



# Charm cross-section activities in HonexComb

## LPCC working group on heavy-ions

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for the HonexComb charm group:**

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# Introduction

- Objectives: obtain a combined measurement of  $\sigma_{tot}(c\bar{c})$  and  $\sigma_{charm}$  vs.  $p_T$  and  $y$  using existing published measurements of ALICE, CMS and LHCb at 5 TeV.
  - Understand theory, find “best” description for total charm cross-section
  - **Critical input for calculations in AA collisions**
- Goals:
  - Collecting in a common database the relevant charm measurements in  $pp$  collisions in a consistent ROOT/txt format.
  - Providing summary plots to be used in review papers and summary talks
  - Providing comprehensive comparisons to theoretical calculations in the various rapidity and transverse momentum regions.
  - Encourage the development of dedicated tunes for theoretical calculations (e.g. Pythia) that consider the knowledge acquired after 10 years of charm measurements at the LHC
  - Common and unique inputs for charm differential cross-section vs.  $p_T$  and rapidity to be used as input for AA theoretical calculations
  - **Provide an estimation of the total charm cross-section, which incorporates the constraints coming from the various LHC experiments**

# Charm results and combination

- Collection of open charm results in  $pp$  collisions at 5 TeV

Experiment	Ref. code	Hadronic decays
ALICE	EPJC 79, 388 (2019)	$D^0 \rightarrow K^- \pi^+$ , $D^+ \rightarrow K^- \pi^+ \pi^+$ , $D_s^+ \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$ , $D^{*+} \rightarrow D^0 \pi^+$ (+ c.c.)
ALICE	PRL (CERN-EP-2020-217)	$\Lambda_c^+ \rightarrow p K^- \pi^+$ , $\Lambda_c^+ \rightarrow p K_S^0$ (+ c.c.)
ALICE	PRC (CERN-EP-2020-218)	$\Lambda_c^+ \rightarrow p K^- \pi^+$ , $\Lambda_c^+ \rightarrow p K_S^0$ (+ c.c.)
CMS	PLB, v. 782, 2018, p 474-496	$D^0 \rightarrow K^- \pi^+$ (+ c.c.)
CMS	PLB, v. 803, 2020, 135328	$\Lambda_c^+ \rightarrow p K^- \pi^+$ (+ c.c.)
LHCb	JHEP, 147 (2017)	$D^0 \rightarrow K^- \pi^+$ , $D^+ \rightarrow K^- \pi^+ \pi^+$ , $D_s^+ \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$ , $D^{*+} \rightarrow D^0 \pi^+$ (+ c.c.)

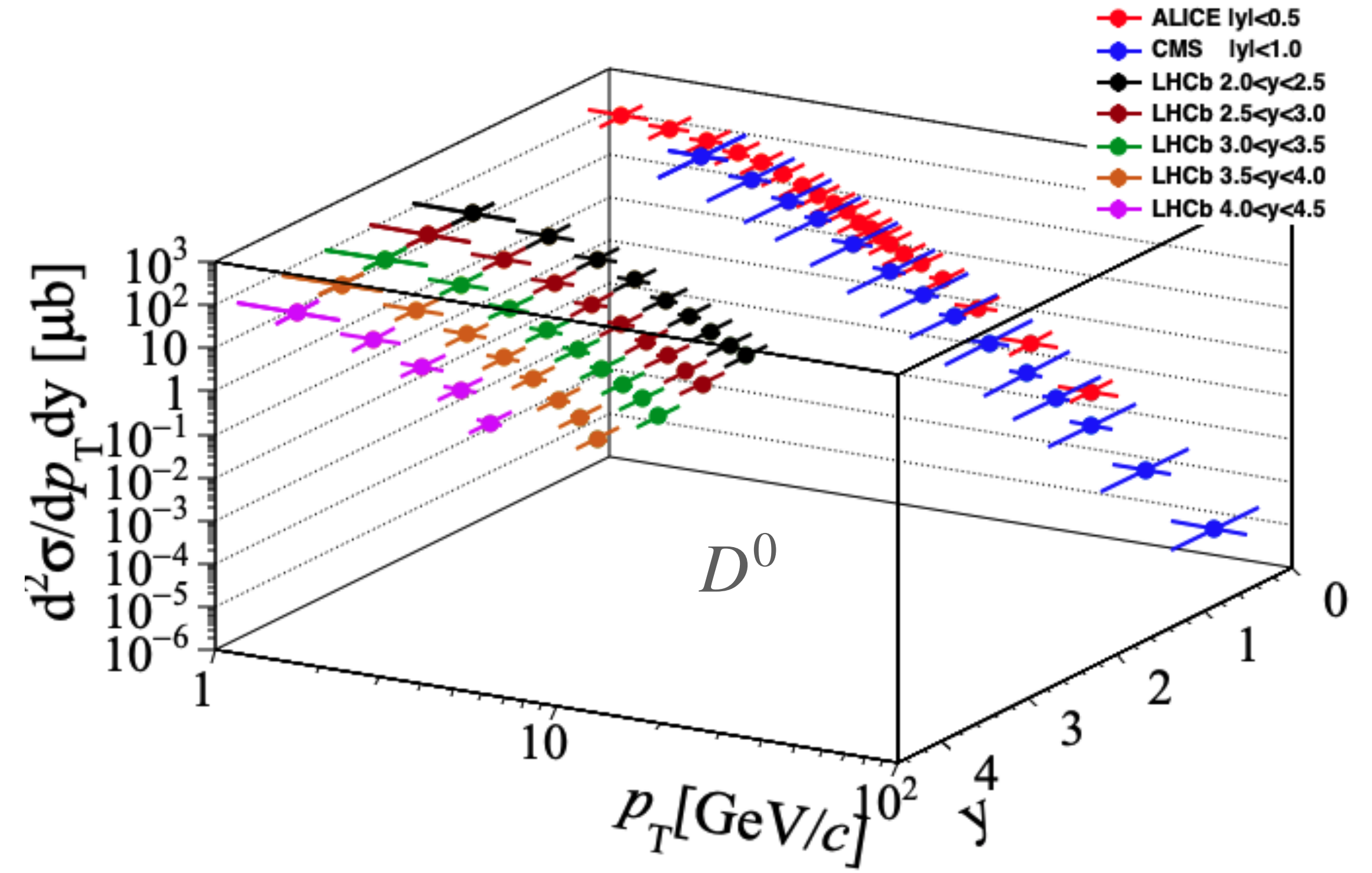
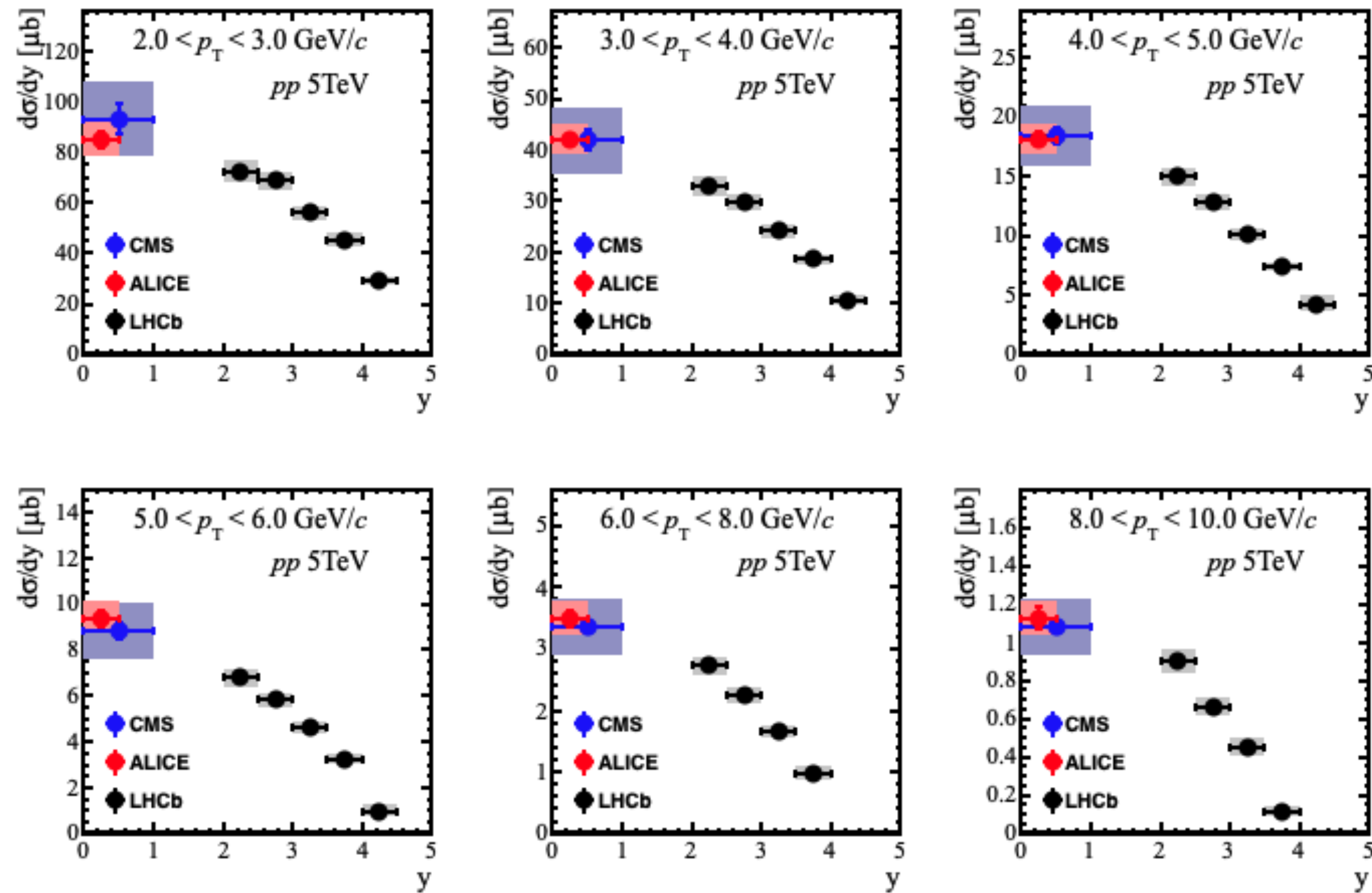
- Kinematic regions ( $D^0$ ):
  - ALICE:  $0 < p_T < 36$  GeV/ $c$ ;  $-0.5 < y < 0.5$
  - CMS:  $2 < p_T < 100$  GeV/ $c$ ;  $-1.0 < y < 1.0$
  - LHCb:  $0 < p_T < 10$  GeV/ $c$ ;  $2.0 < y < 4.5$  in  $\Delta y = 0.5$  bins
- Produce compilation plots of  $\sigma_{charm}$  vs.  $p_T$  and  $y$
- All information collected and accessible in twiki:
- <https://twiki.cern.ch/twiki/bin/view/Honexcomb/HonexcombCharmSection>

Decay	Branching ratio
$D^0 \rightarrow K^- \pi^+$	$3.950 \pm 0.031\%$
$D^+ \rightarrow K^- \pi^+ \pi^+$	$9.38 \pm 0.16\%$
$D_s^+ \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$	$2.24 \pm 0.08\%$
$\Lambda_c \rightarrow p K^- \pi^+$	$6.28 \pm 0.32\%$
$\Lambda_c \rightarrow p K_S^0 \rightarrow p \pi^+ \pi^-$	$1.59 \pm 0.08\%$



# Combination plots for $D^0$

- $D^0$  cross-section in  $p_T$  and  $y$
- $D^0$  cross-section vs.  $y$  in  $p_T$  slices
- Next: comparison to Pythia and FONLL event generators...

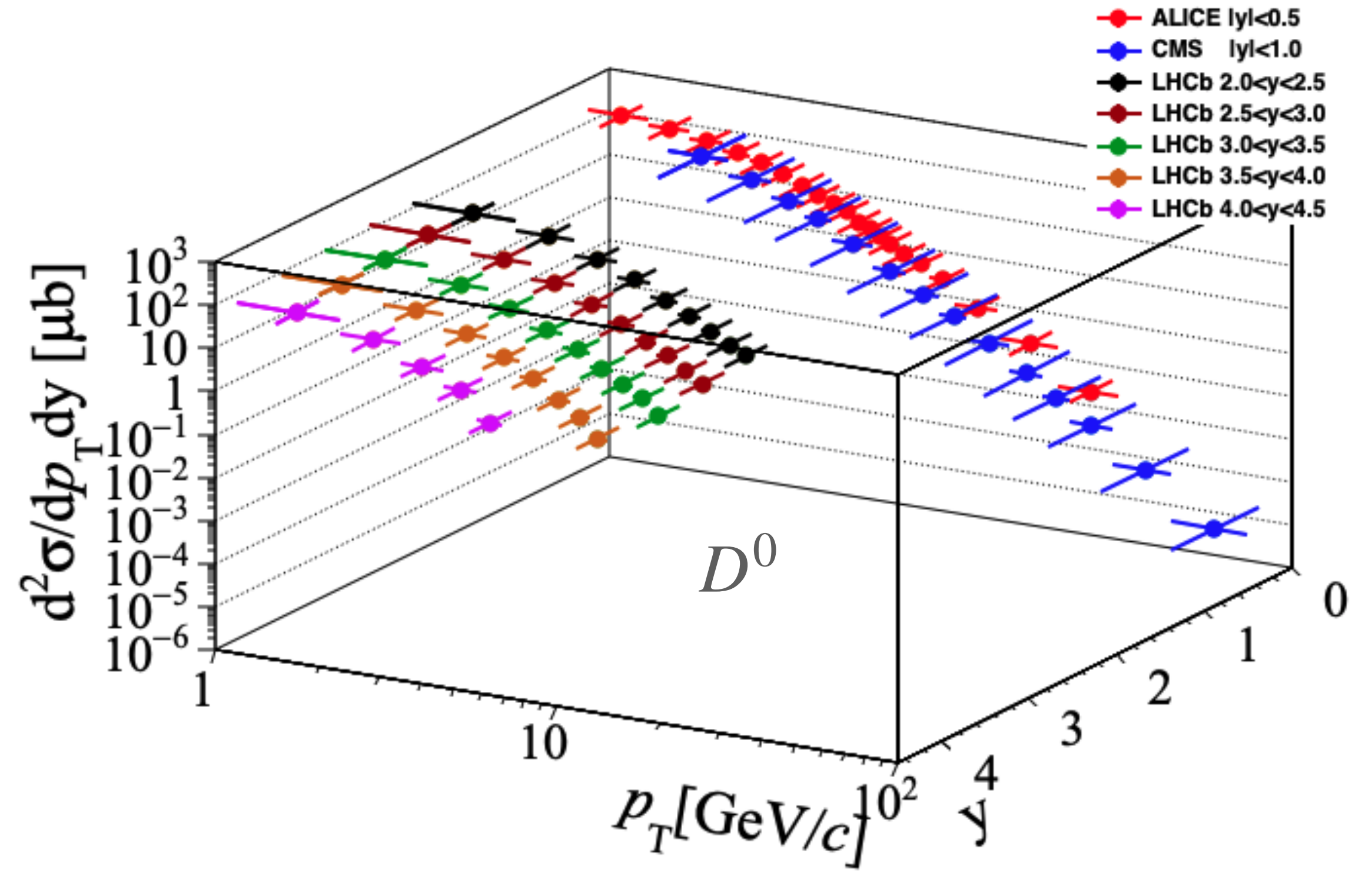
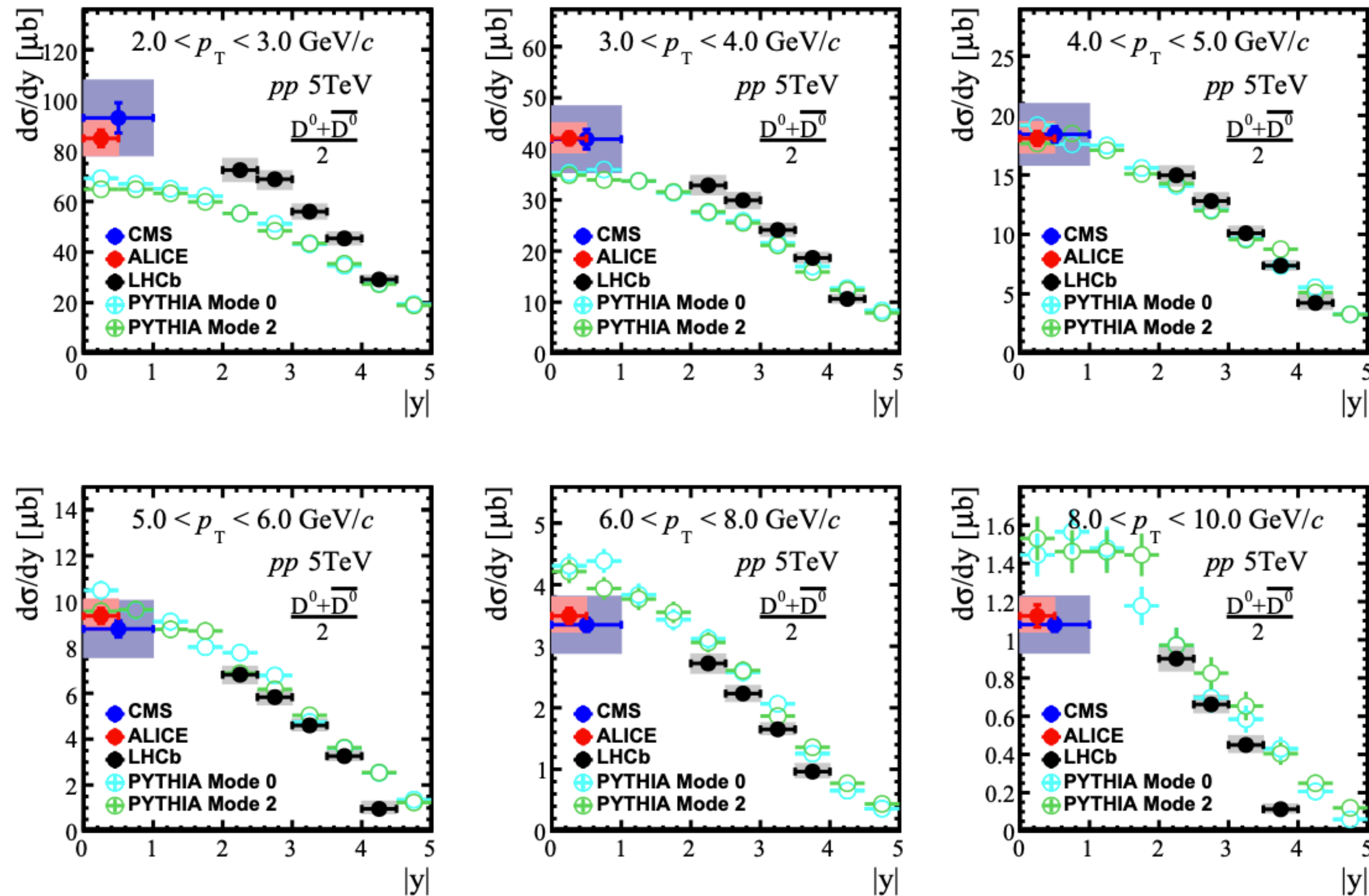


