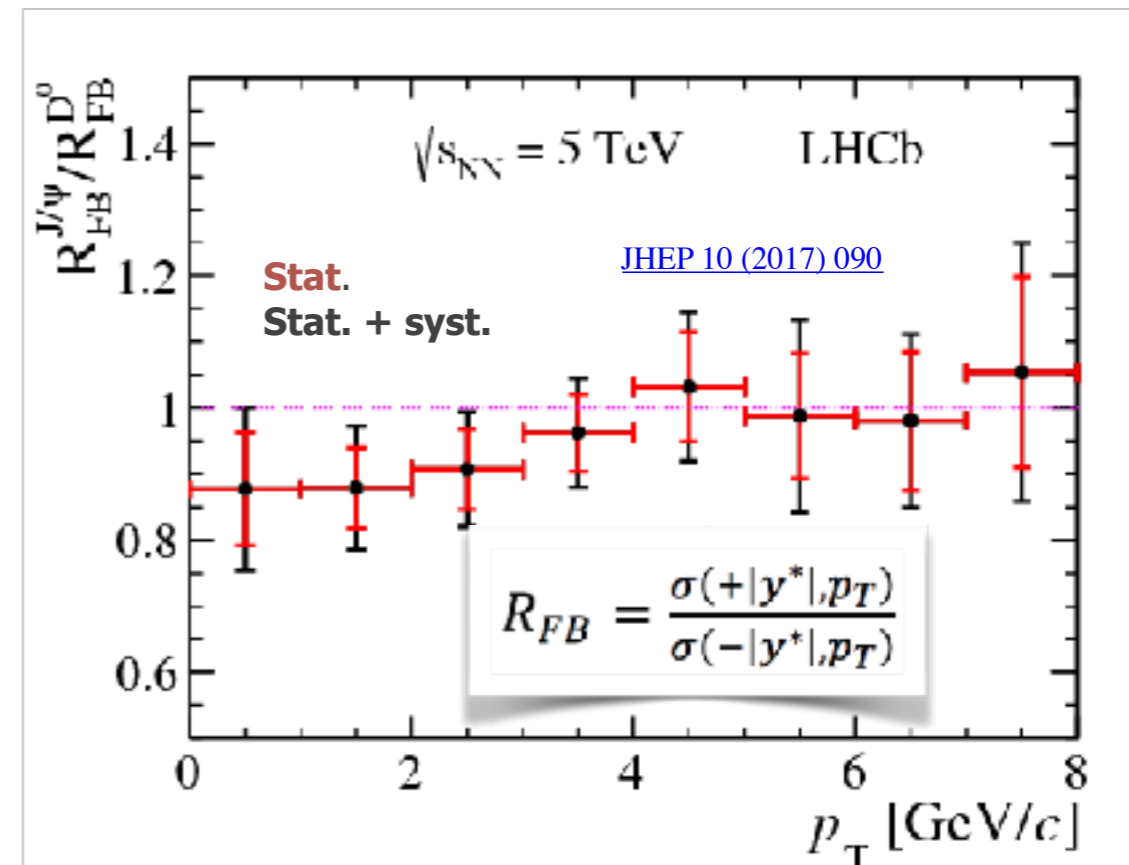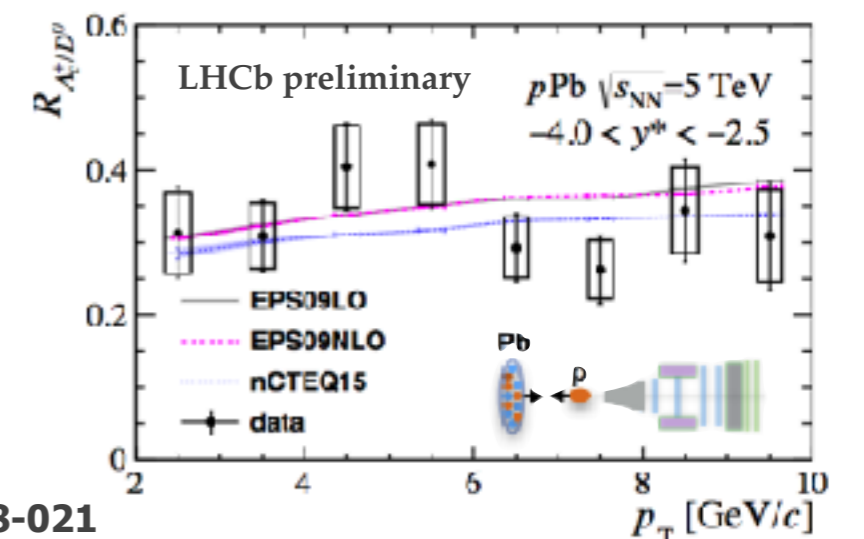