Open heavy flavor measurements

Honex-Comb

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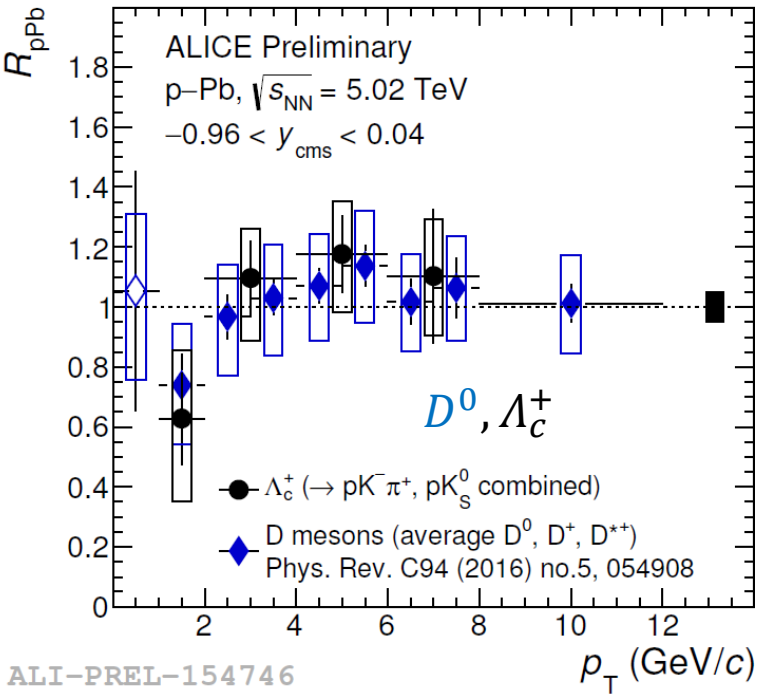
Outline

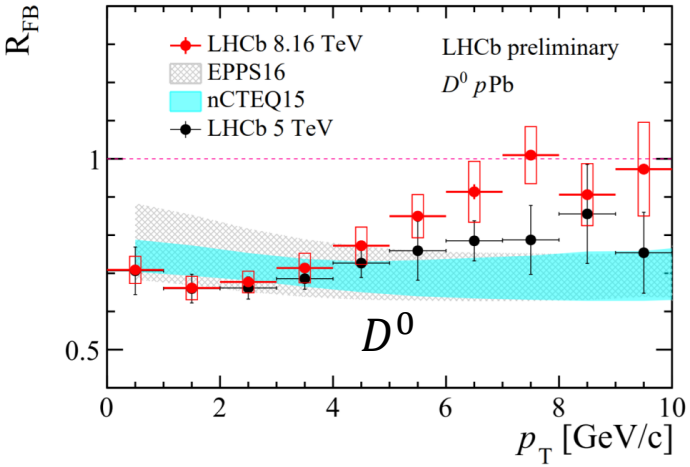
- Heavy flavor production and nuclear modification factors
  - Open charm in *p*Pb and PbPb collisions
  - Open beauty in *p*Pb and PbPb collisions
  - Open charm in fixed target mode
- Hadronisation and particle ratios in *pp*, *p*Pb and PbPb collisions
  - Strangeness enhancement
  - Heavy flavor baryon/meson ratio
- Heavy flavor azimuthal anisotropy v_n measurements
  - v_1: initial magnetic field
  - v_2: collective flow
  - v_3: initial fluctuations

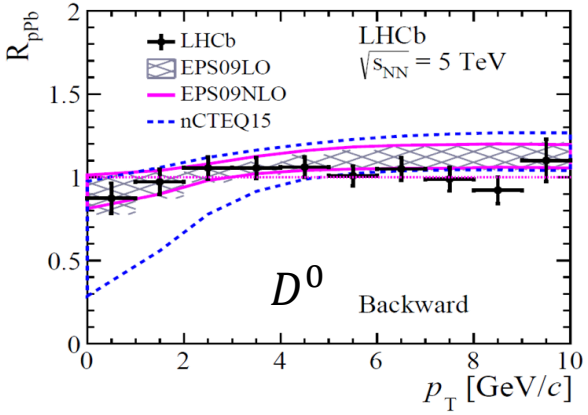
Open charm productions in *p*Pb collisions

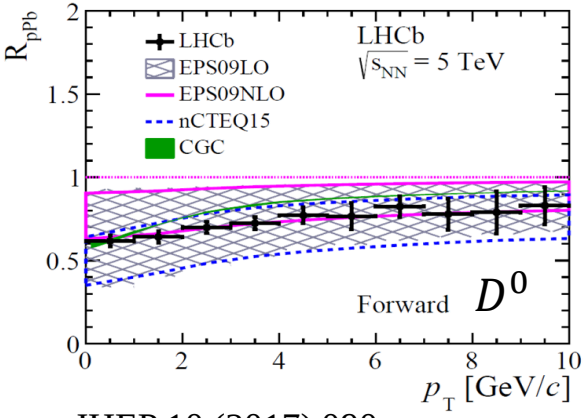
- Suppression in forward rapidity
- Close to 1 in mid and backward rapidity
- Constrain nPDFs down to x~10^{-5}
- R_{FB}: data > nPDF models at higher p_T