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- $D^0$  cross-section vs.  $y$  in  $p_T$  slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.  
[ATL-PHYS-PUB-2017-008](https://arxiv.org/abs/1702.05470)

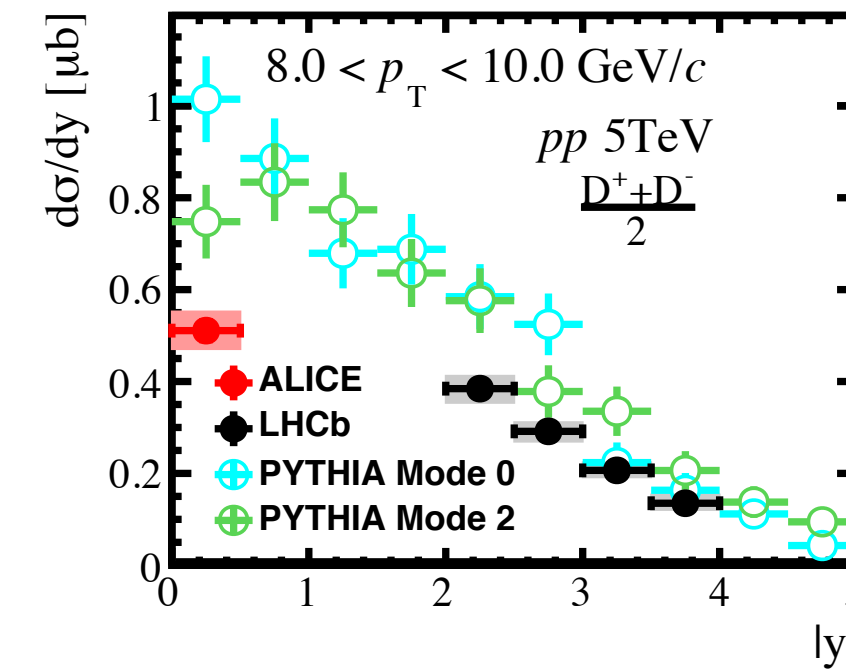
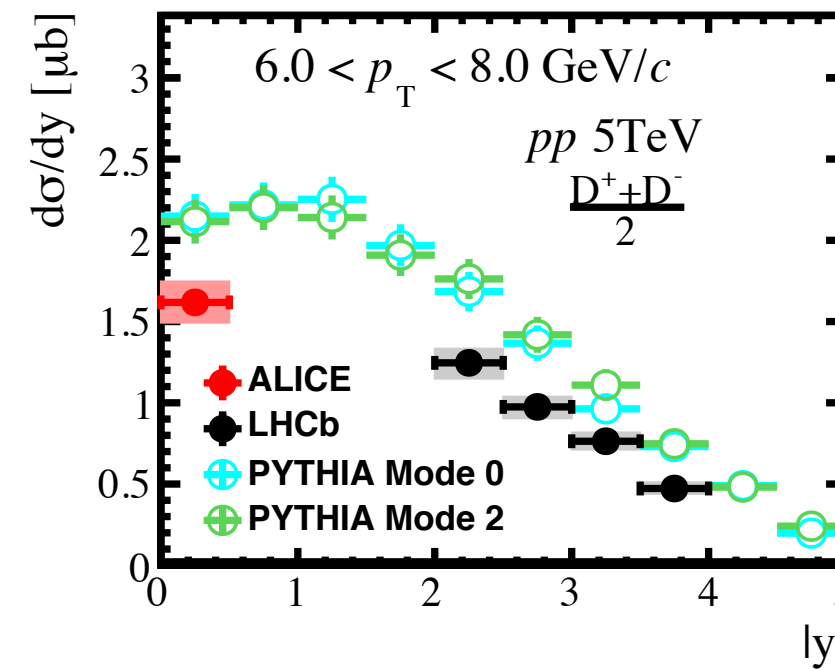
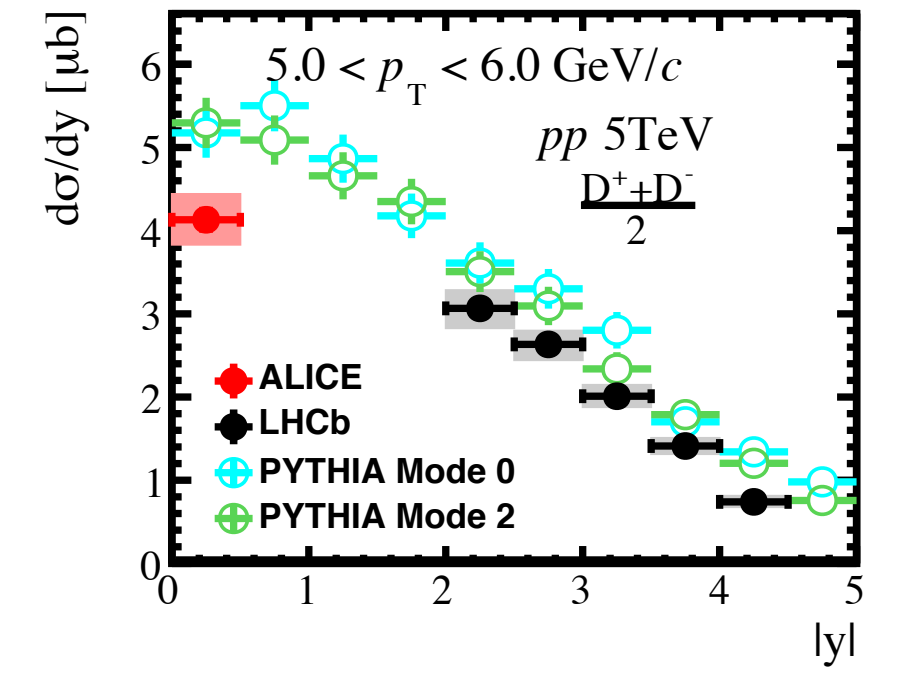
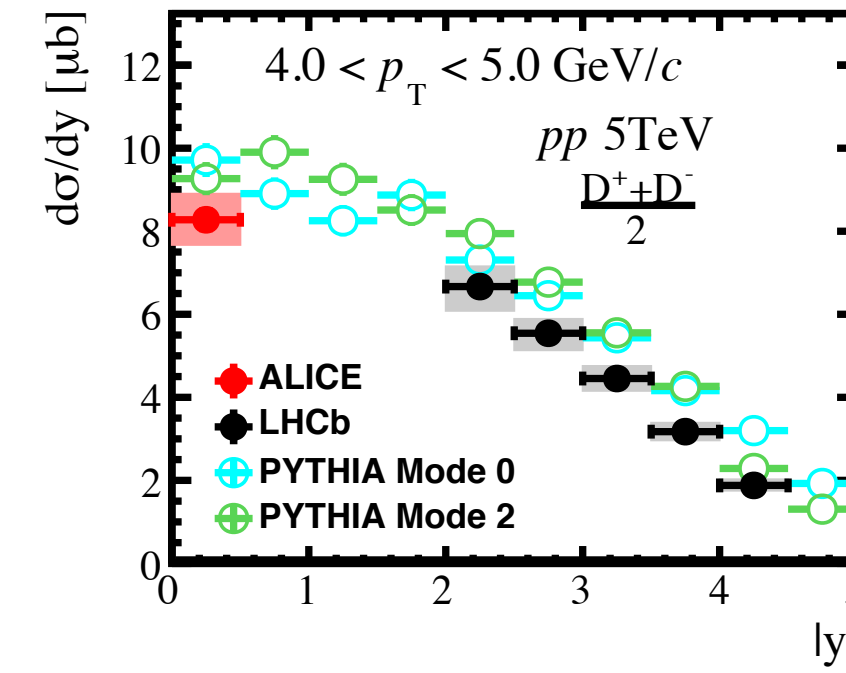
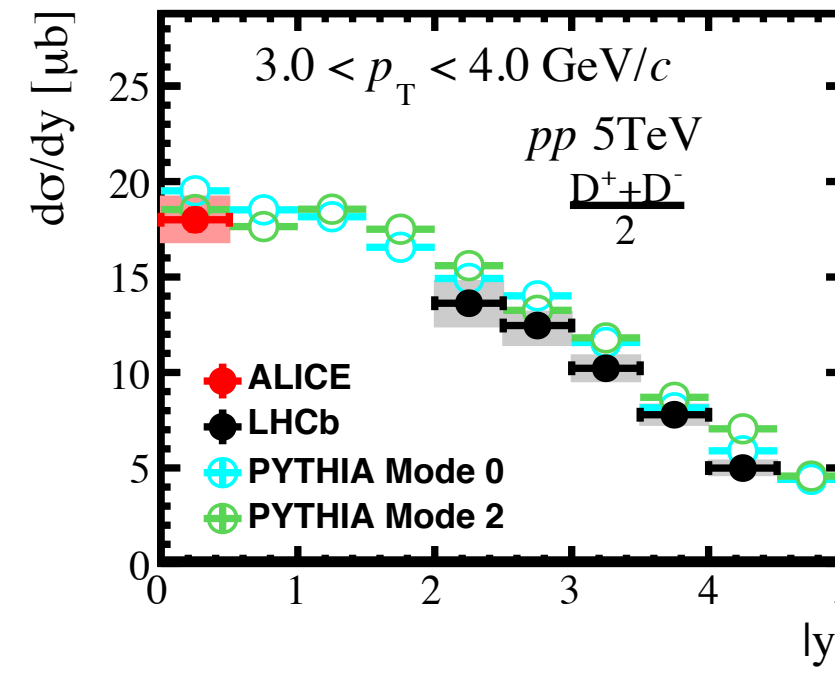
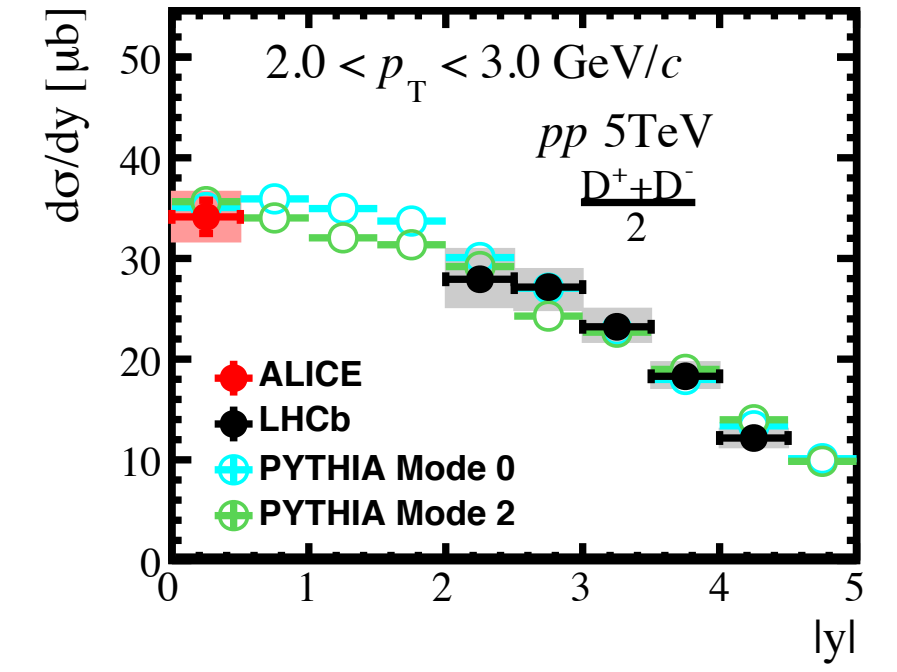
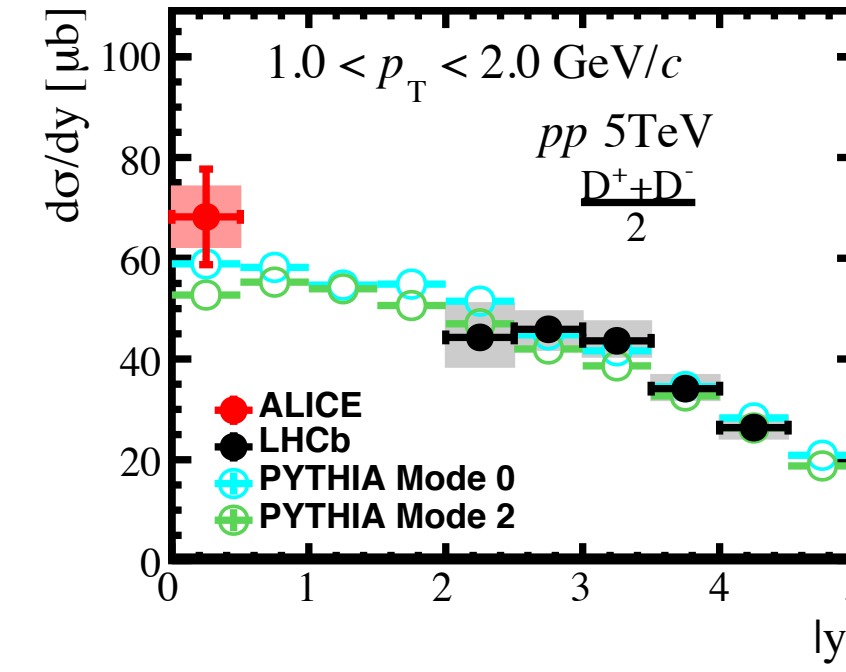
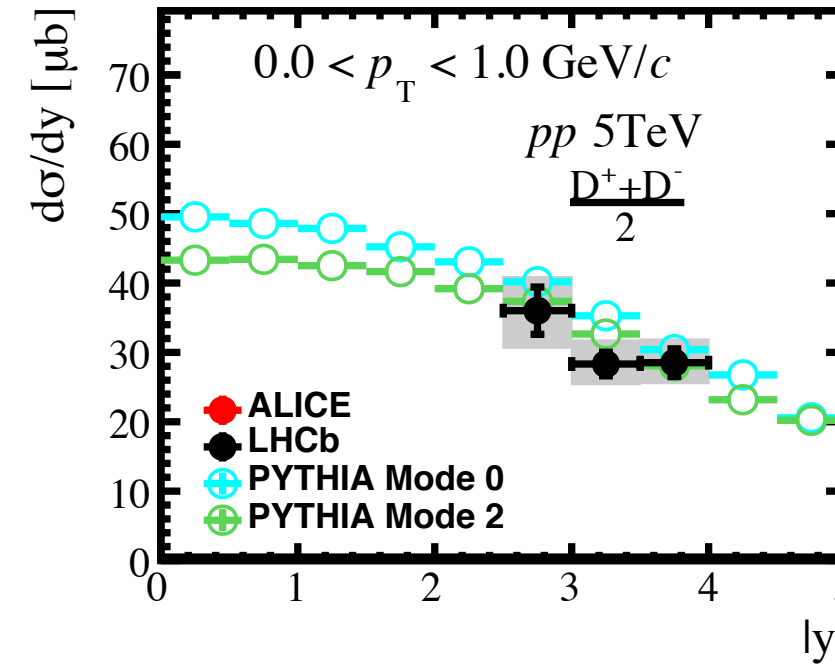
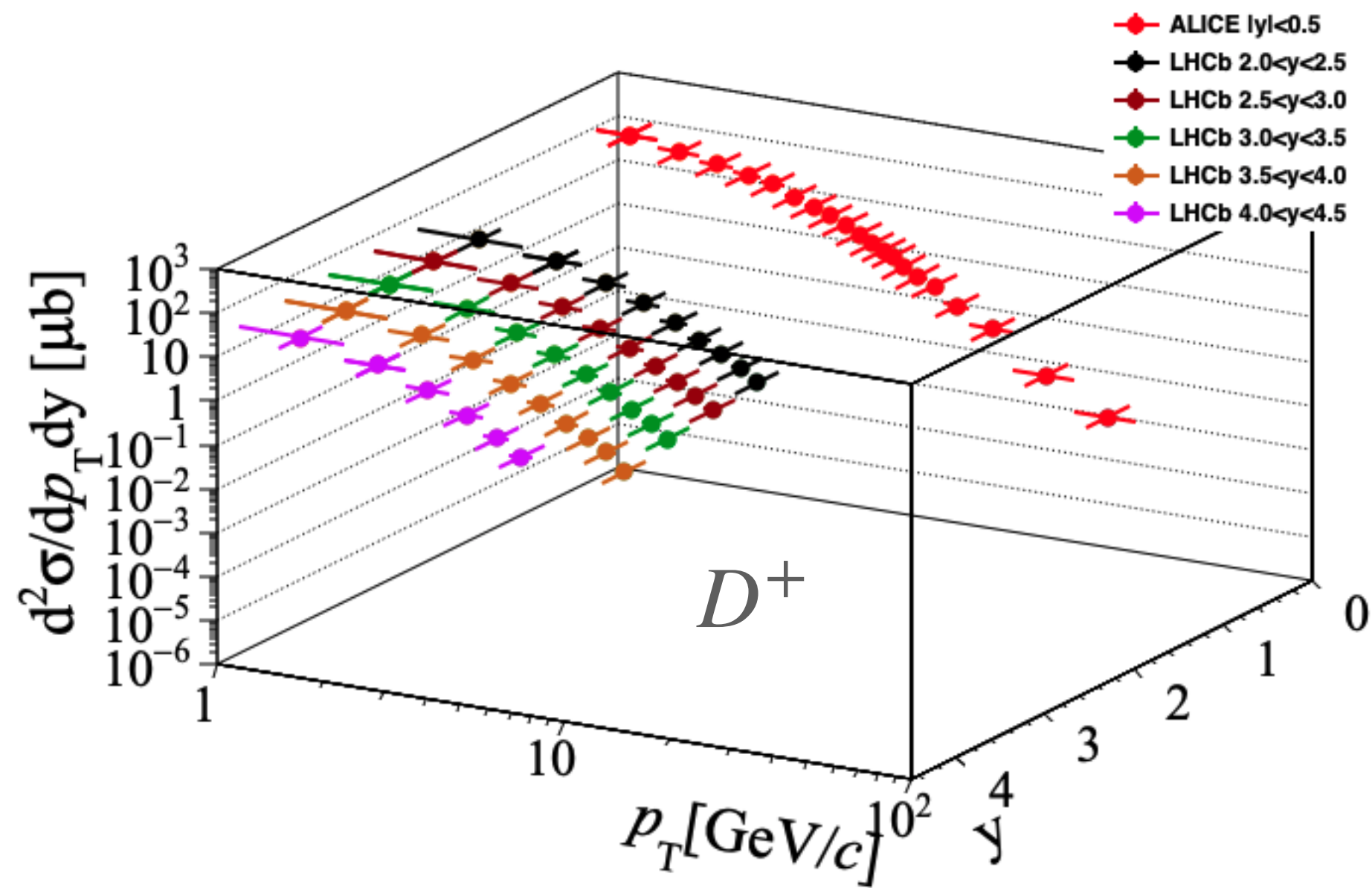