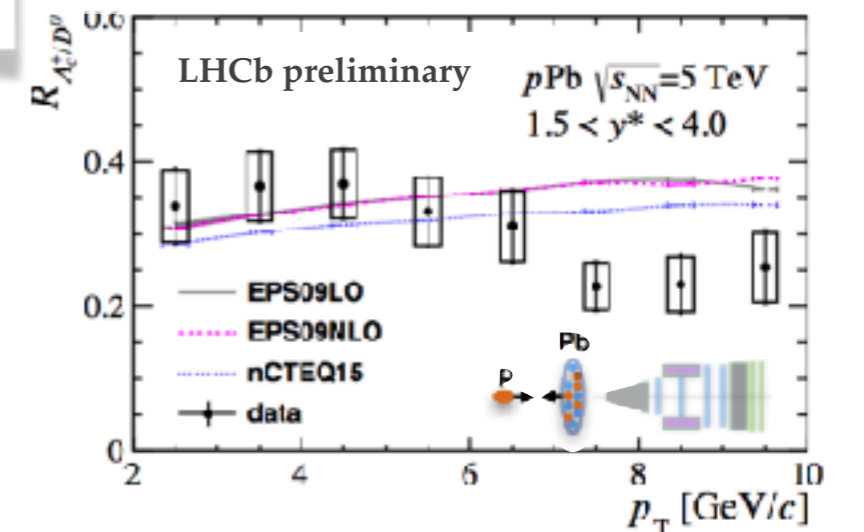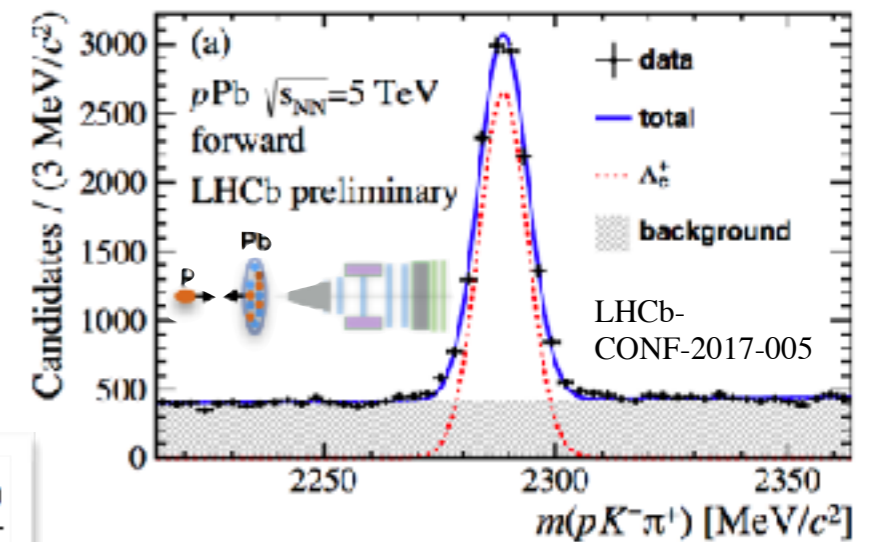