JHEP 1912 (2019) 092





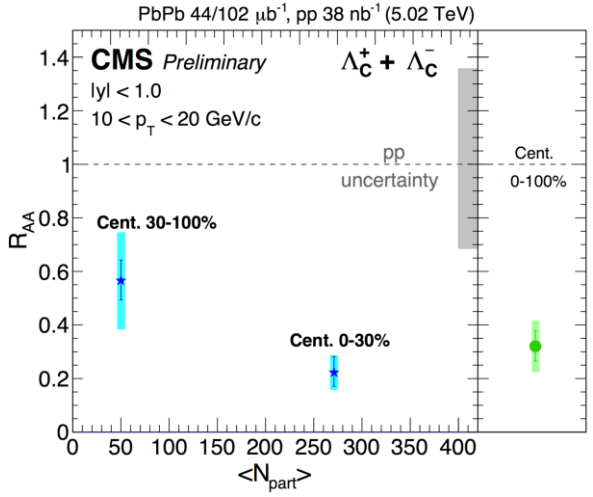


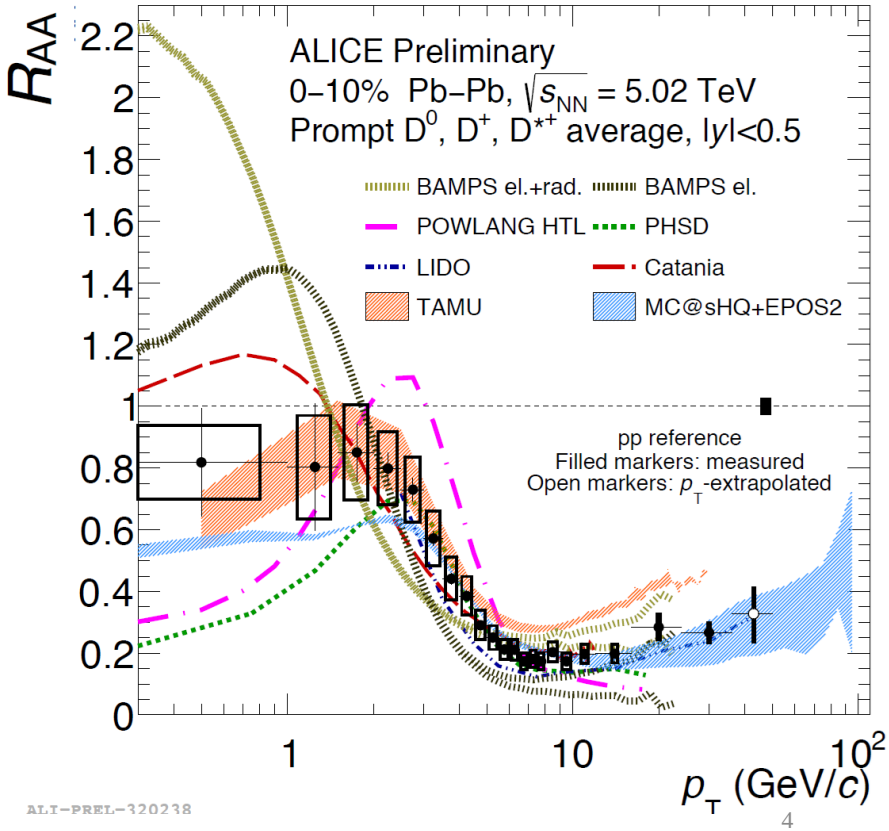


JHEP 10 (2017) 090

Open charm production in PbPb collisions

- D^0 R_{AA} down to p_T~0
- Strong constrain on theories
  - Charm energy loss
  - Initial state effects (shadowing)
  - Radial flow
  - Recombination…
- Constraints on the total charm cross-section at the LHC
- Λ_c^+ R_{AA} show strong suppression at $10 < p_T < 20$GeV/c
- Λ_c^+ and D^0 results in mid-peripheral PbPb collisions from LHCb coming soon…

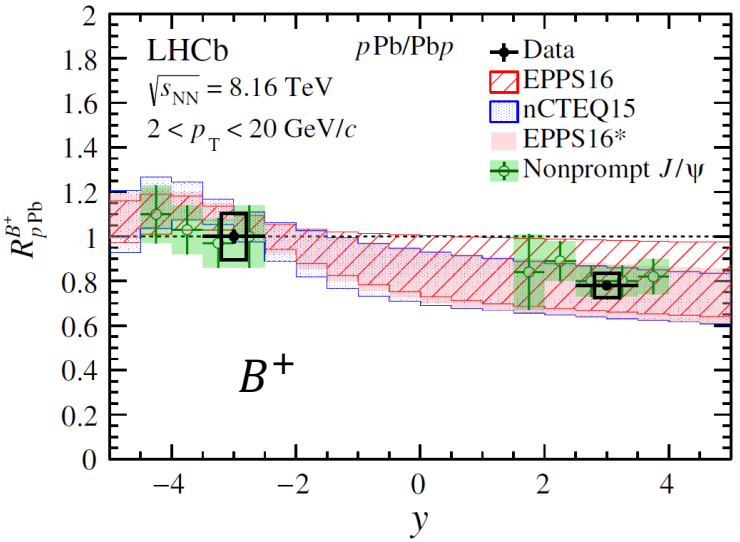


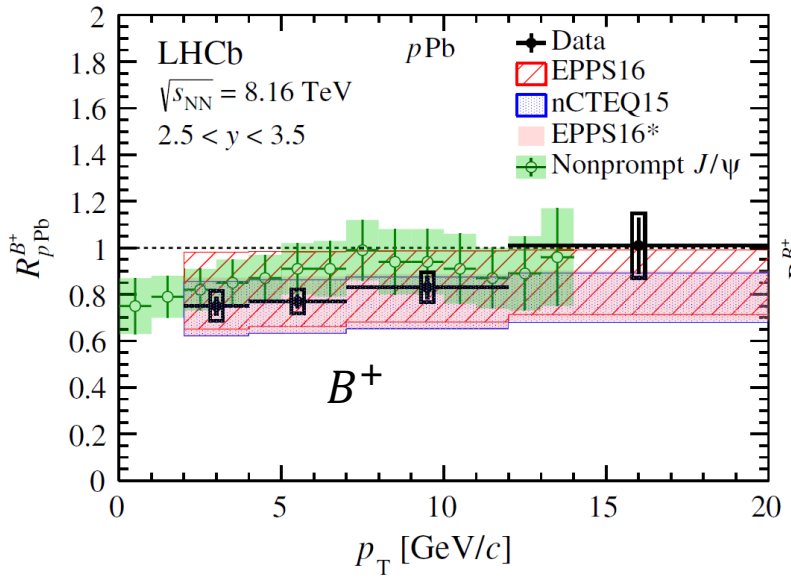


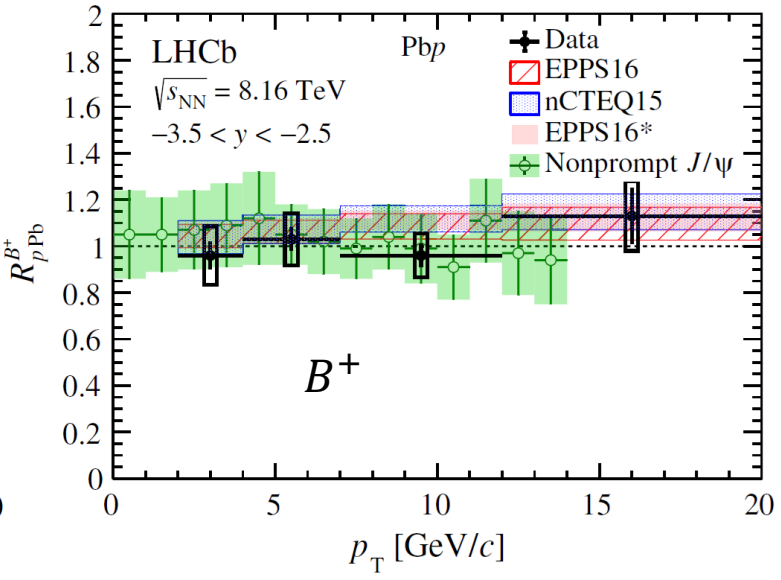
ALI-PREL-320238

Open beauty productions in *p*Pb collisions

- B^+ suppression at forward rapidity. Smaller than open charm
- Consistent with 1 at backward rapidity
- Consistent with nPDF calculations
- Consistent with nonprompt J/ψ