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# Combination plots for $D^+$

- $D^+$  cross-section in  $p_T$  and  $y$
- $D^+$  cross-section vs.  $y$  in  $p_T$  slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

[ATL-PHYS-PUB-2017-008](#)

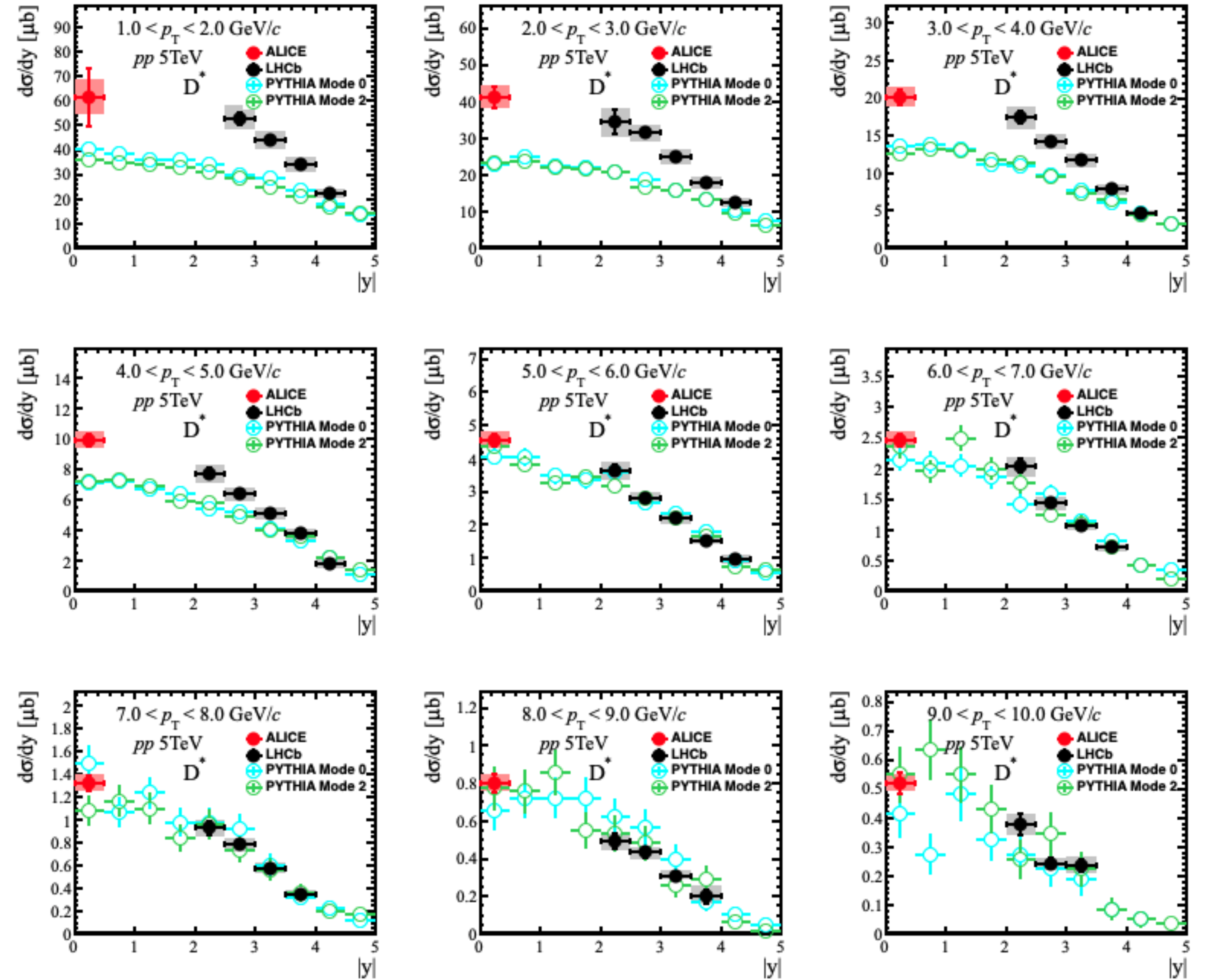
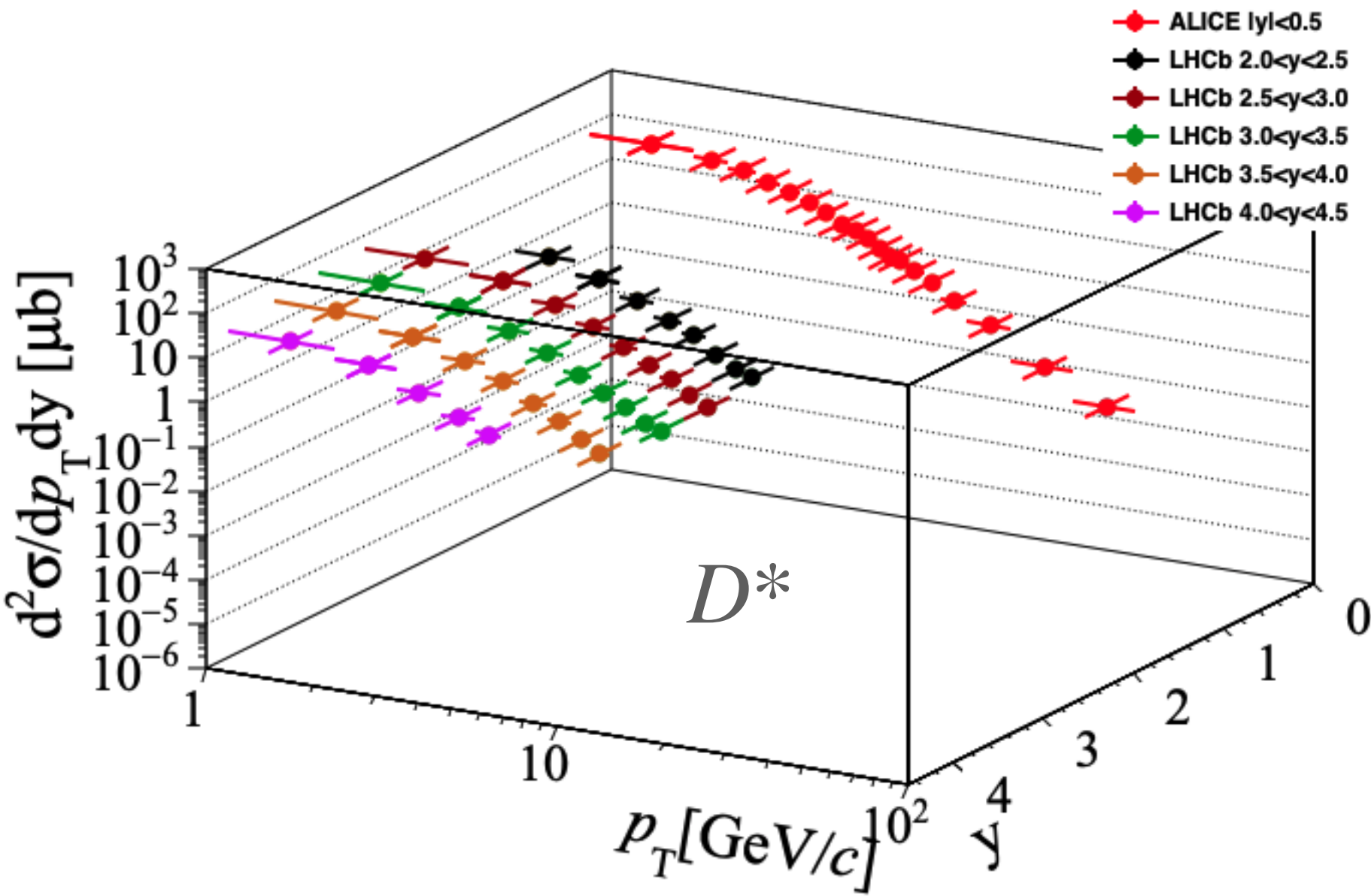




# Combination plots for $D^*$

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- $D^*$  cross-section vs.  $y$  in  $p_T$  slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

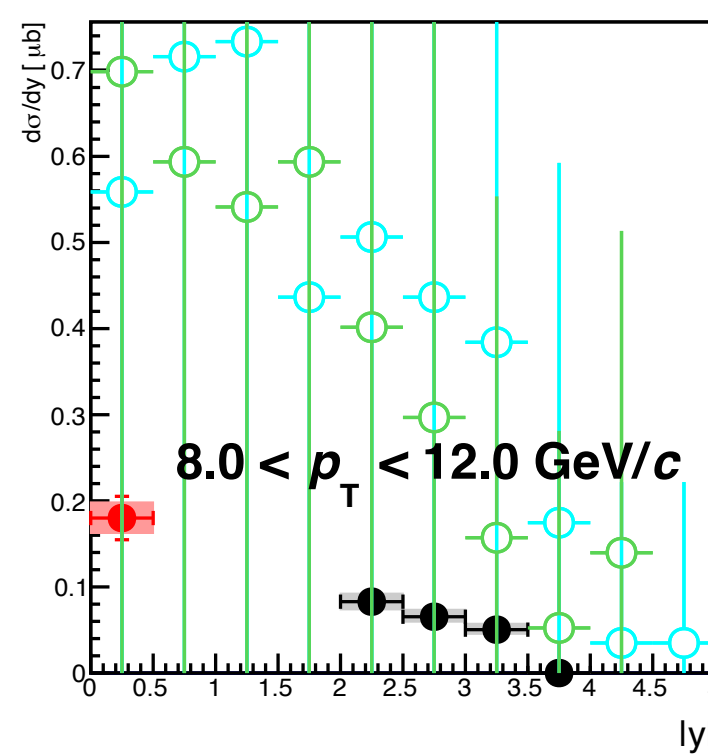
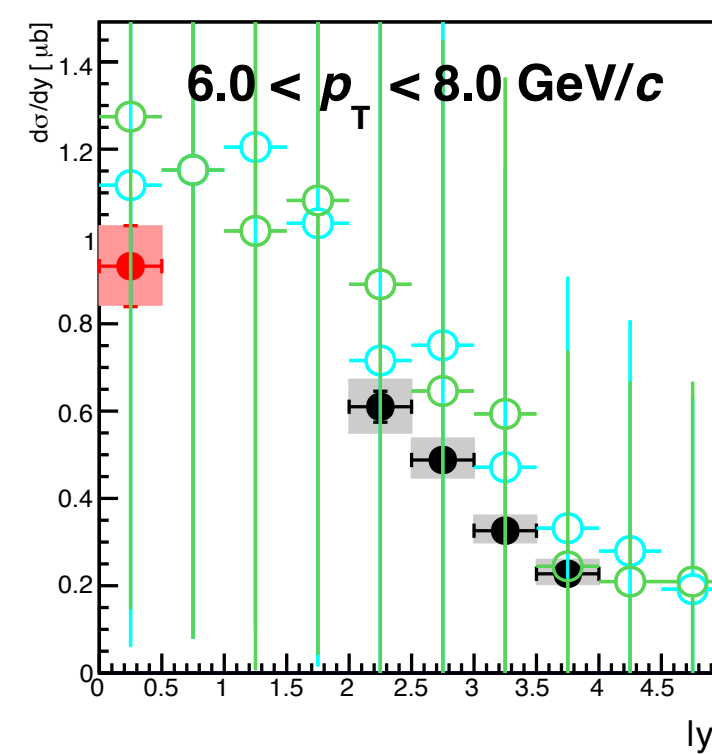
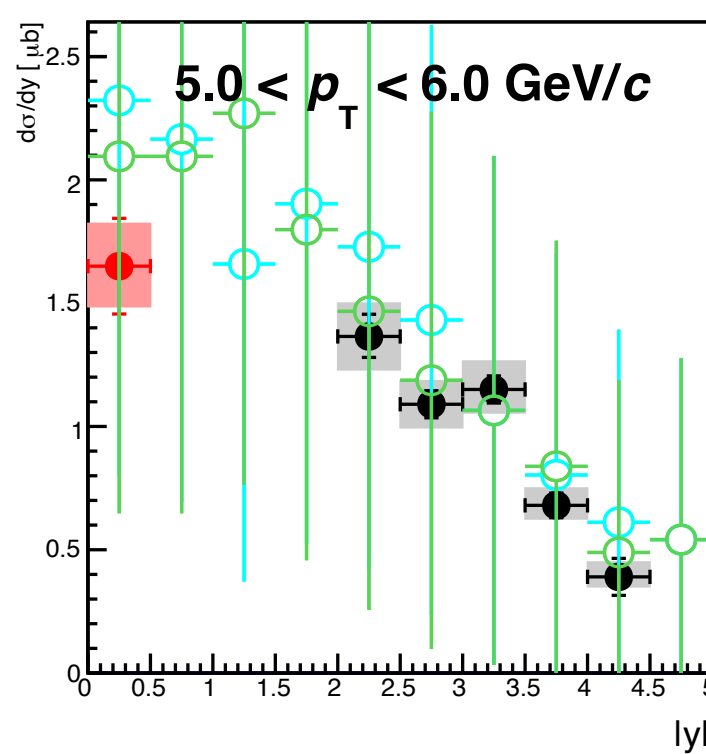
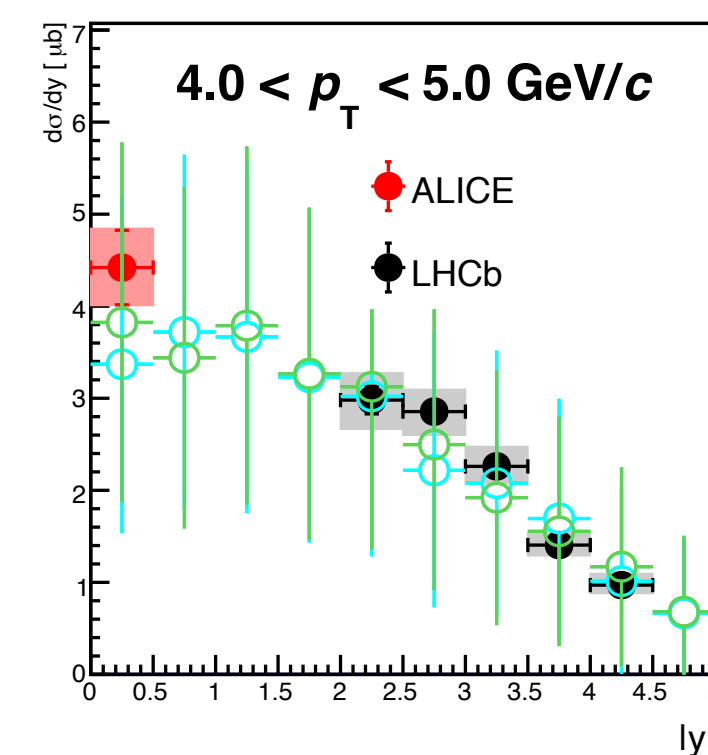
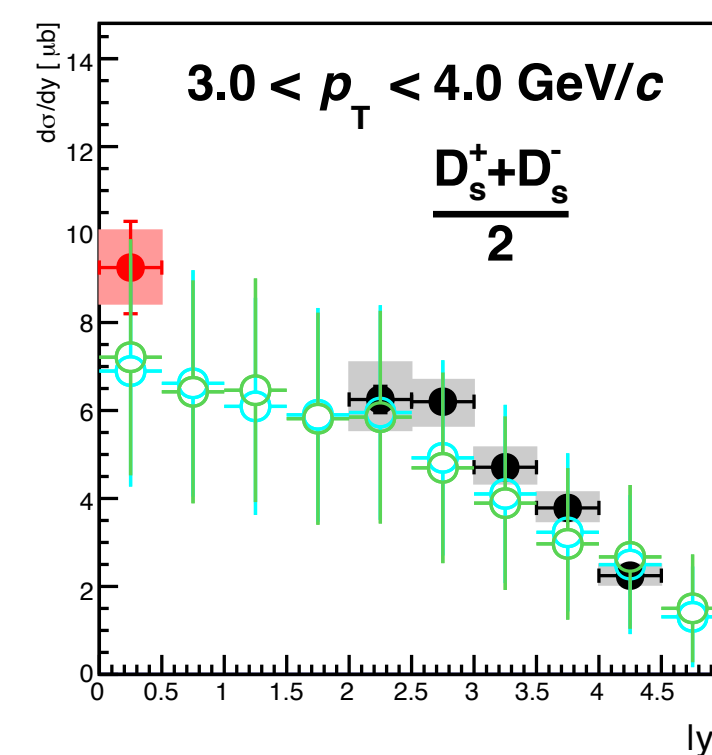
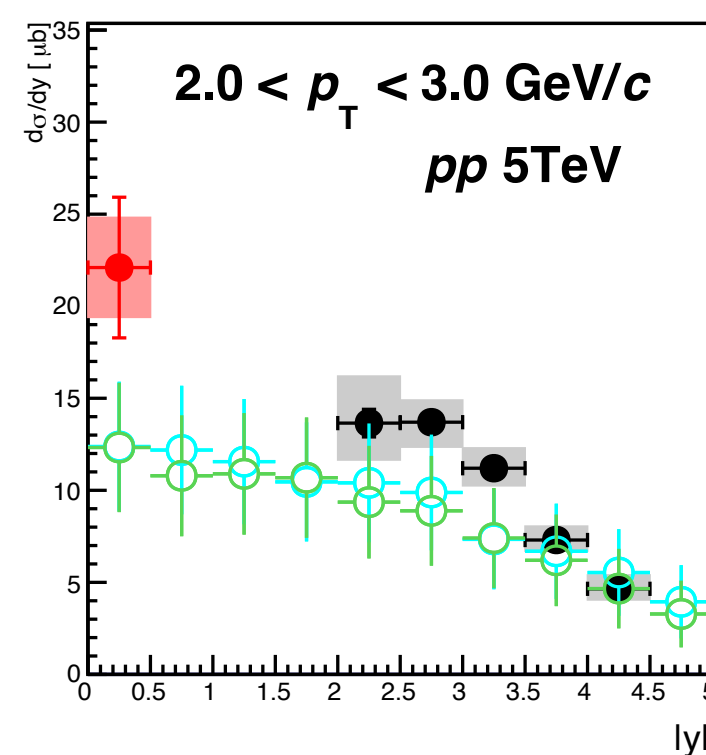
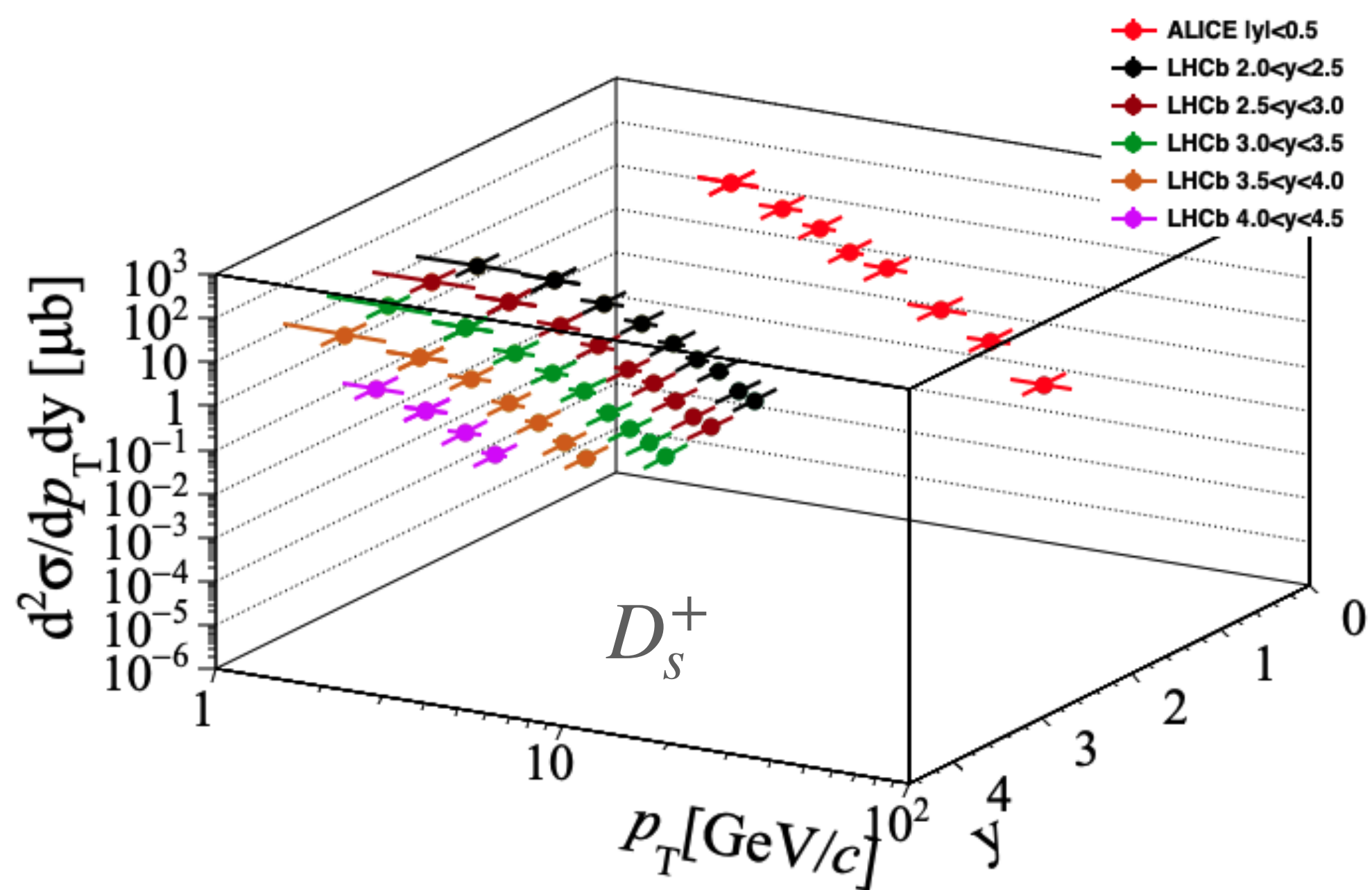
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# Combination plots for $D_s^+$