- ❖ ψ = c-c̄ bound state.

- ❖ Data **compatible** with **no relative** J/ψ-to-D⁰ suppression, with **small deviation** from unity **at low** p_T.

- ❖ Relative ψ(2s)-to-D0 (and J/ψ) suppression **still not fully understood**

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

Λ_c^+-to-D^0 production in p-Pb@5.02 TeV

❖ **New** : Λ_c^+ cross section

❖ Λ_c^+-to-D^0 = Baryon-to-meson ratio, *sensitive to charm hadronization mechanism.*

$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*,p_T)}{\sigma_{D^0}(y^*,p_T)}$$

❖ Model predictions based on measured *pp* cross section.

❖ **Forward rapidity** : **discrepancies between data and models** at high-p_T.

❖ **Backward rapidity** : **good agreement** between data and model predictions.

LHCb-CONF-2017-005

LHCb-PAPER-2018-021
in preparation

Results for beauty productions

$\Upsilon(1S)$ in p-Pb@5.02 TeV

LHCb
pPb $\sqrt{s_{NN}}$ = 5 TeV

$1.5 < y < 4.0$
$p_T < 15$ GeV/c

JHEP 07 (2014) 094

LHCb
pPb $\sqrt{s_{NN}}$ = 5 TeV

JHEP 07 (2014) 094

EPS09 at NLO in Ref.[3]

$\Upsilon(1S)$
Prompt J/ψ

LHCb, $\Upsilon(1S)$
LHCb, Prompt J/ψ
LHCb, J/ψ from b

LHCb
pPb $\sqrt{s_{NN}}$ = 5 TeV

JHEP 07 (2014) 094

E.loss+EPS09 NLO in Ref.[7]