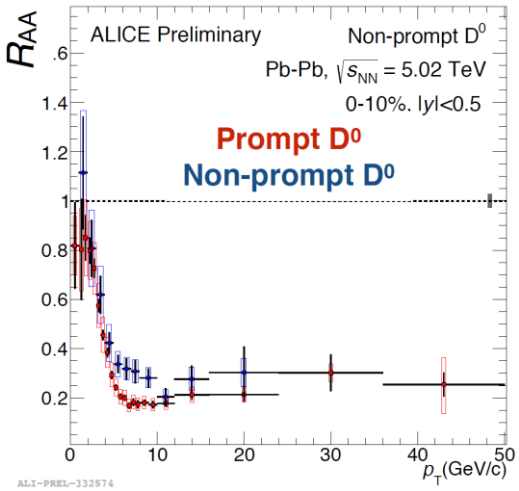


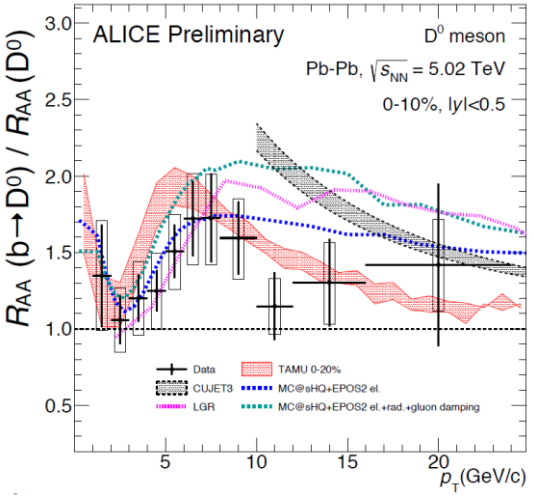


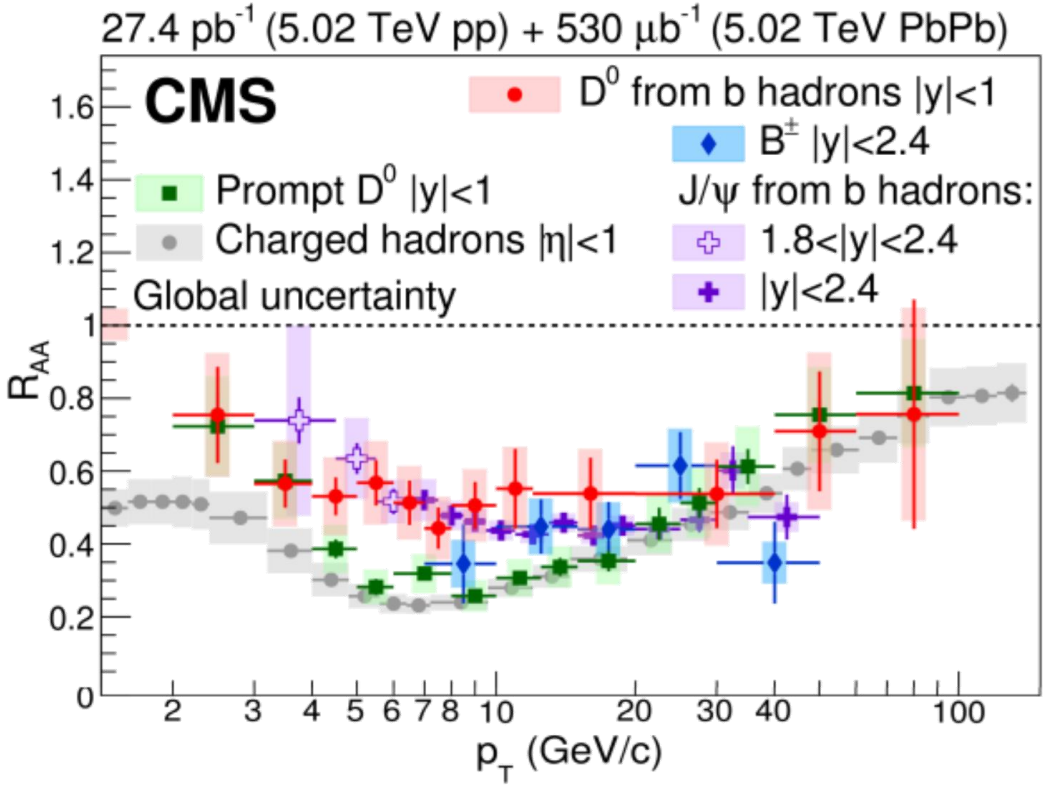
PRD99 052011 (2019)

Beauty production in PbPb

- Smaller suppression for non-prompt D^0
- B^+, nonprompt D^0 and J/ψ R_{AA} measured by CMS
- $R_{AA}(b) > R_{AA}(c) \sim R_{AA}(h)$
- Suggests quark mass dependence of the energy loss in QGP