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- $D_s^+$  cross-section vs.  $y$  in  $p_T$  slices
- PYTHIA: SoftQCD with color reconnection (CR) modes.

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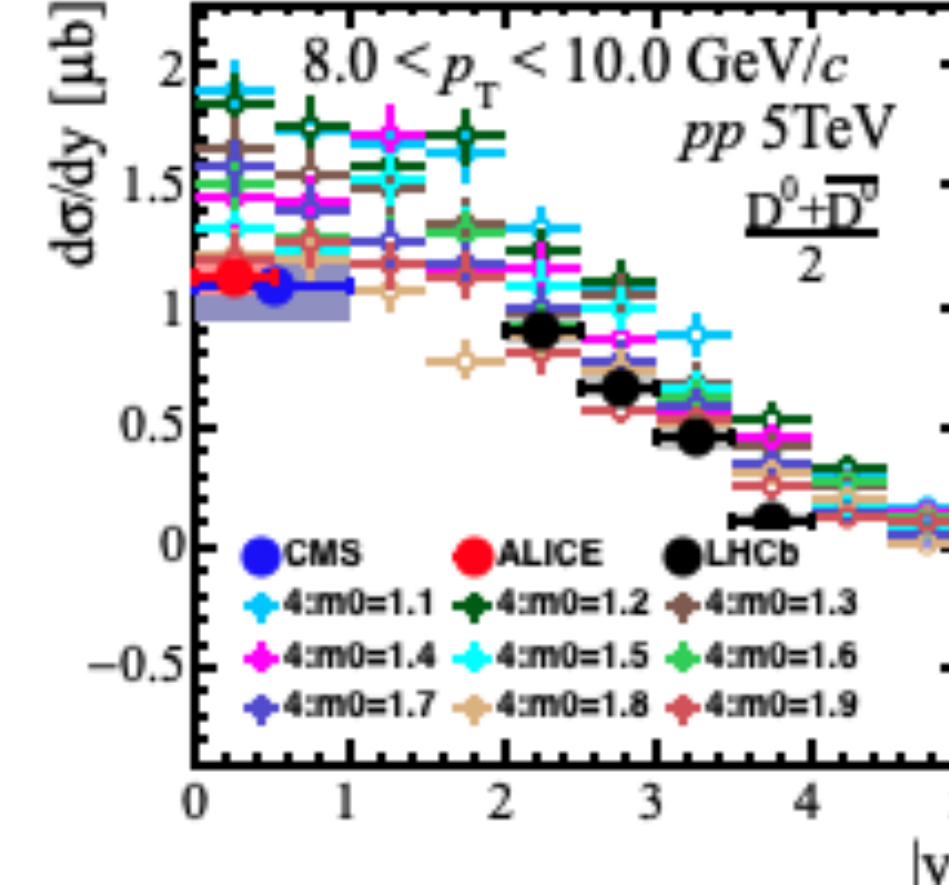
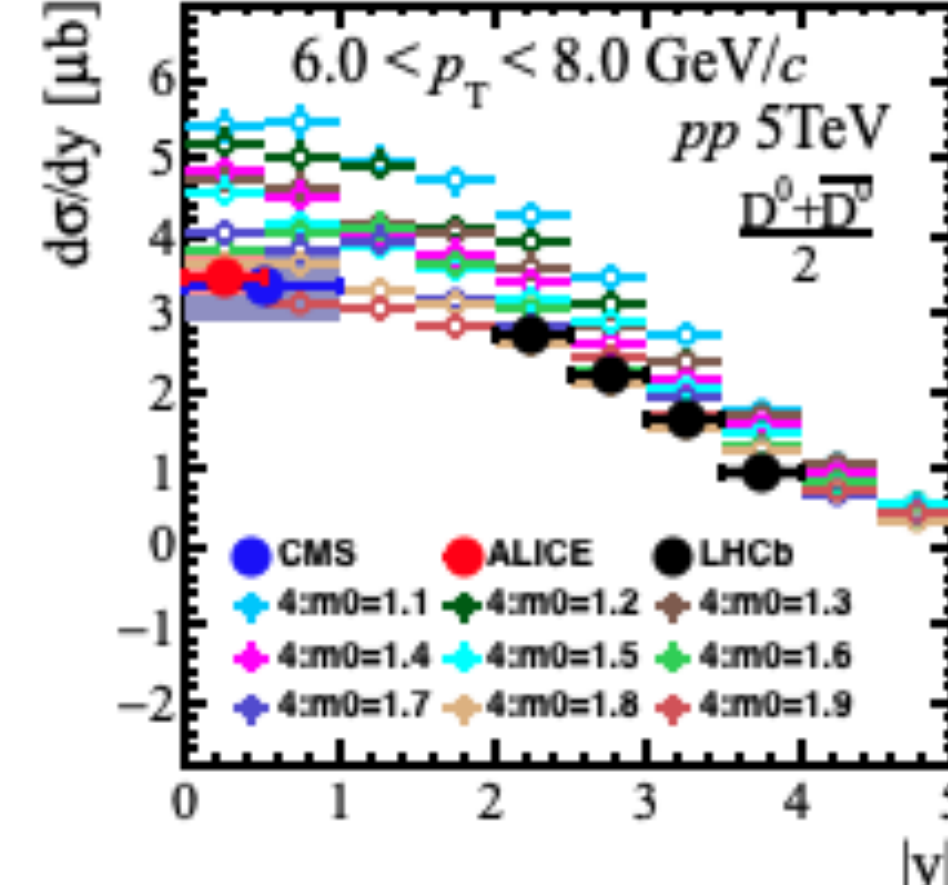
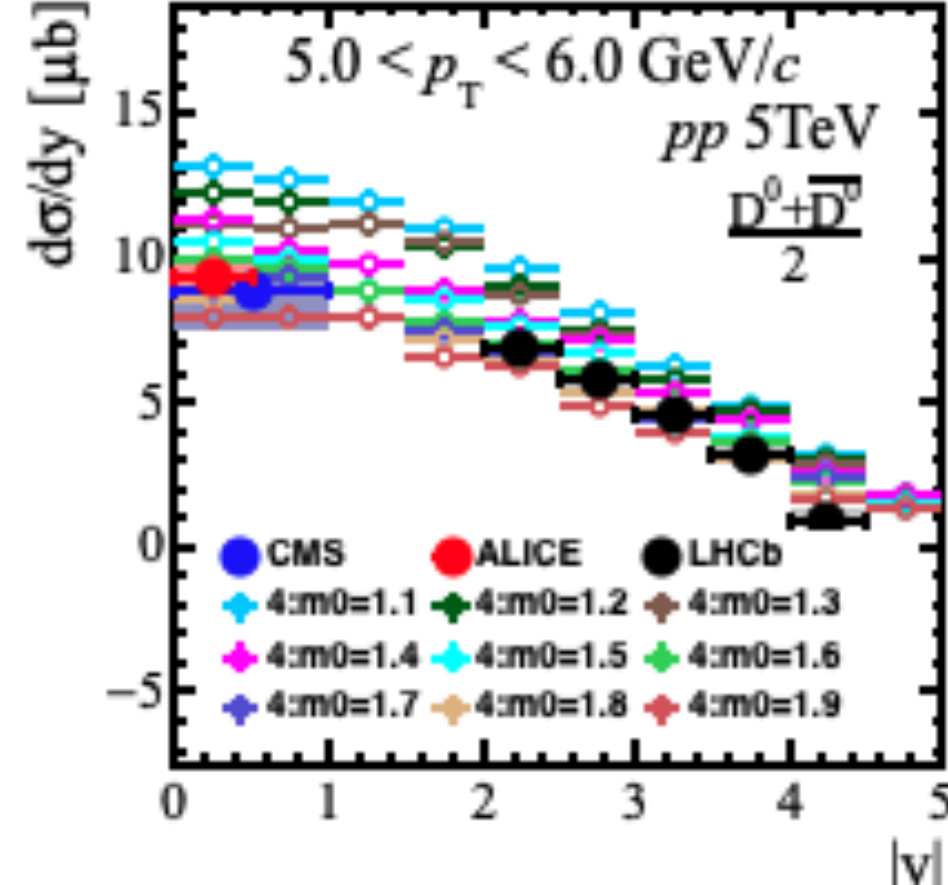
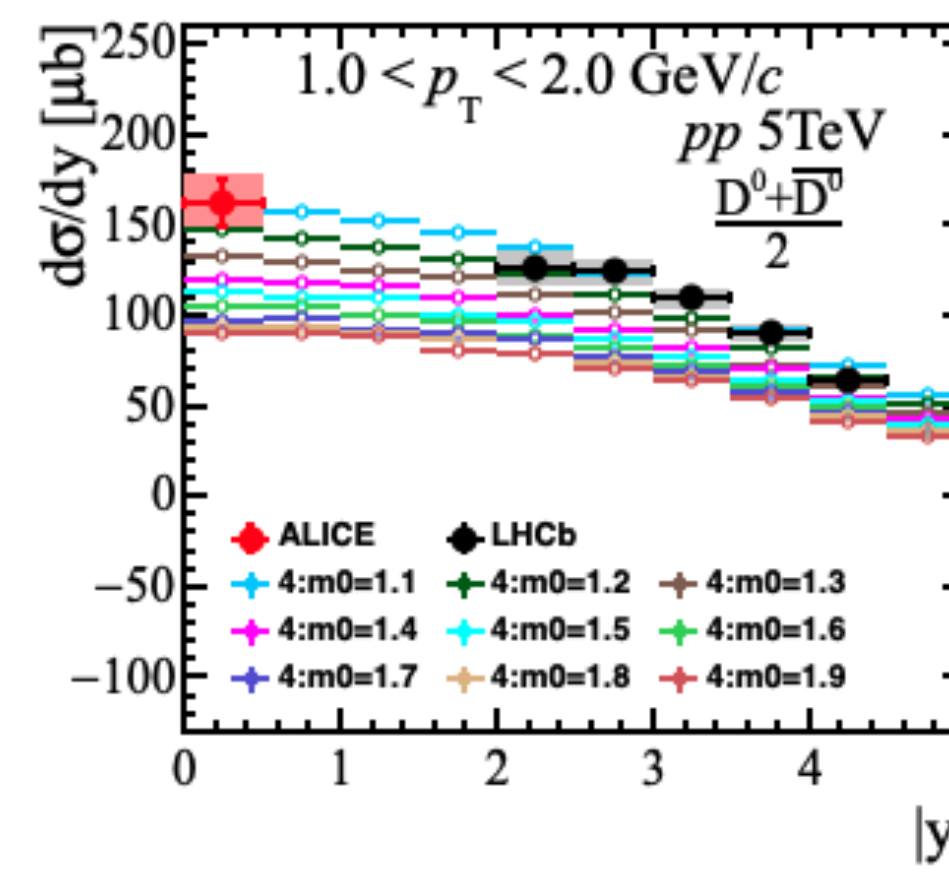
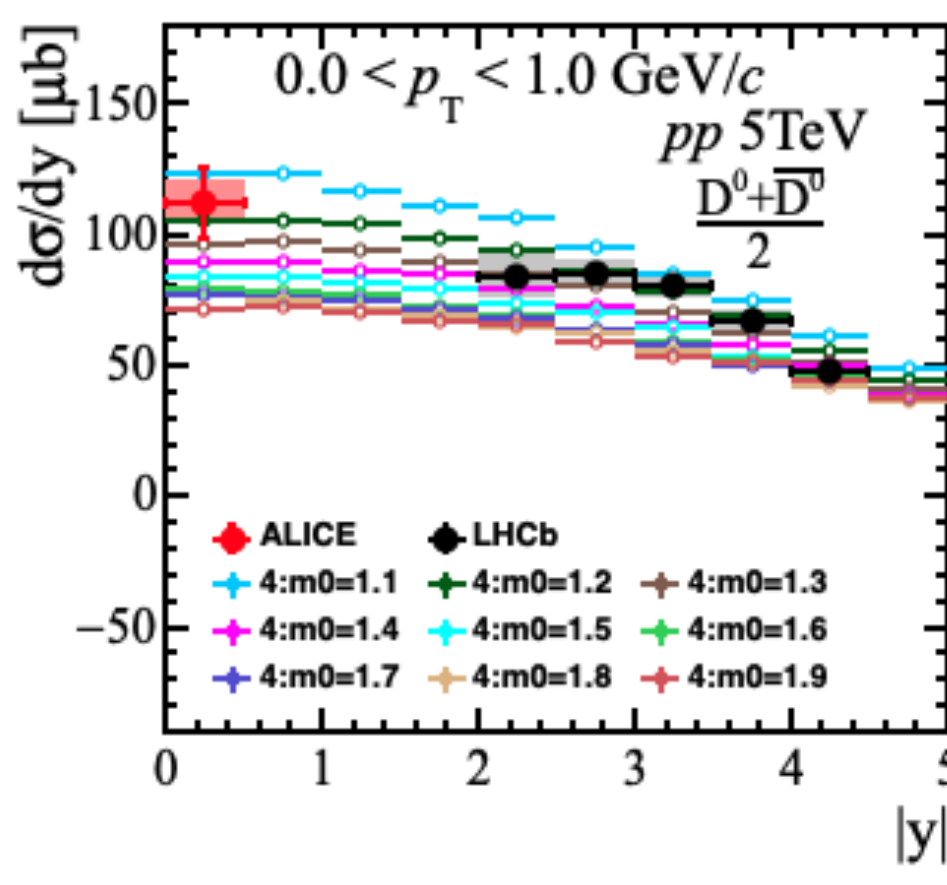
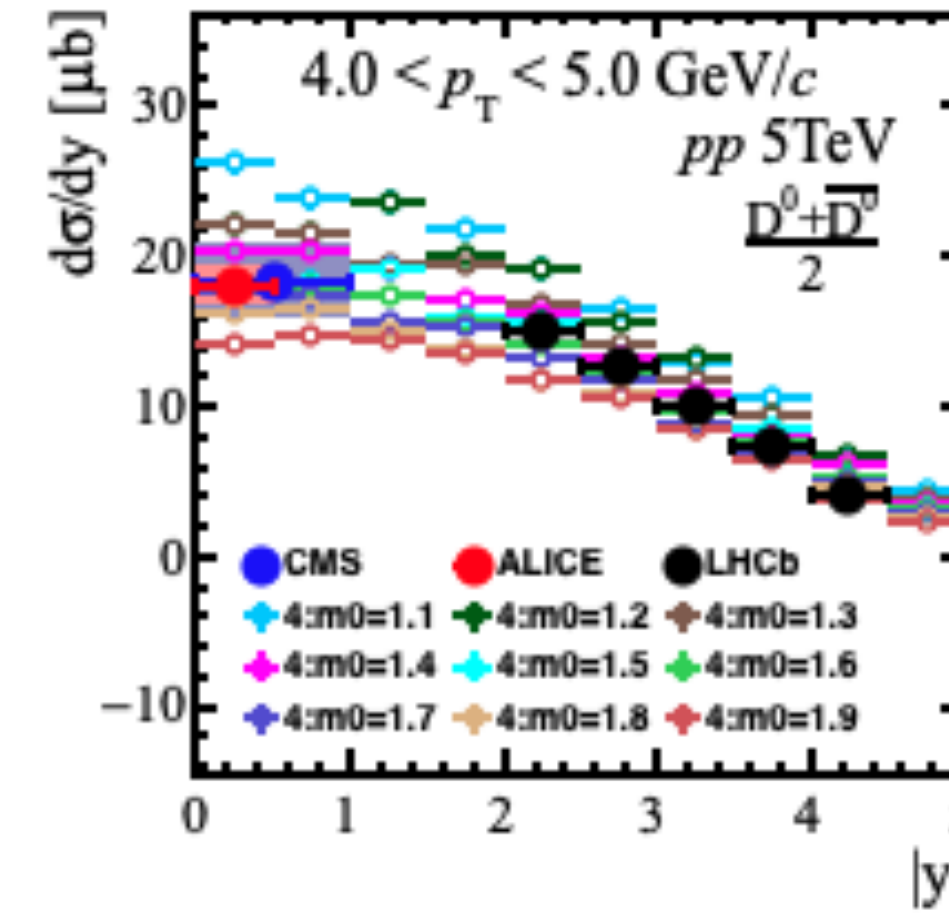
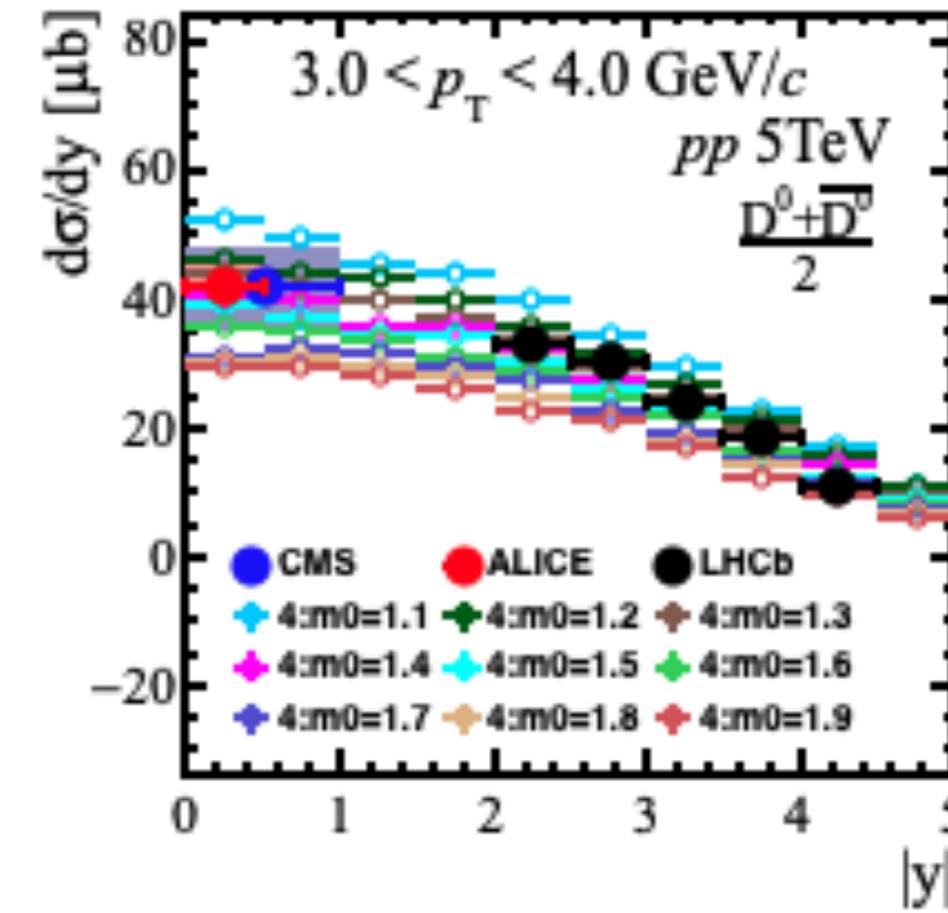
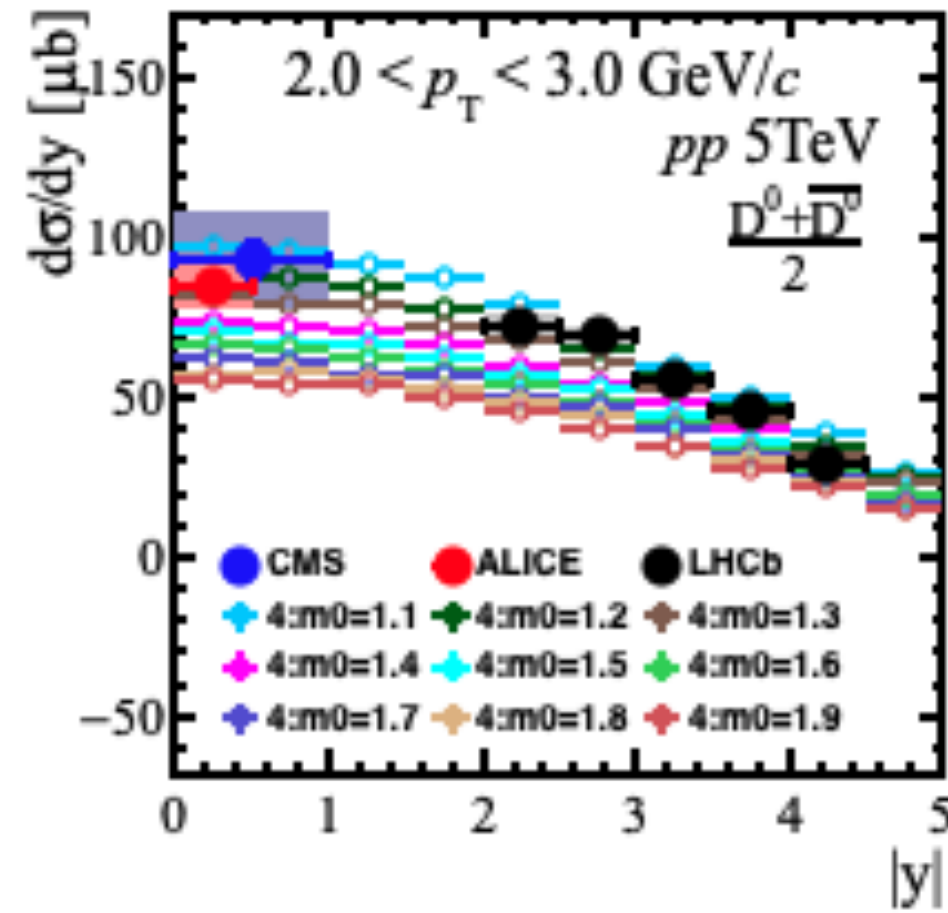