$\Upsilon(1S)$
Prompt J/ψ
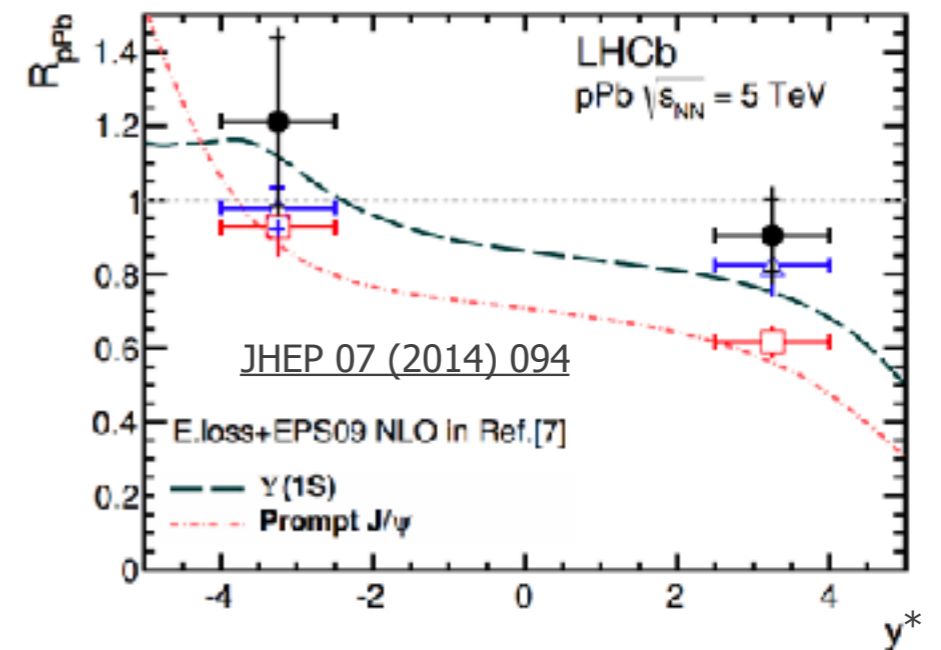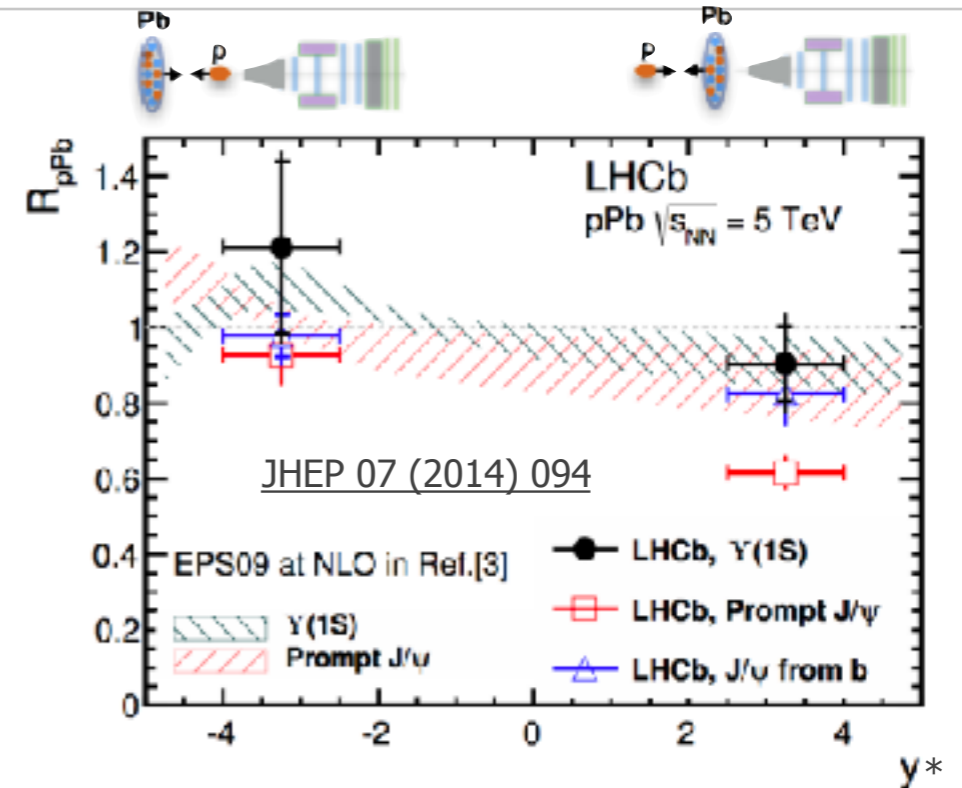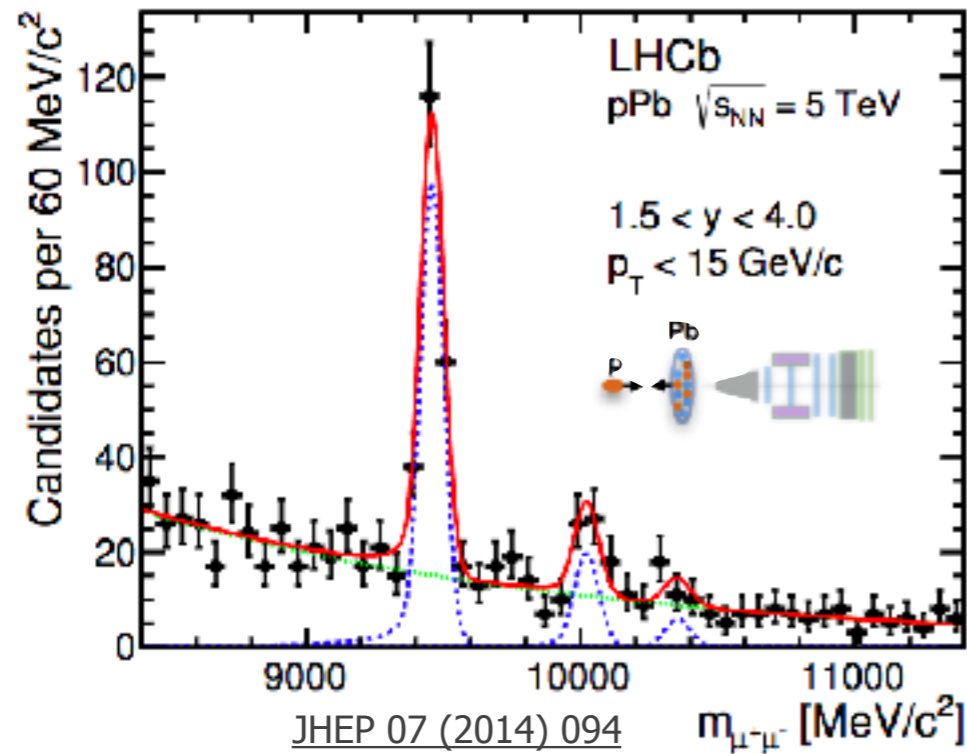
- ❖ $\Upsilon = b\text{-}\bar{b}$ bound state.