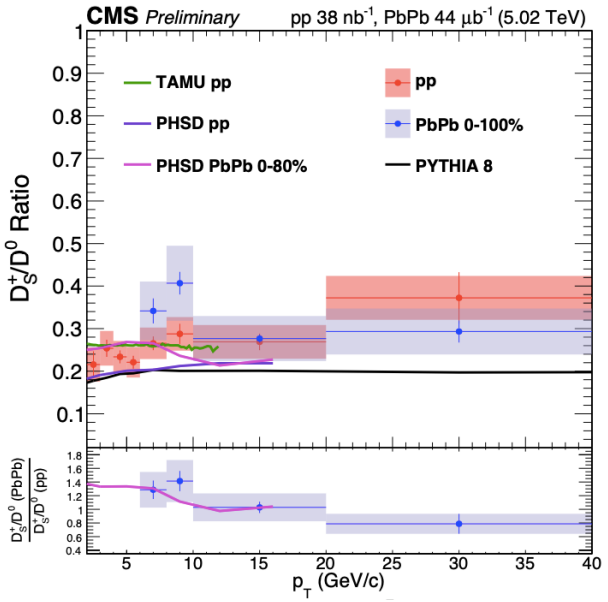




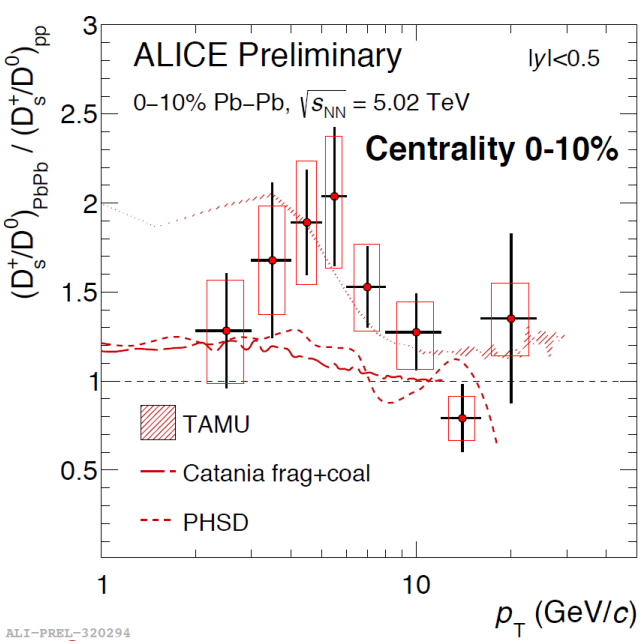


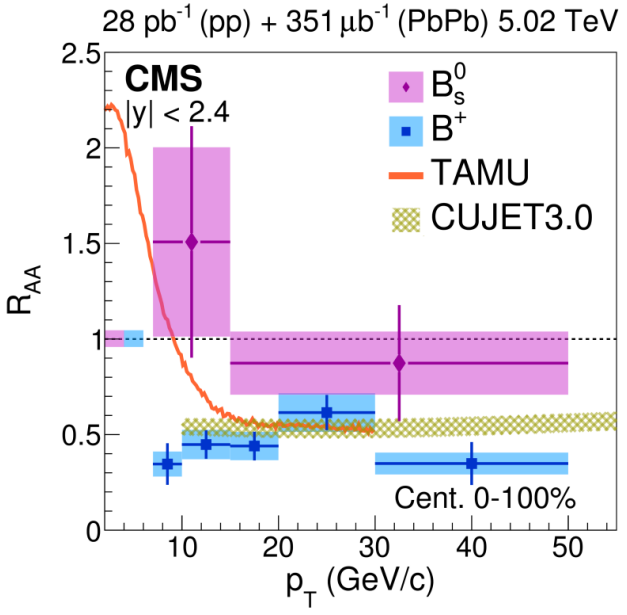
Strangeness in PbPb collisions

- Recombination and strangeness enhancement in QGP
- Possible strange heavy flavor hadron enhancement in heavy ion collisions

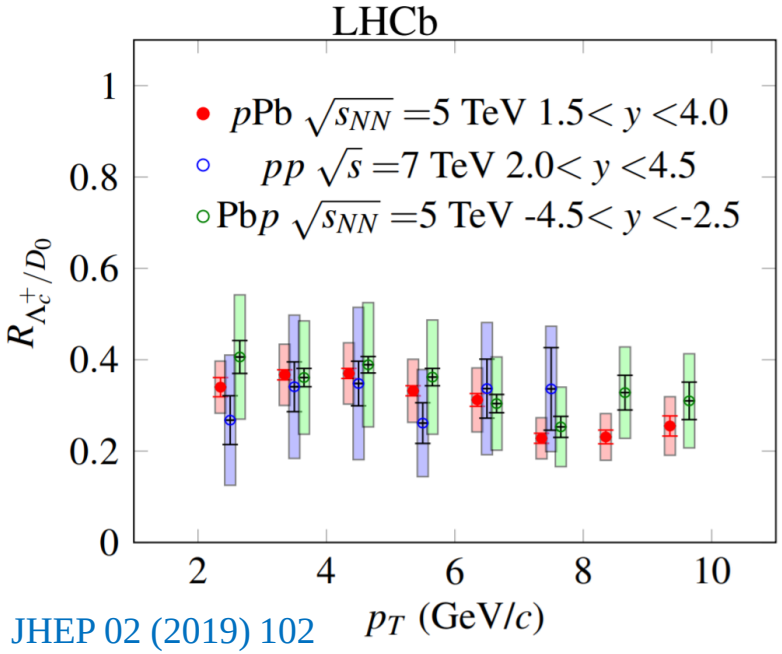


CMS-PAS-HIN-18-017





Charmed baryon/meson ratio in *p*Pb



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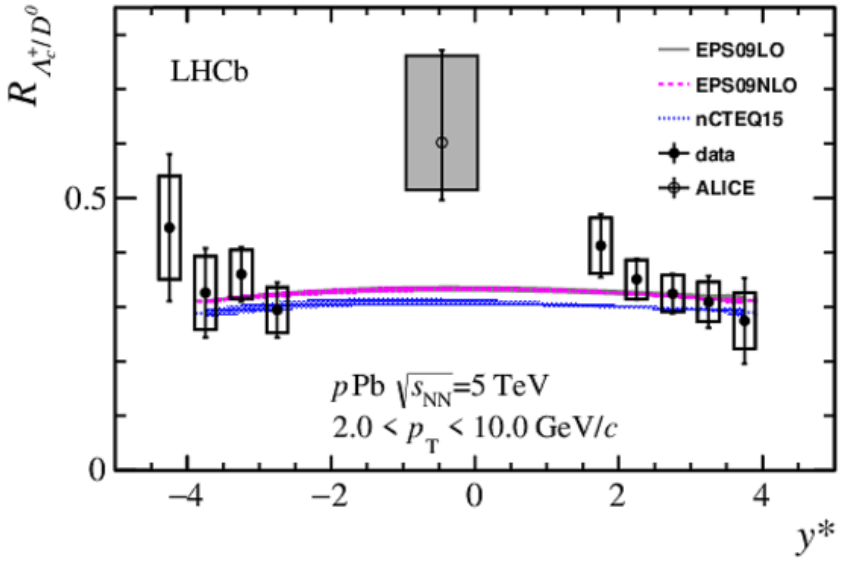