# PYTHIA-data comparison

- Data from ALICE, CMS and LHCb do not cover the full rapidity range, interpolation and extrapolation must be performed to estimate the total charm cross section.
  - PYTHIA and FONLL event generators
- PYTHIA settings:
  - Parton-shower approach for charm production in very low  $p_T$
  - For hard  $2 \rightarrow 2$  process use the PYTHIA model for multiparton interactions [[PRD 36 \(1987\) 2019](#)]
  - The only remaining parameter to fix is the charm mass, default value in PYTHIA is 1.5 GeV
- Scan charm mass from 1.1 to 1.9 GeV, in 0.1 GeV step size. Produce 10M PYTHIA events for each charm mass value.
- Find the best charm mass value from simultaneous fit to measured charmed hadrons cross-section in  $(p_T, y)$  space.
- Currently, made comparisons for  $D^0$ ,  $D^+$  and  $D^*$  mesons. Comparison for  $D_s^+$  meson is upcoming.

# $D^0$ comparison to PYTHIA

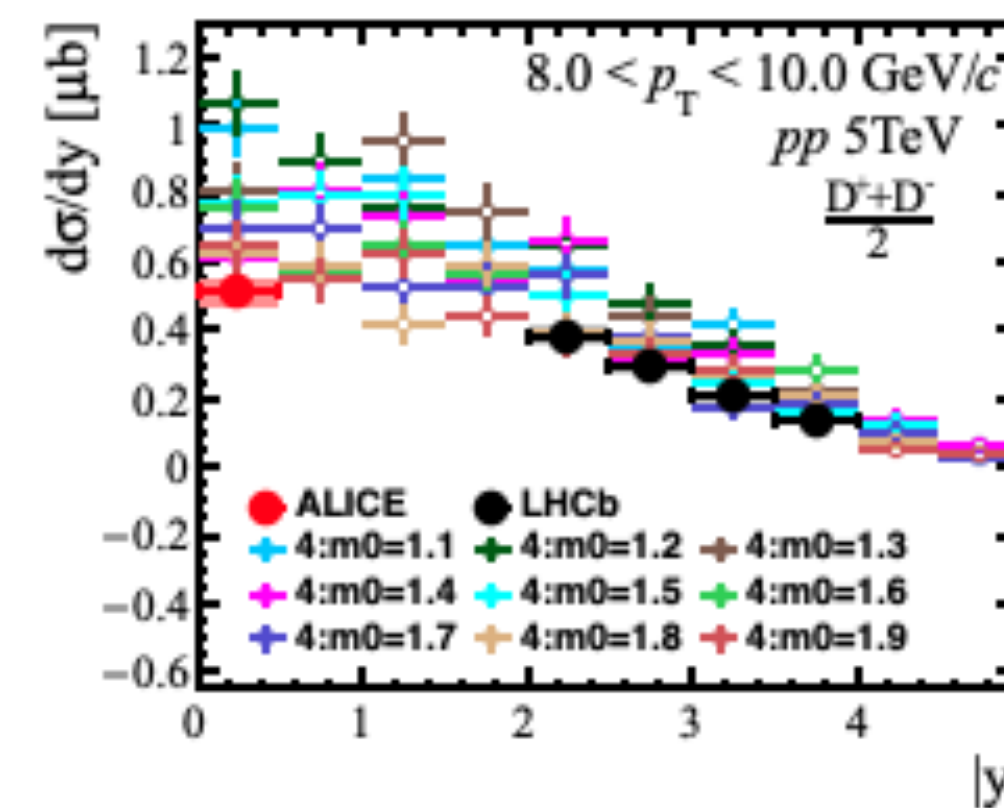
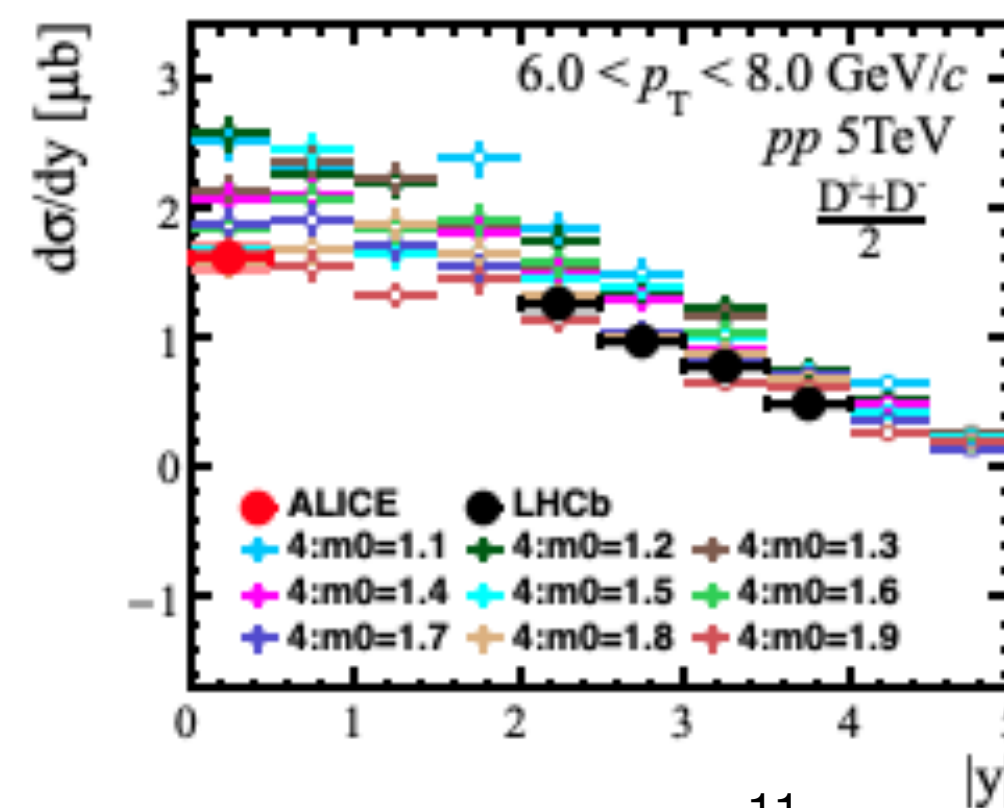
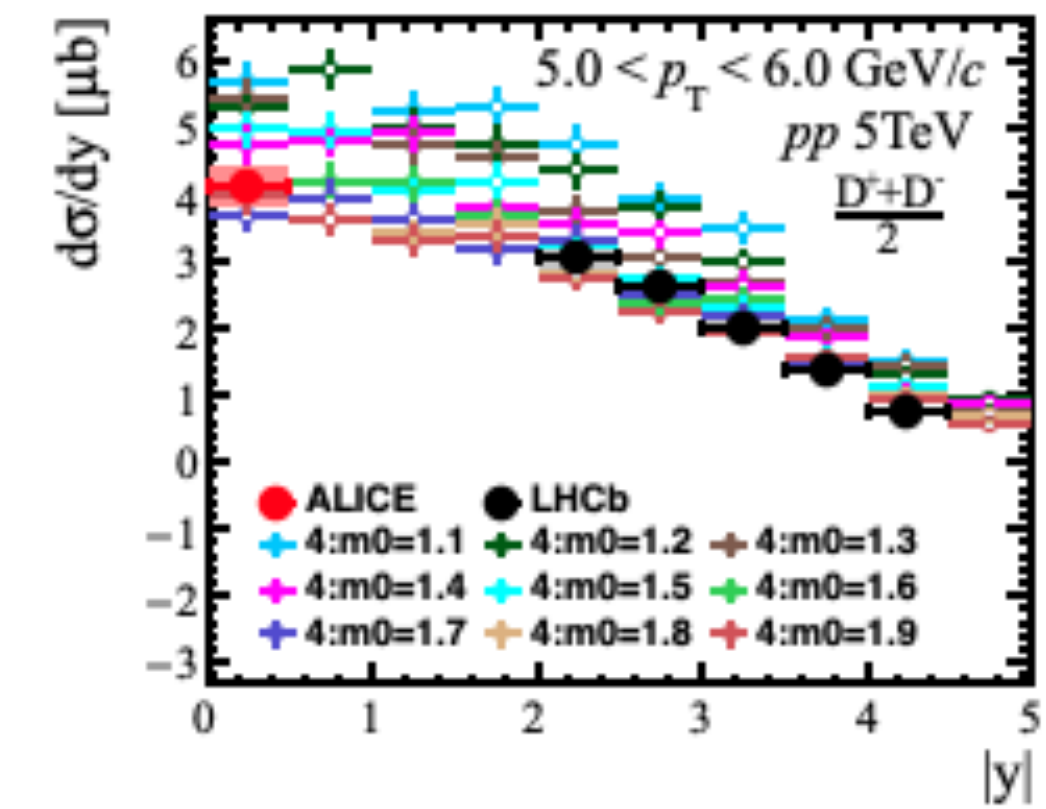
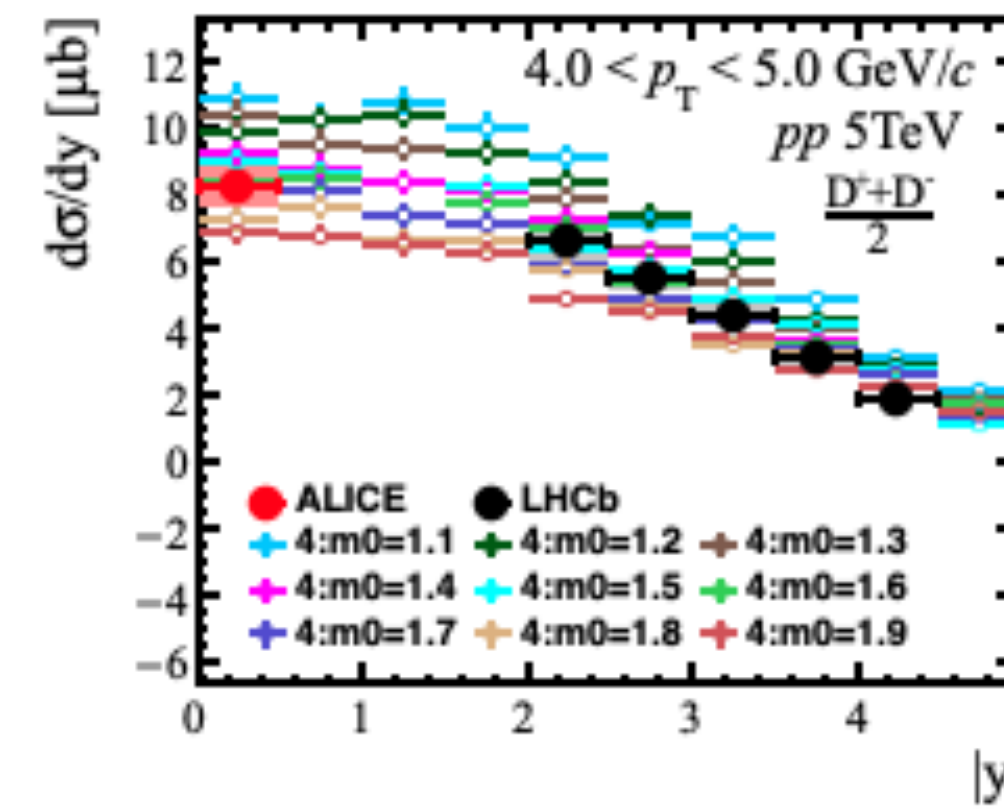
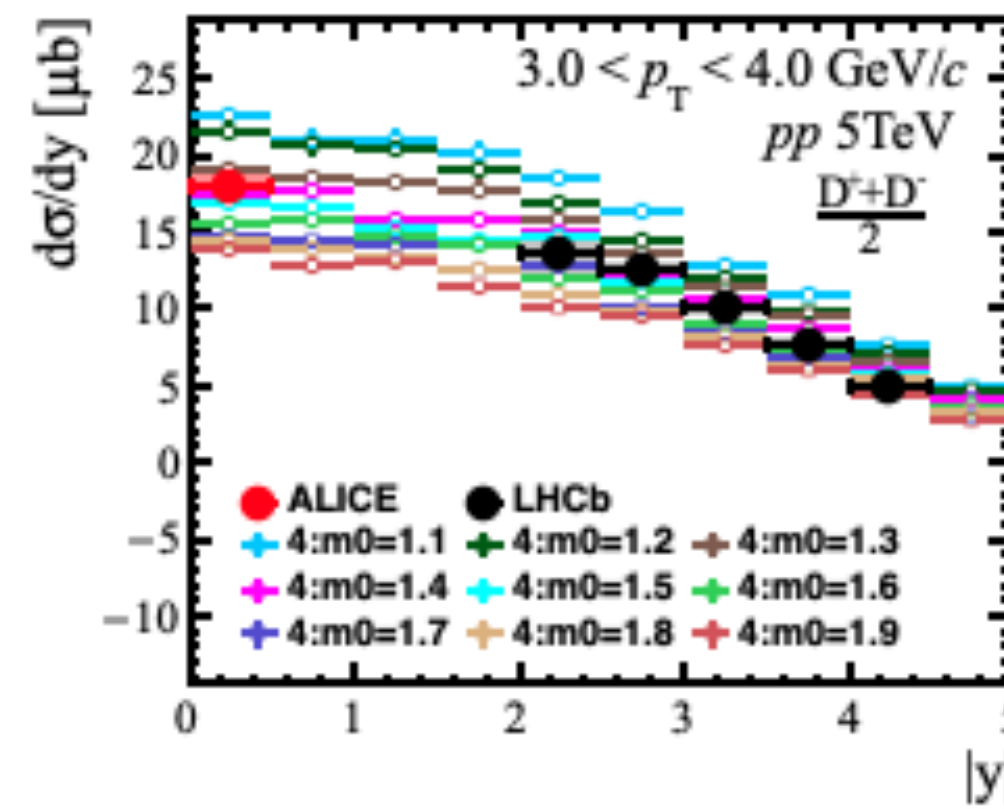
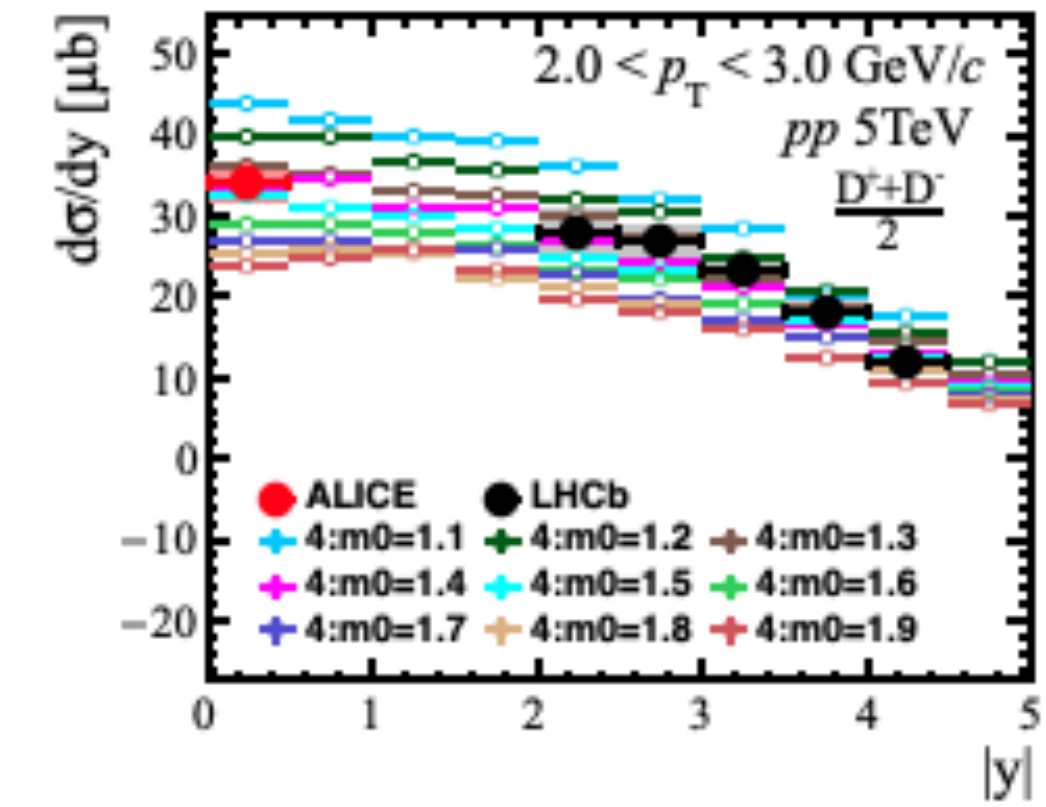
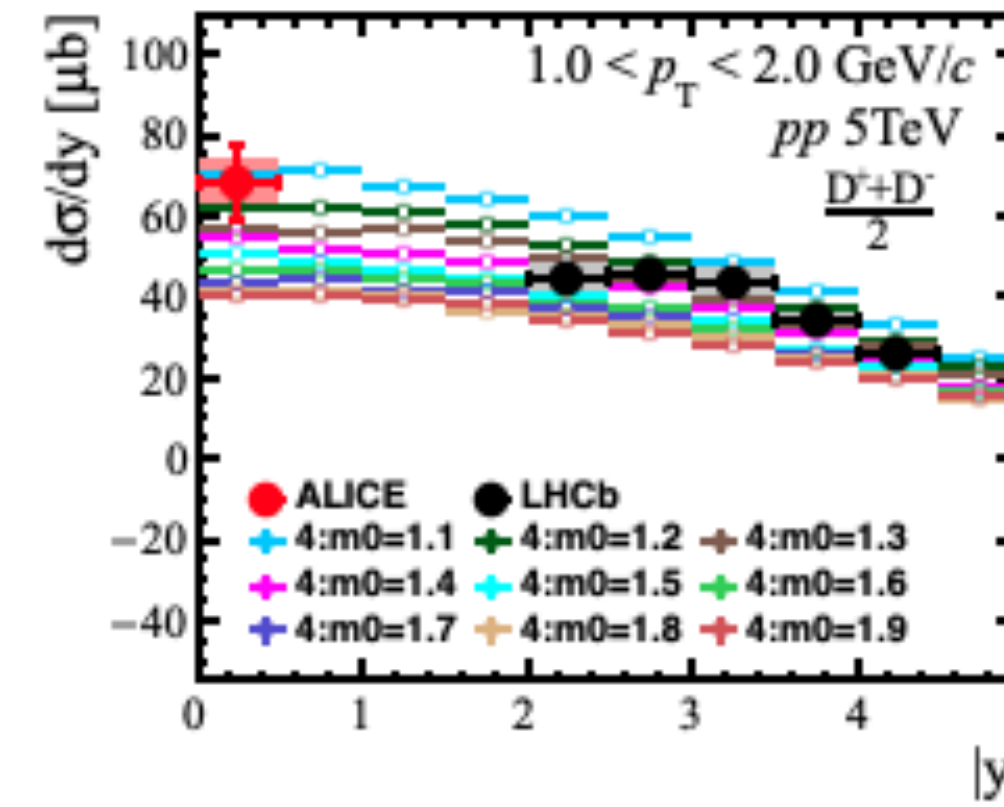
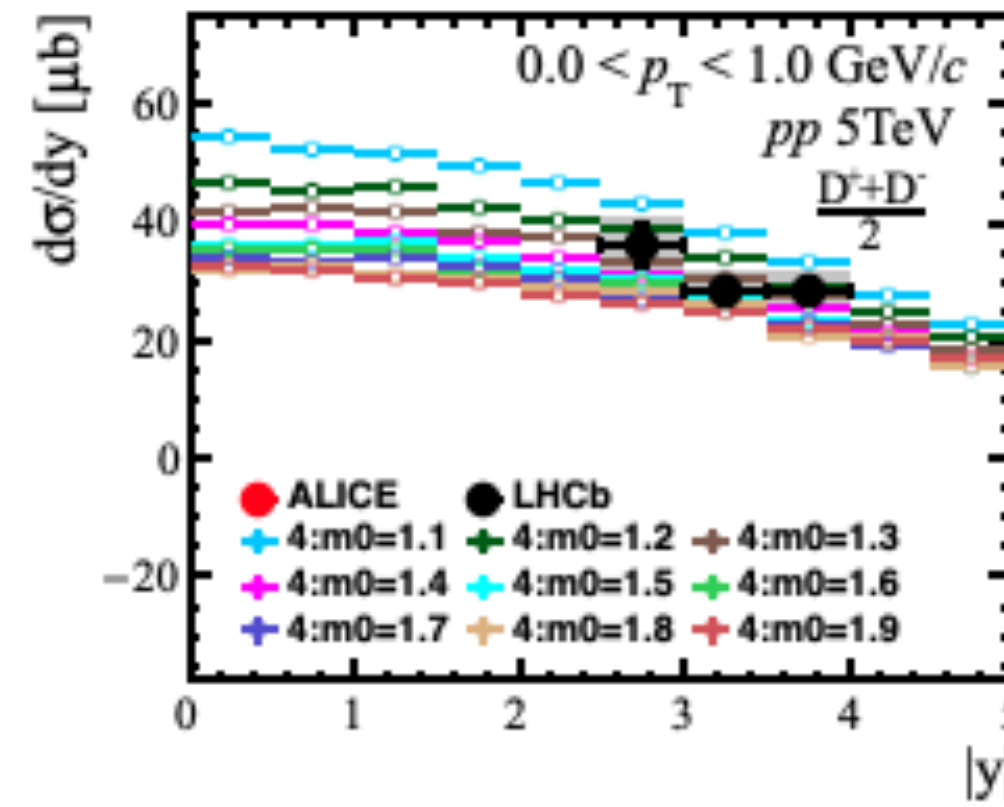
- 10M PYTHIA events for each charm mass value ( $m_0$ ) from 1.1 to 1.9 GeV, in 0.1 GeV step.
- Cross-section vs. rapidity in  $p_T$  slices
- Using 5TeV  $pp$  data from ALICE, CMS and LHCb