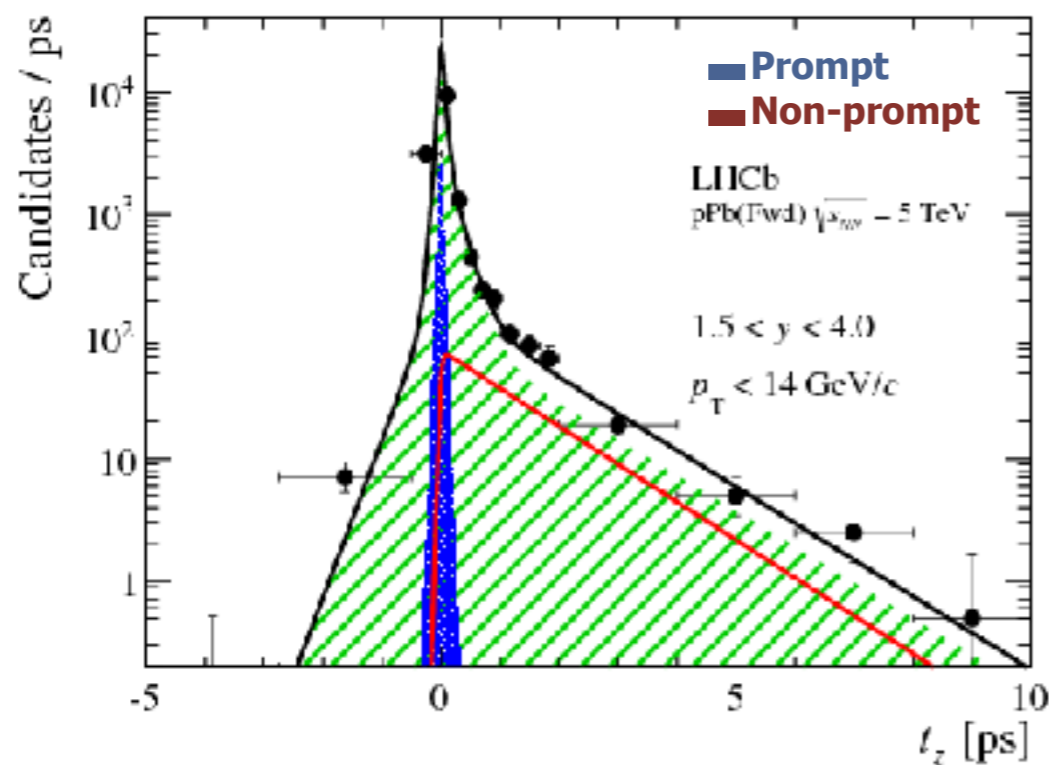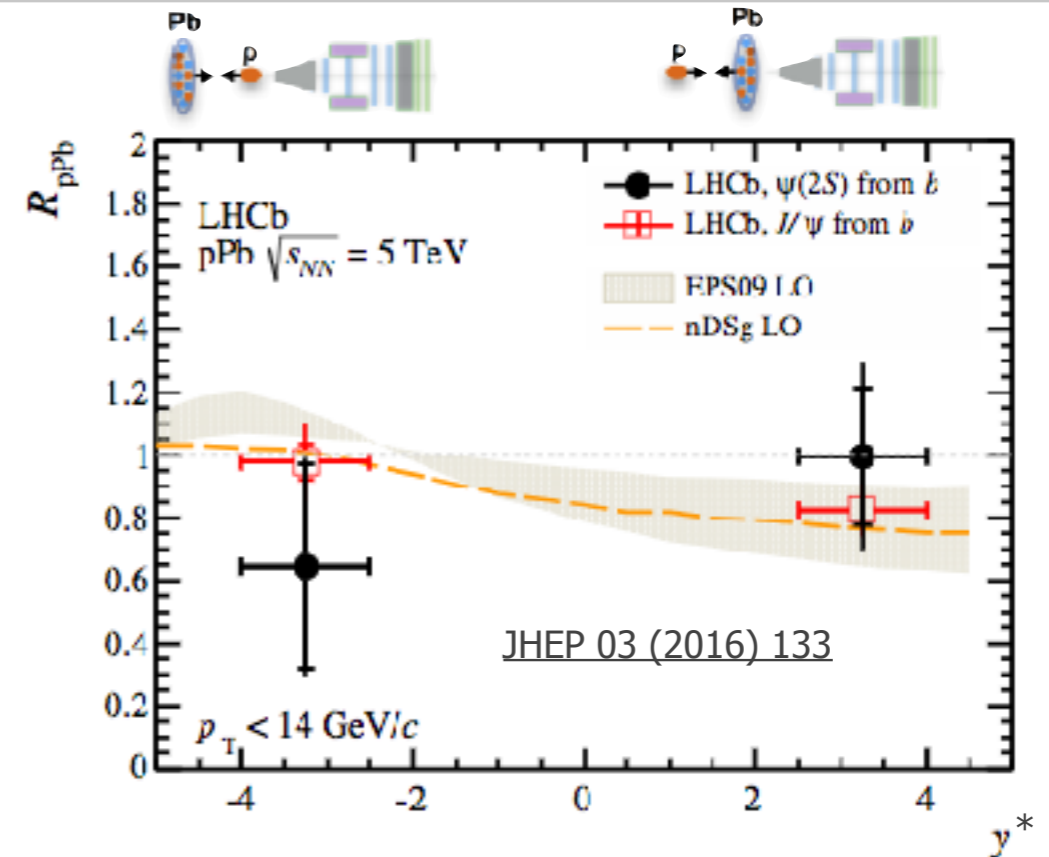