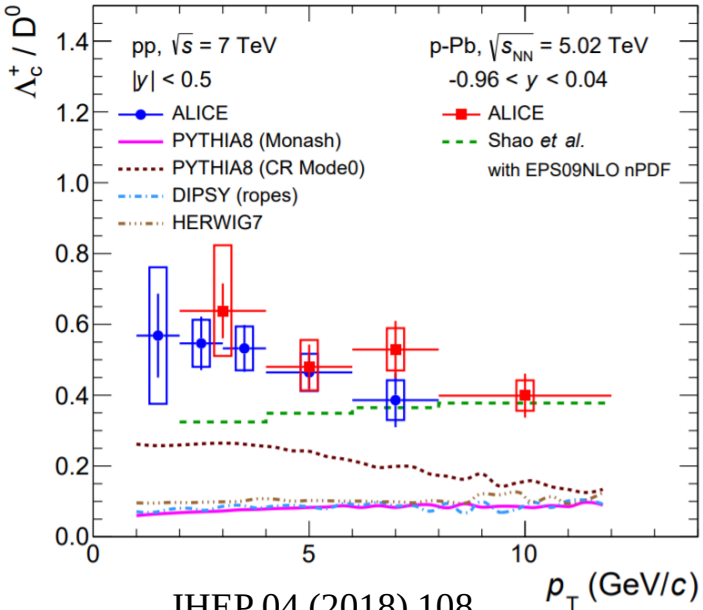

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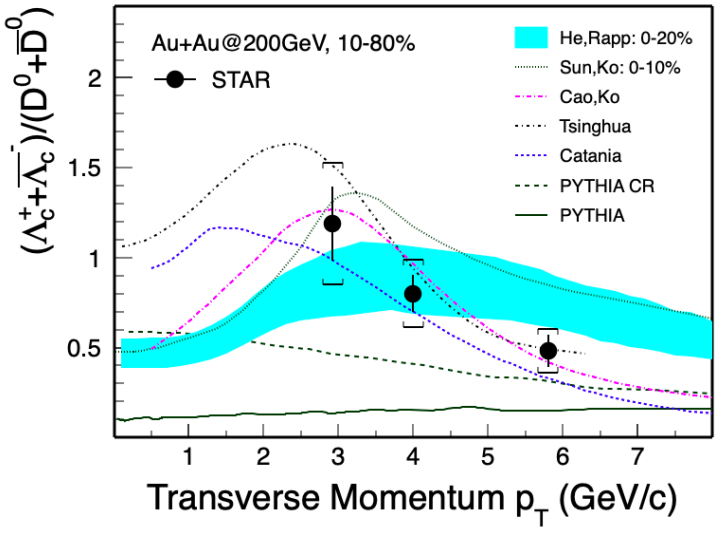
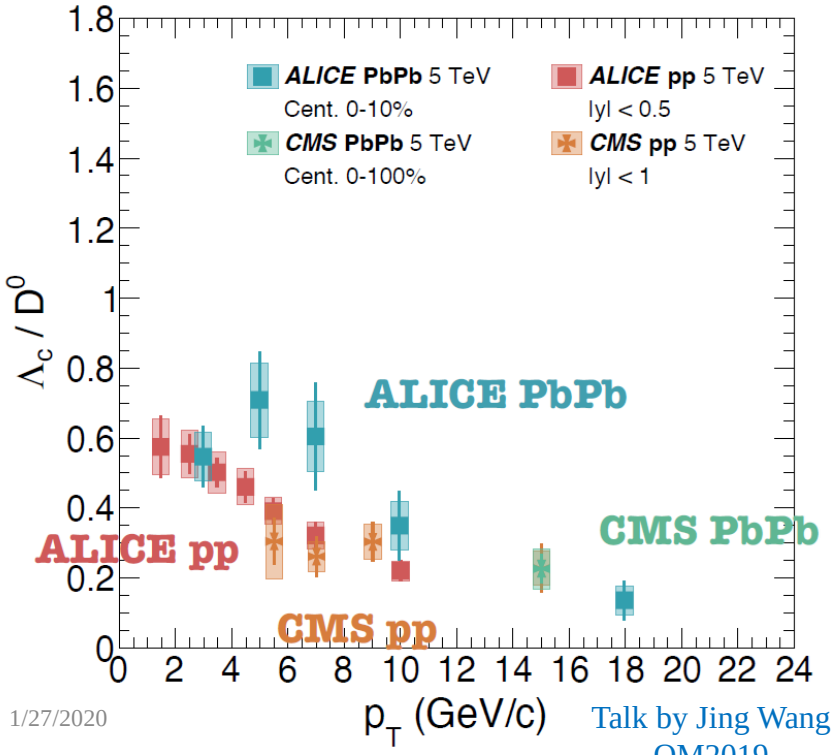
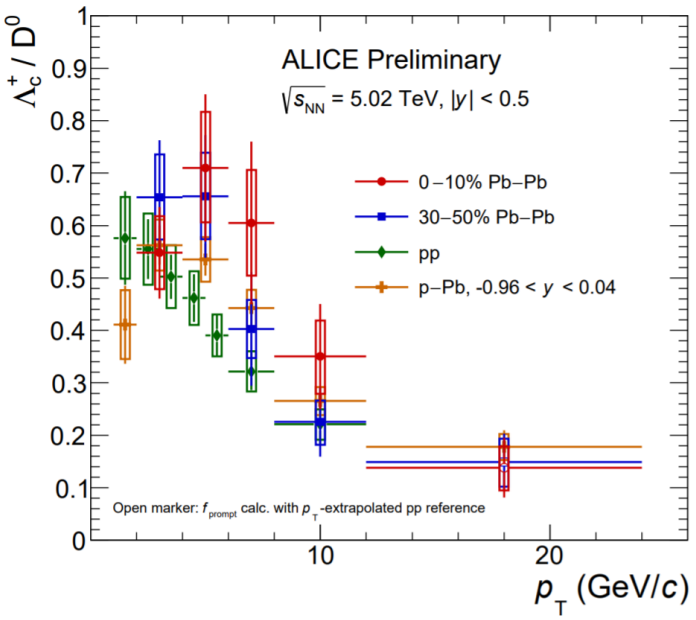
- Λ_c^+/D^0 ratio in pp > in e^+e^- and ep collsions
- Λ_c^+/D^0 ratio in midrapidity > in forward rapidity
- Λ_c^+/D^0 ratio in *p*Pb close to *pp*