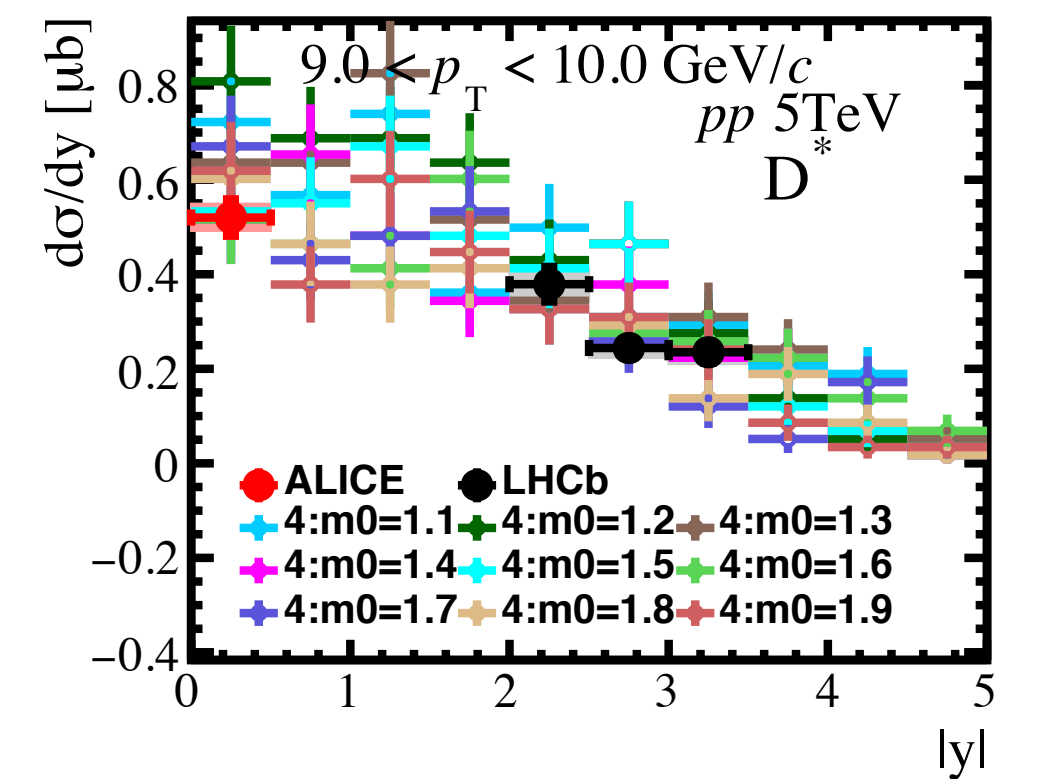
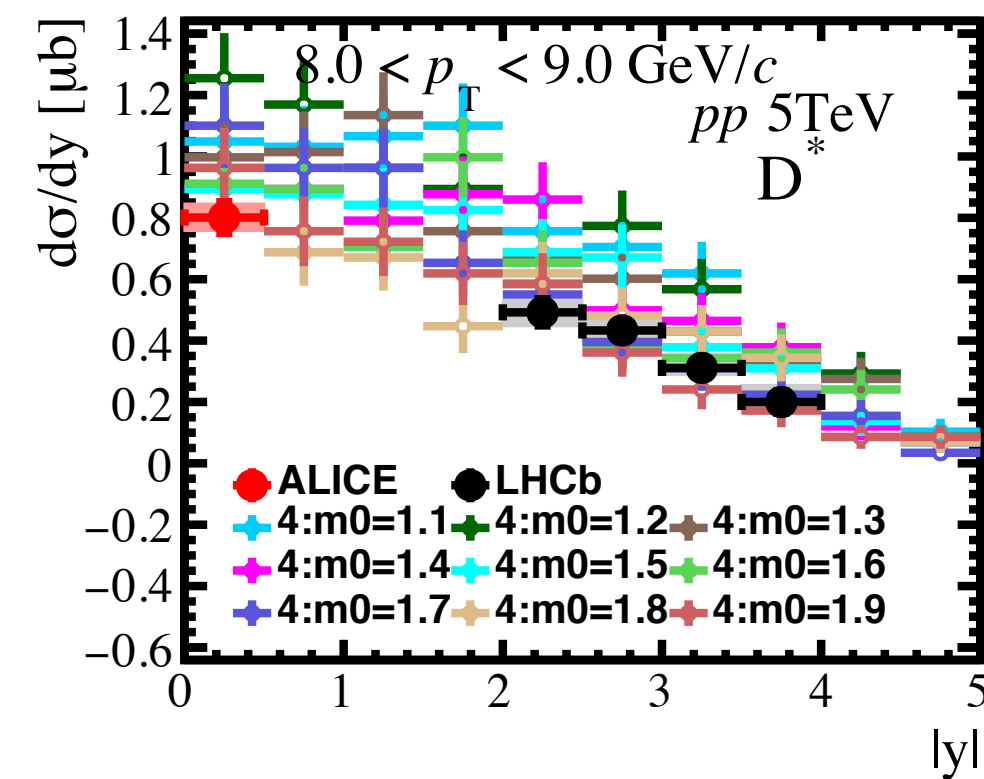
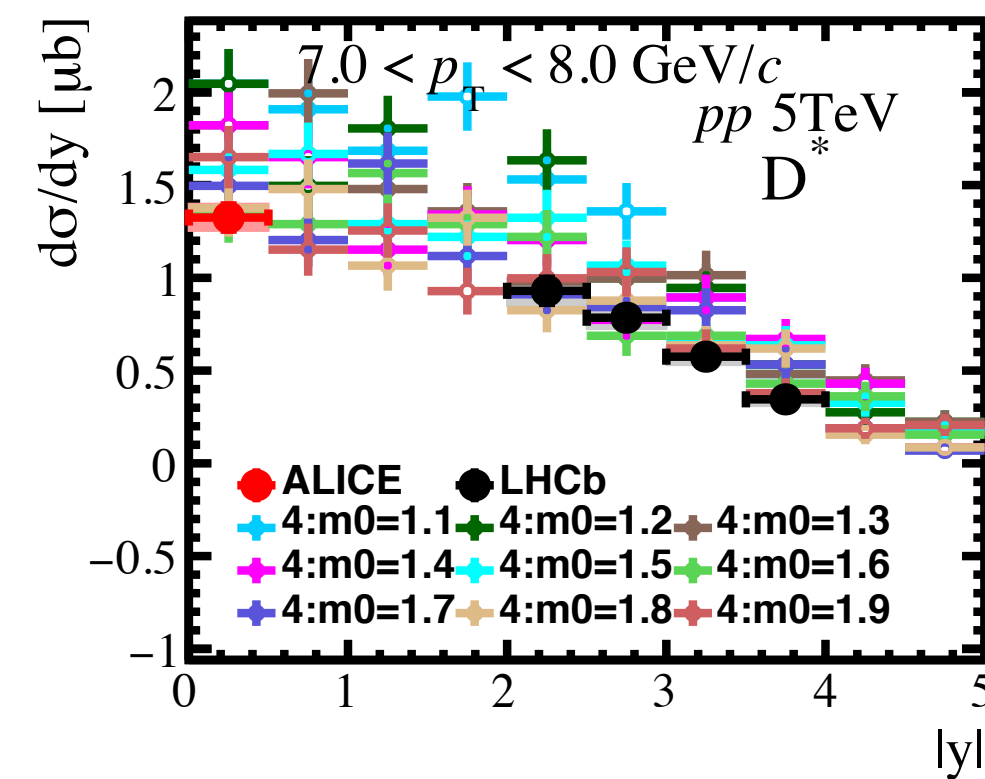
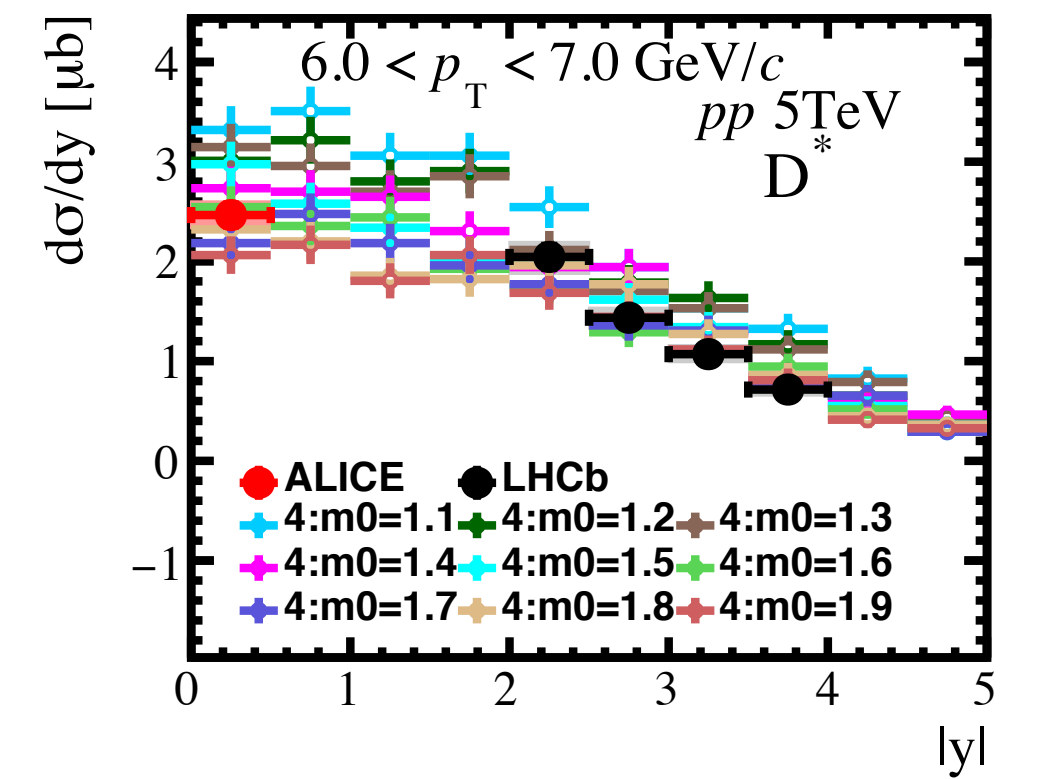
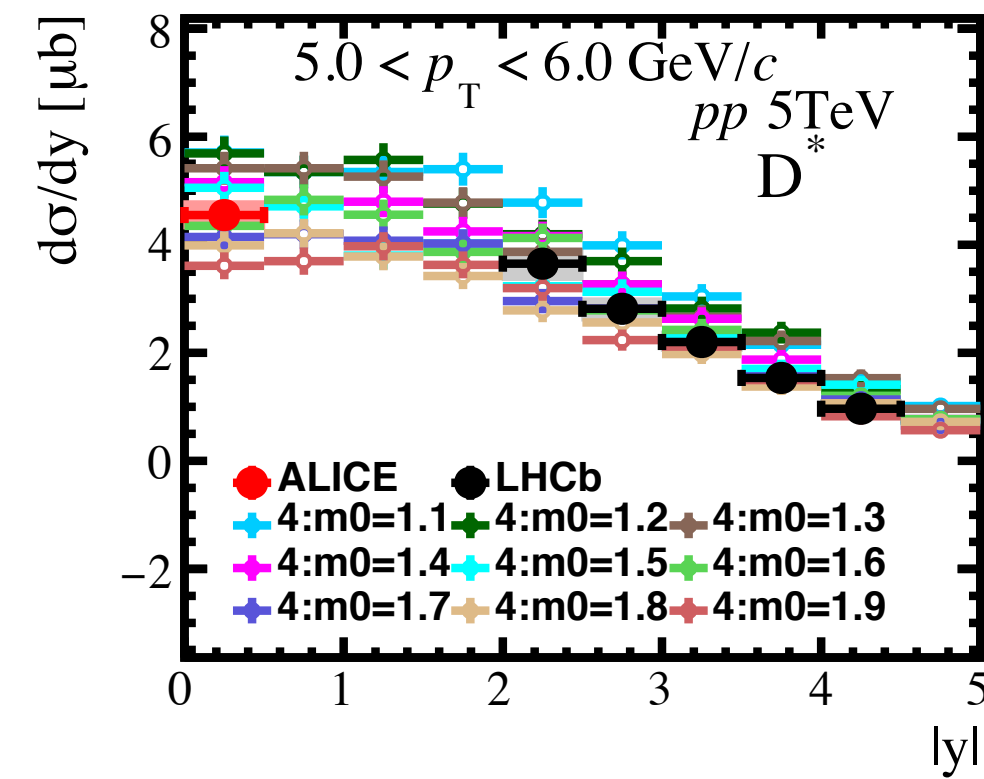