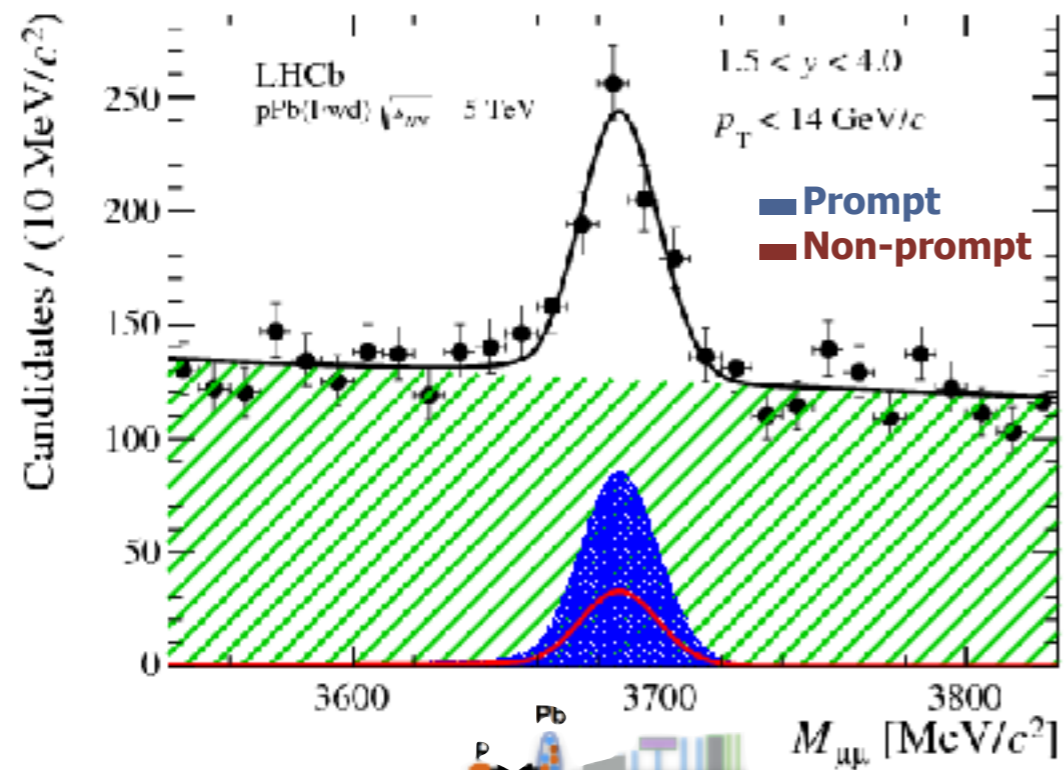- ❖ $\Upsilon(1S)$'s R_{pPb} **compatible with unity versus rapidity.**