Λ_c^+ / D^0 ratio in PbPb

- enhancement STAR > ALICE
- in *pp*:
  - CMS ~ LHCb
  - CMS ~ ALICE (p_T > 5GeV/c)
- in PbPb:
  - CMS ~ ALICE (p_T > 10GeV/c)
  - No coalescence seen by CMS at large p_T

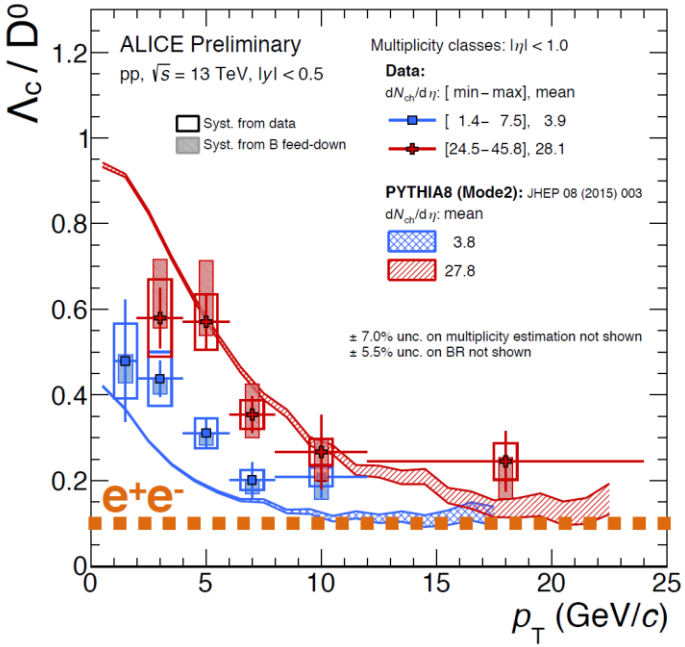


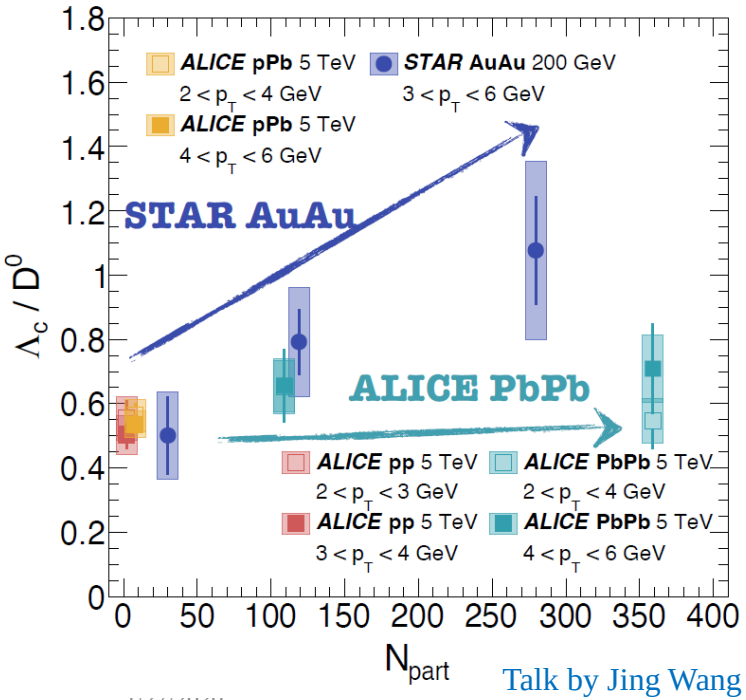


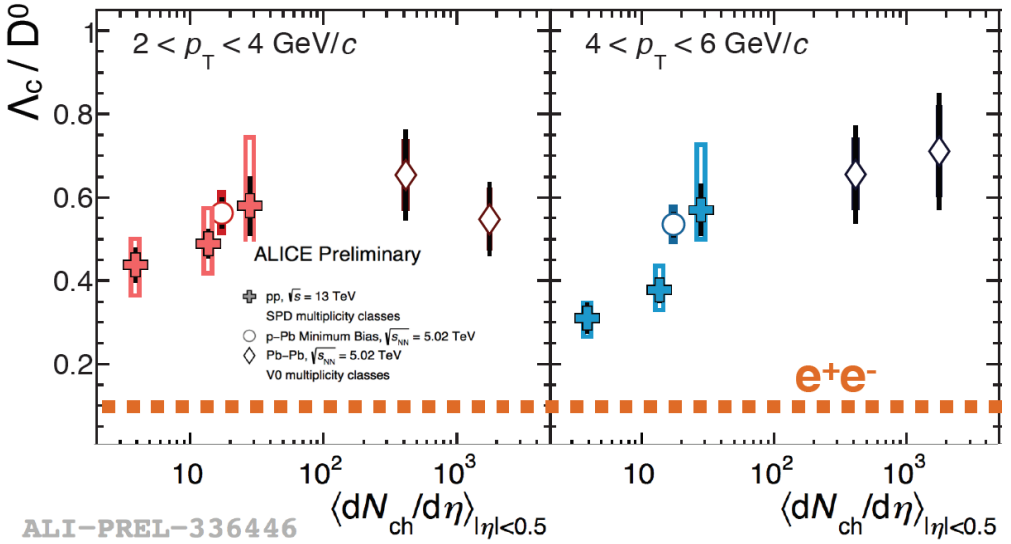


Λ_c^+ / D^0 ratio vs. multiplicity

- Multiplicity dependence of Λ_c^+ / D^0 ratio observed in *pp* collisions
- Smooth increase from *pp* to PbPb
- Different slope btw STAR and ALICE