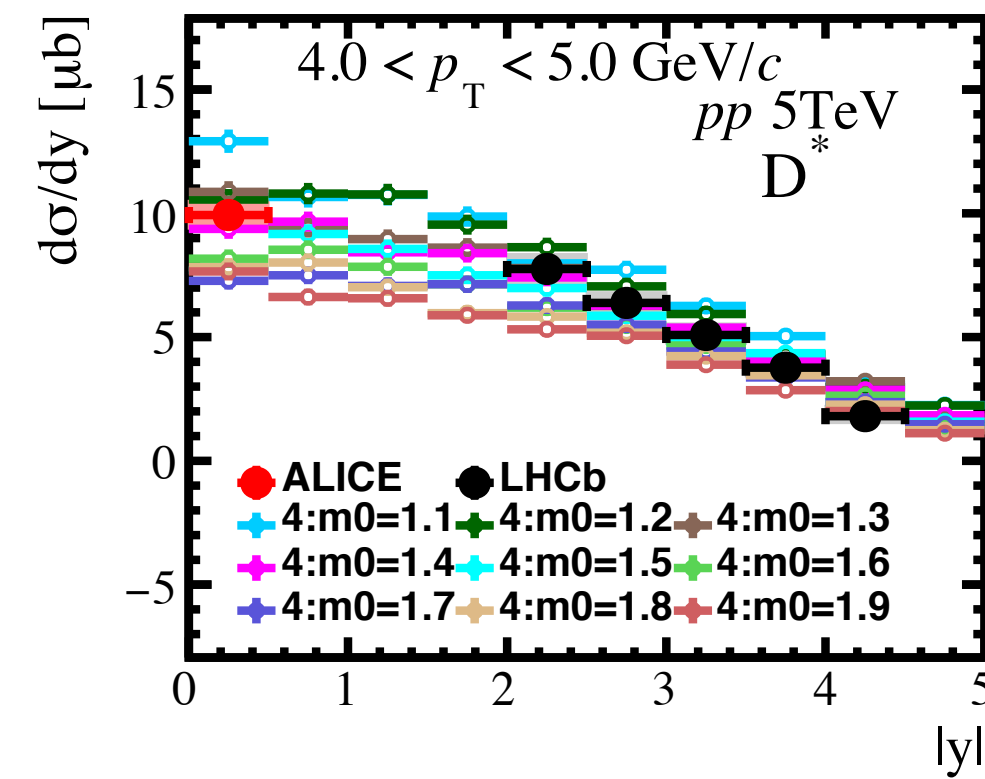
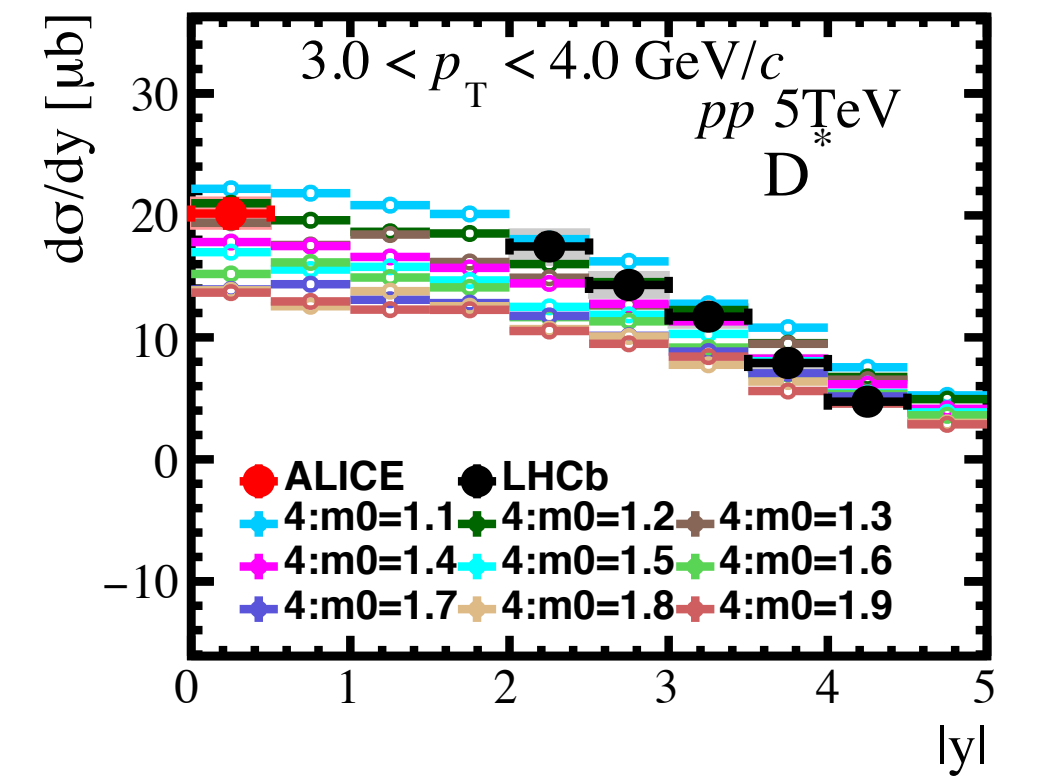
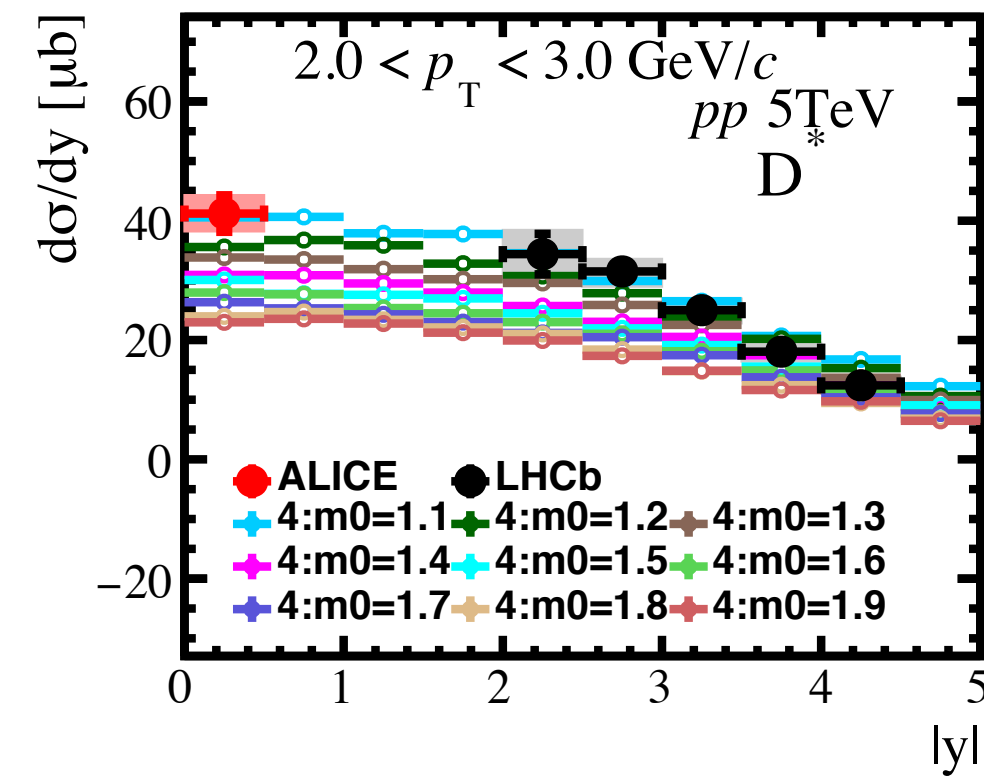
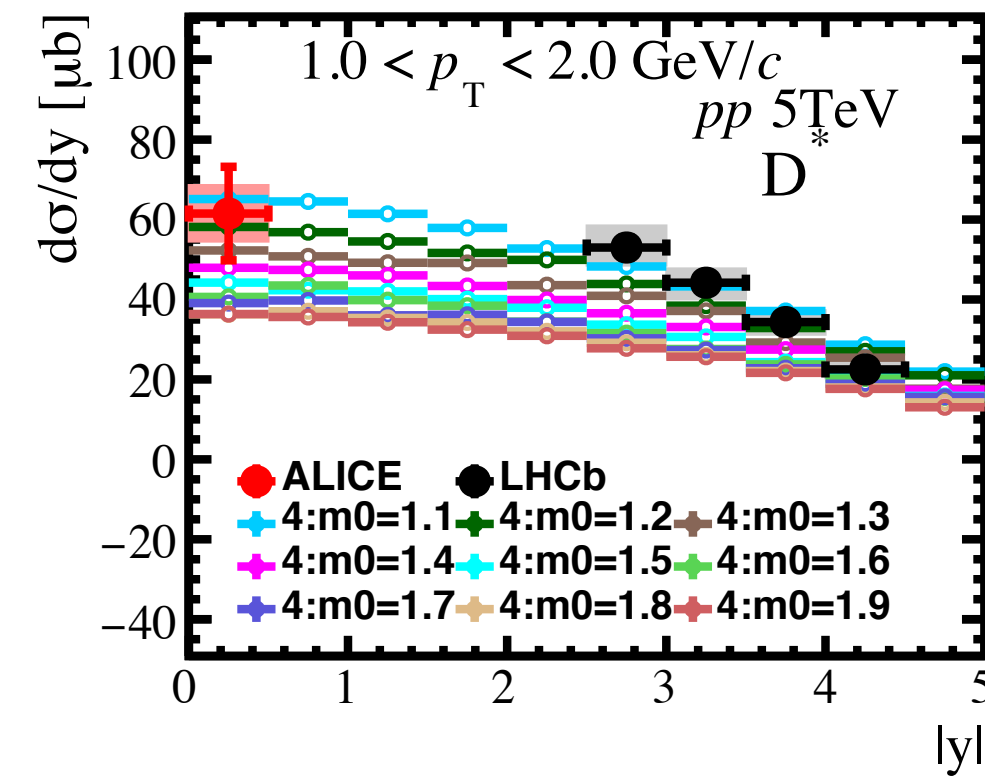
# $D^+$ comparison to PYTHIA