- ❖ Theory predictions **compatible** with the measurements.

Non-prompt charmonia in p-Pb@5.02 TeV

JHEP 03 (2016) 133

- ❖ Non-prompt : coming from b decay.

- ❖ Non-prompt $\psi(2S)$'s R_{pPb} compatible with unity within (large) statistical uncertainties.

- ❖ Small deviation from unity of non-prompt J/ψ's R_{pPb} at forward rapidity, compatible with unity at backward rapidity

- ❖ Theory predictions compatible with non-prompt J/ψ measurements.

- ❖ For results in pPb@8.16TeV, see Shanzen's presentation on Thursday !

Conclusions and outlooks

❖ **Heavy-quarks production:**

  ➡ In Pb-Pb : probes for the Quark-Gluon Plasma

  ➡ In p-A : sensitive to cold nuclear matter effects !

❖ **The LHCb detector :**

  ➡ Unique **single arm spectrometer fully instrumented** in pseudo-rapidity range **$2 < \eta < 5$.**

  ➡ Fixed-target program completes the wide picture of cold-nuclear effect studies. (see Jihyun Bhom's talk on Saturday!)

❖ **Current results in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV:**

  ➡ *Open-Charm production* : **D^0 and Λ_c^+**

    - **General good description** of the data by the model predictions.

    - **Discrepancies between data and models at high-p_T in the Λ_c^+-to-D^0 ratio.**

  ➡ *Beauty production* : **$\Upsilon(1S)$ and non-prompt J/ψ, $\psi(2S)$**

    - **General good description** of the data by the model predictions.

    - **Large statistical uncertainty :** see Shanzen Chen's talk for pPb@8.16TeV results !