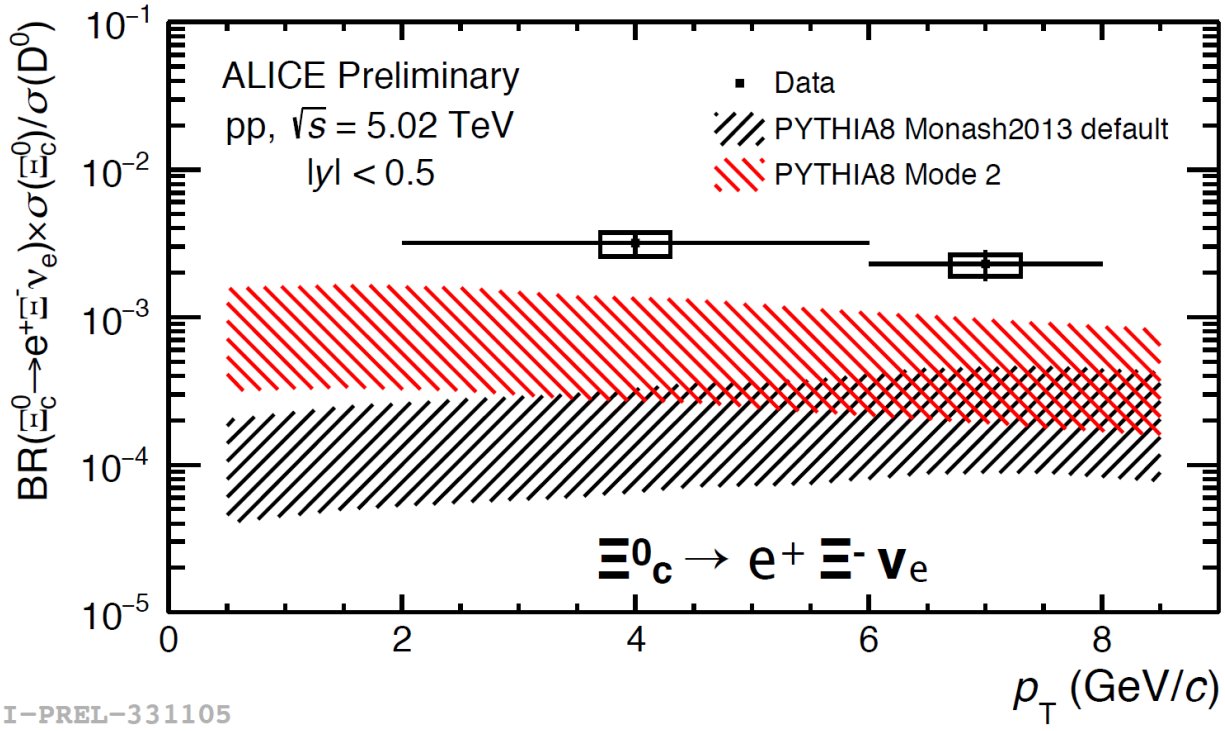




Talk by Jing Wang
QM2019

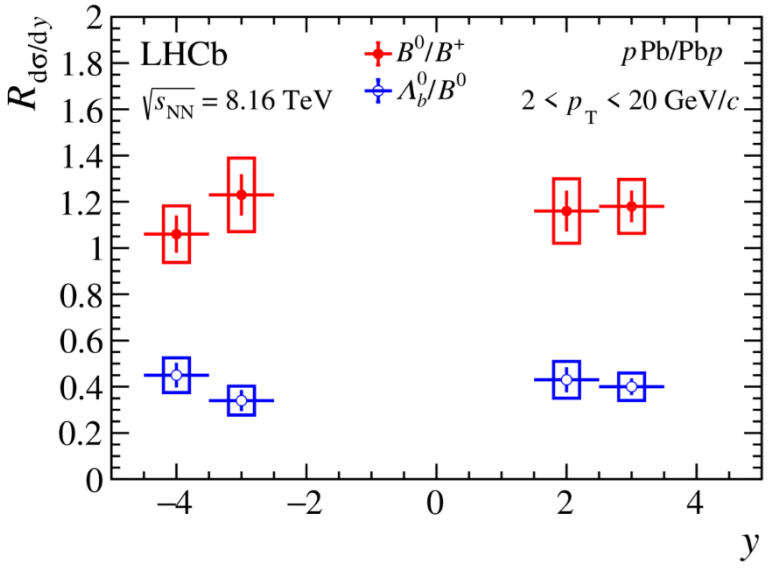
Ξ_c^0/D^0 ratio in *pp* collisions

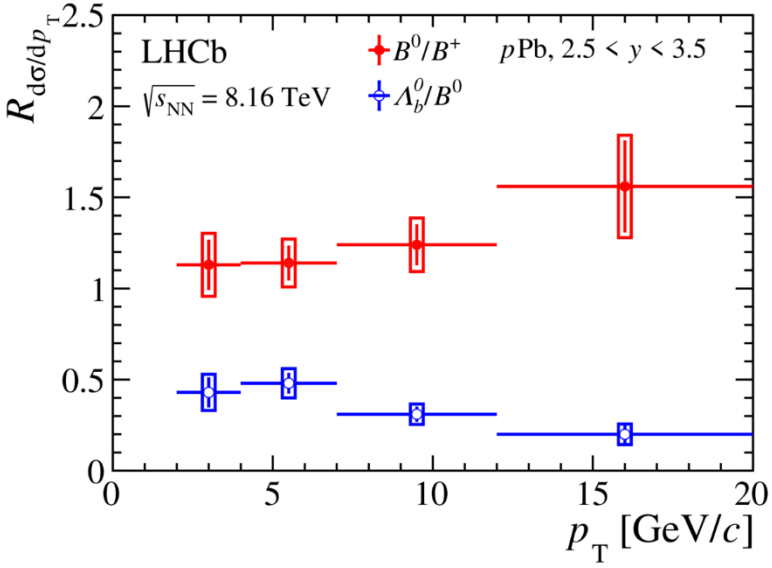
- Ξ_c^0/D^0 ratio in *pp* also larger than MC generator



Λ_b^0/B^0 ratio in pPb collisions

PRD99 052011 (2019)