- 10M PYTHIA events for each charm mass value ( $m_0$ ) from 1.1 to 1.9 GeV, in 0.1 GeV step.
- Cross-section vs. rapidity in  $p_T$  slices
- Using 5TeV  $pp$  data from ALICE and LHCb



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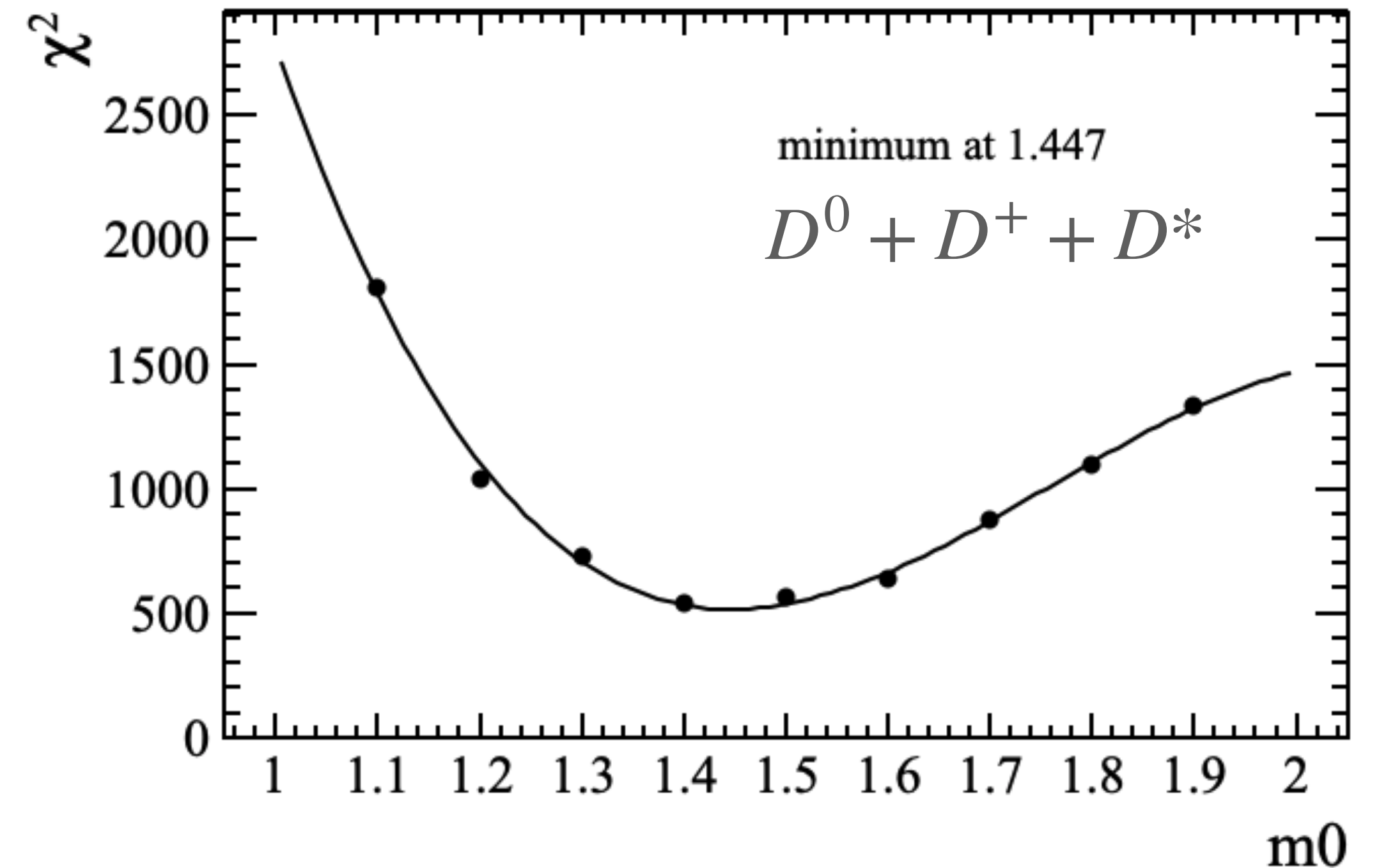
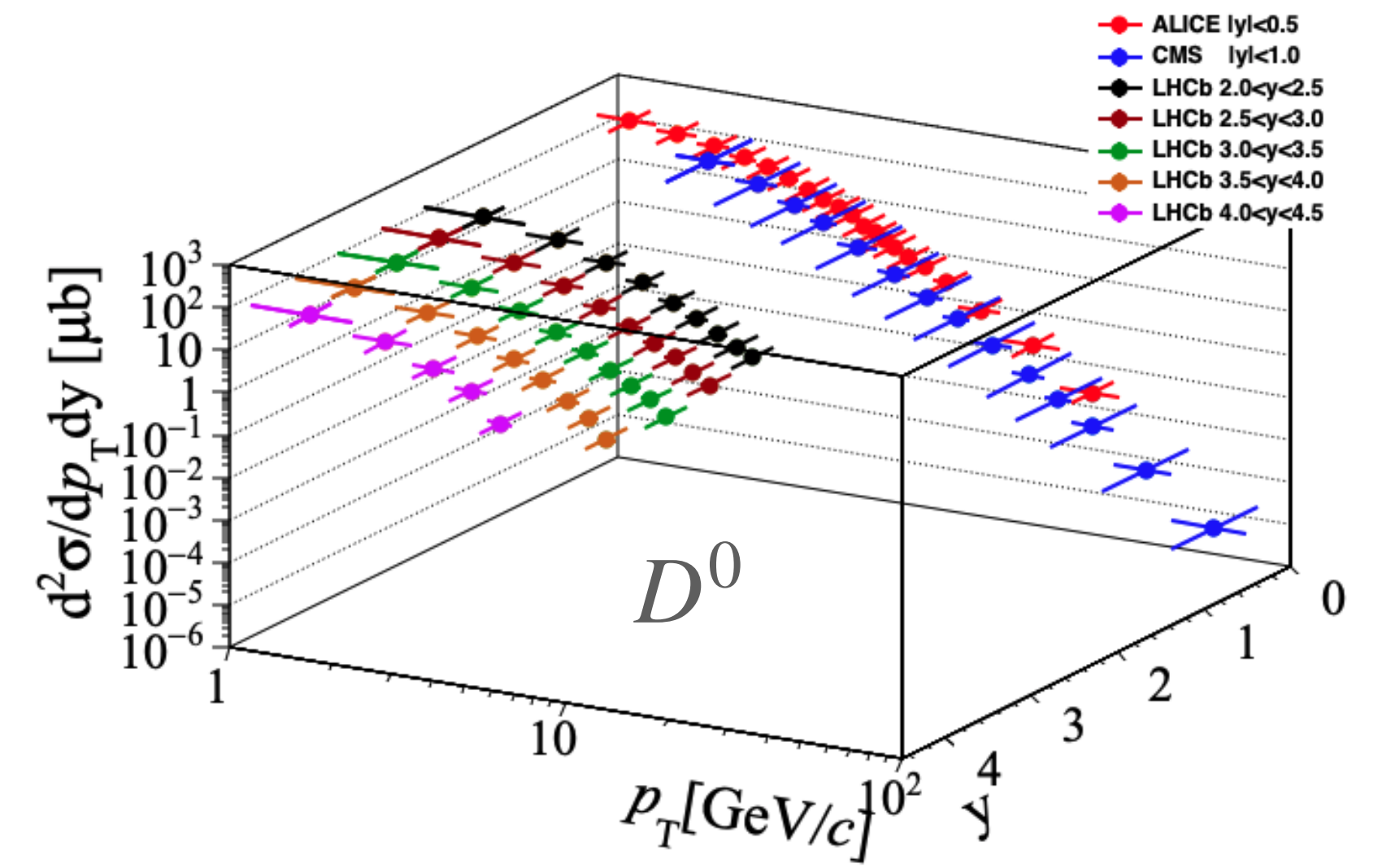




# Simultaneous fit

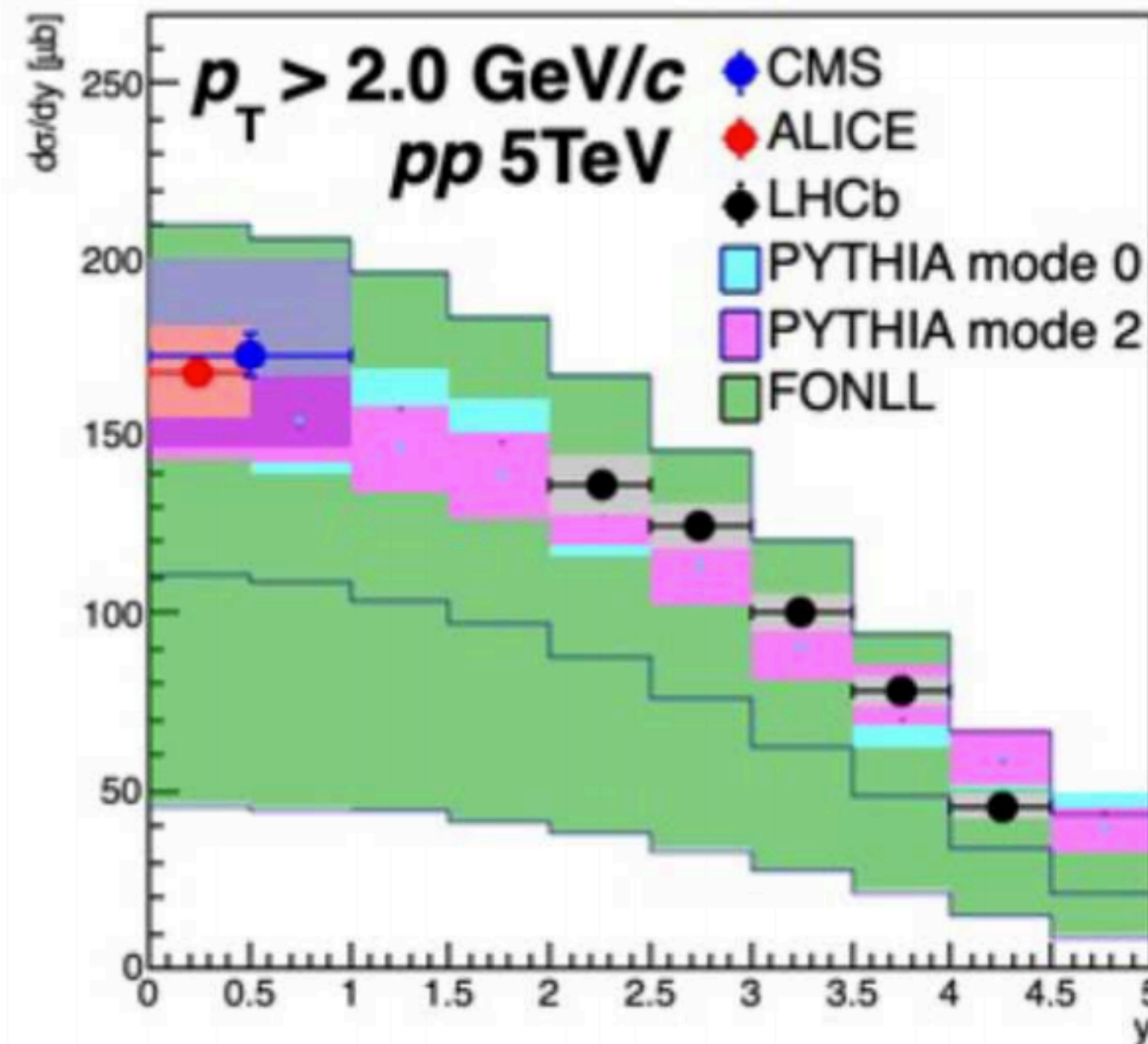
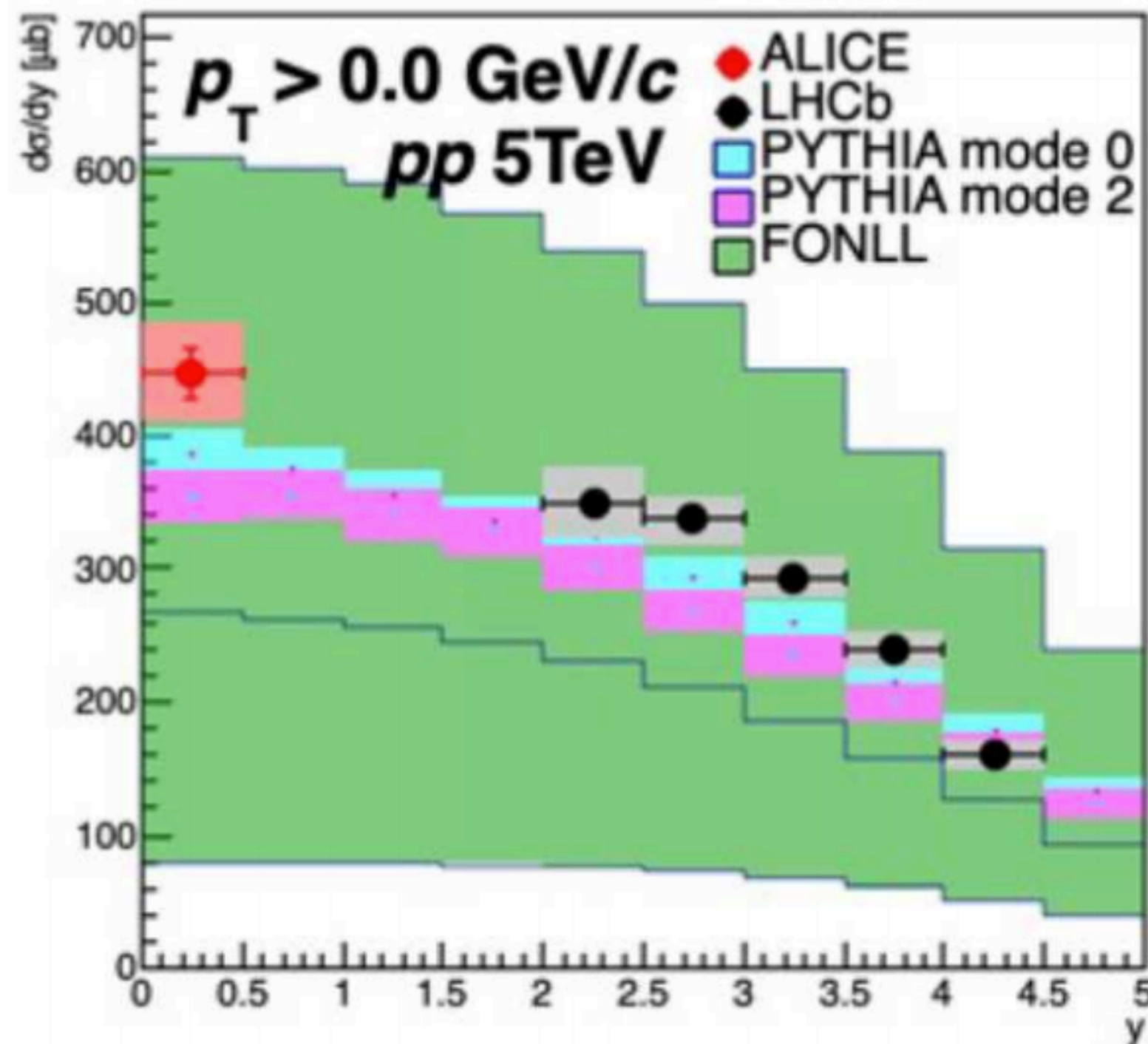
*Work in progress*

- Simultaneous fit across  $D^0$ ,  $D^+$  and  $D^*$  to find the best charm mass value ( $m_0$ ).
- Use the same binning as the published data from ALICE/CMS/LHCb, compare each point between data and PYTHIA, calculate  $\chi^2$
- For this plot, using  $p_T < 6$  GeV/c, ALICE and LHCb points. Using total uncertainty. Fit with a 3rd order polynomial function.
- LHCb points provide most constraint.
- Next steps:
  - Add  $D_s^+$ , also consider  $\Lambda_c^+$
  - Add contribution from CMS data points. Produce more MC at higher  $p_T$ .
  - Fine tune uncertainty treatment



# Comparison with FONLL for $D^0$

*Work in progress*



- [FONLL](#) settings:
  - PDF: CTEQ 6.6 + unc.
  - mc:  $1.5 \pm 0.2$  GeV
- Fragmentation tuned to LEP data

FONLL: NLO + NLL QCD prediction, absolute prediction with uncertainties



# Summary

- The project of total charm cross-section from combining ALICE, CMS and LHCb measurements is making good progress.
- Comparisons with theoretical models are ongoing.
  - Working on fixing charm mass parameter for PYTHIA
  - Parallel work on FONLL ongoing
- Extrapolation to obtain total cross-section, with uncertainty determination.
- Preparing paper on data/theory comparisons and total charm cross-section in the next 1-2 months.