❖ **Many results to come !**

Teaser ...
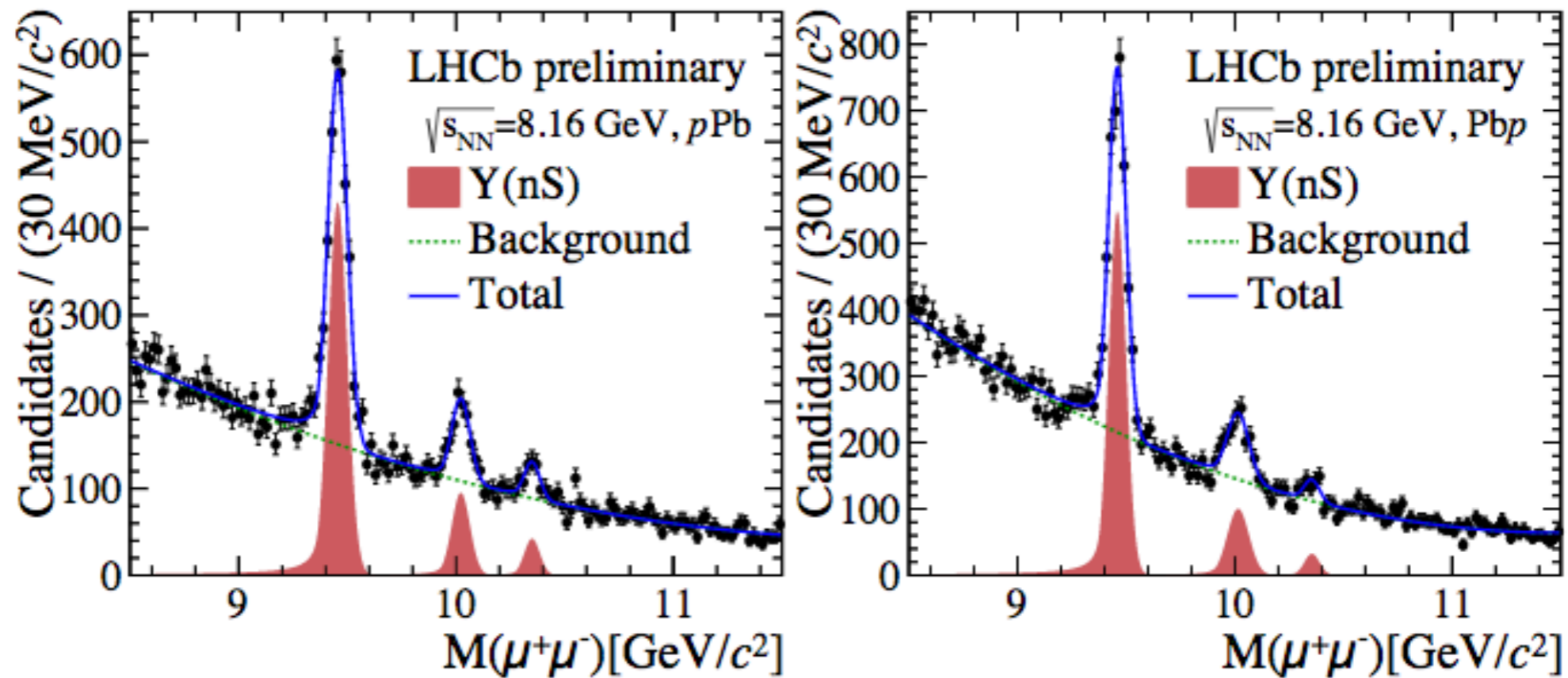
Analysis ongoing !

Back-up

D⁰ production at $\sqrt{s_{NN}} = 5.02$ TeV

Uncertainty table

Source	Relative uncertainty (%)	
Correlated between bins	Fwd	Bwd
Mass fits to determine signal yields	0-5	0-5
χ^2_{IP} fits	0-5	0-5
Tracking	3.0	5.0
PID efficiency	0.6–17	0.6–30
Luminosity	1.9	2.1
$\mathcal{B}(D^0 \to K^-\pi^+)$	1.	1.
Uncorrelated between bins		
MC Sample size	1.0-4.0	1.0-5.0
Statistical uncertainty	0.5-20	1-20