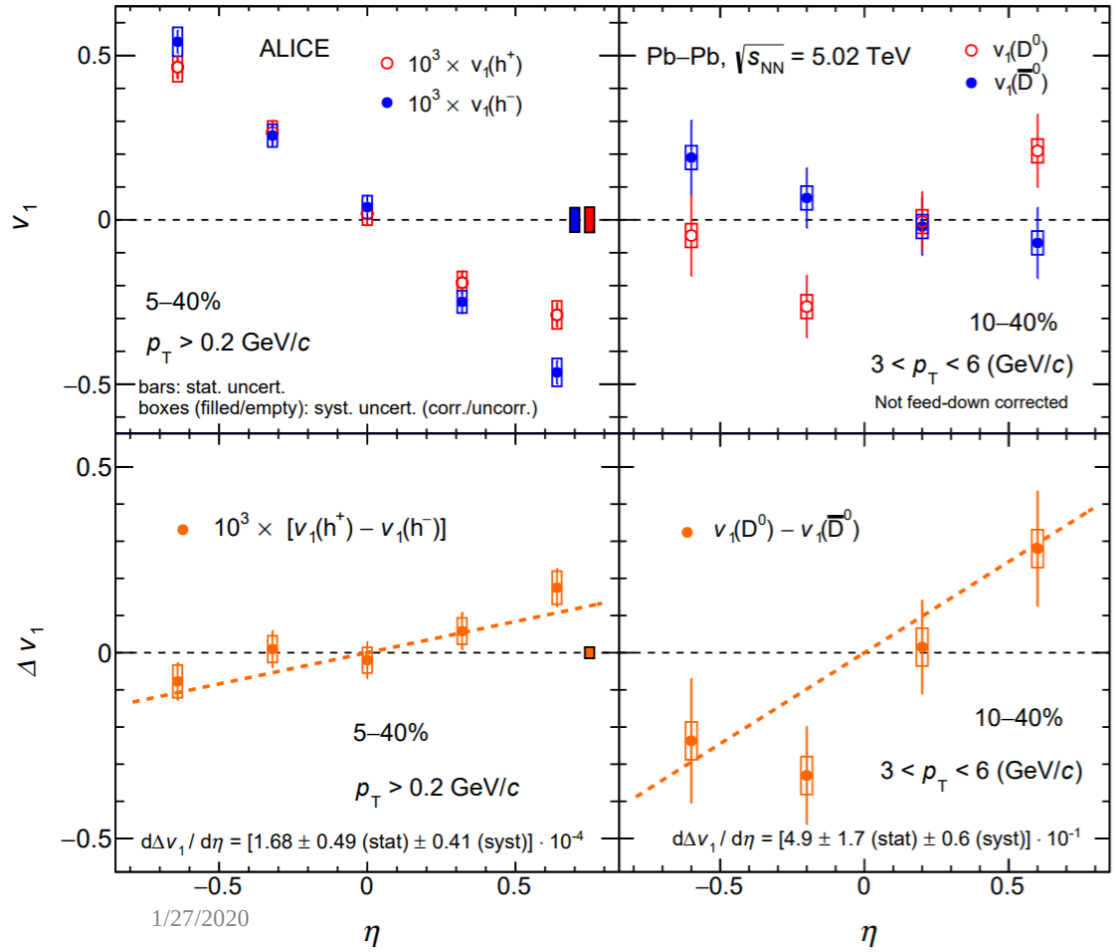


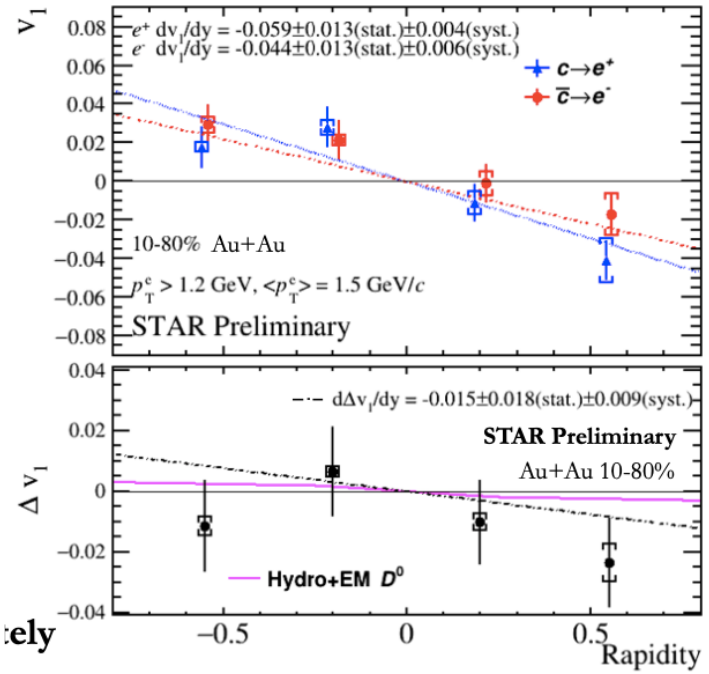


- $R_{\Lambda_b^0/B^0}$
  - ~0.4, no strong rapidity dependence
  - Similar values observed in LHCb pp measurement JHEP 08 (2014) 143
  - Decreases with p_T when $p_T > 5$ GeV/c

Initial magnet field effects

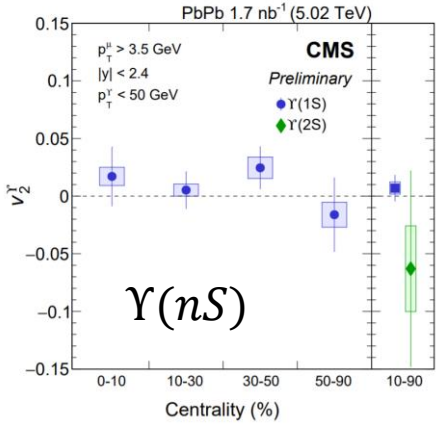
- Charge asymmetry of directed flow v_1 probes the strong initial EM field
- Charm more sensitive than light quarks:
  - slope(D^0) >> slope($h^{\pm}$)
- STAR negative slope vs. ALICE positive slope

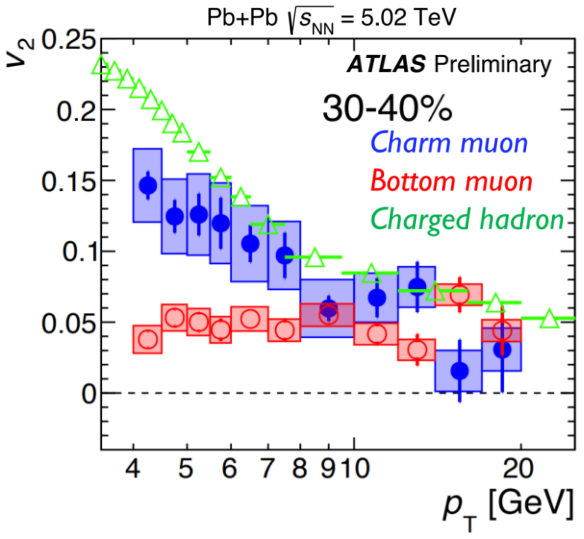


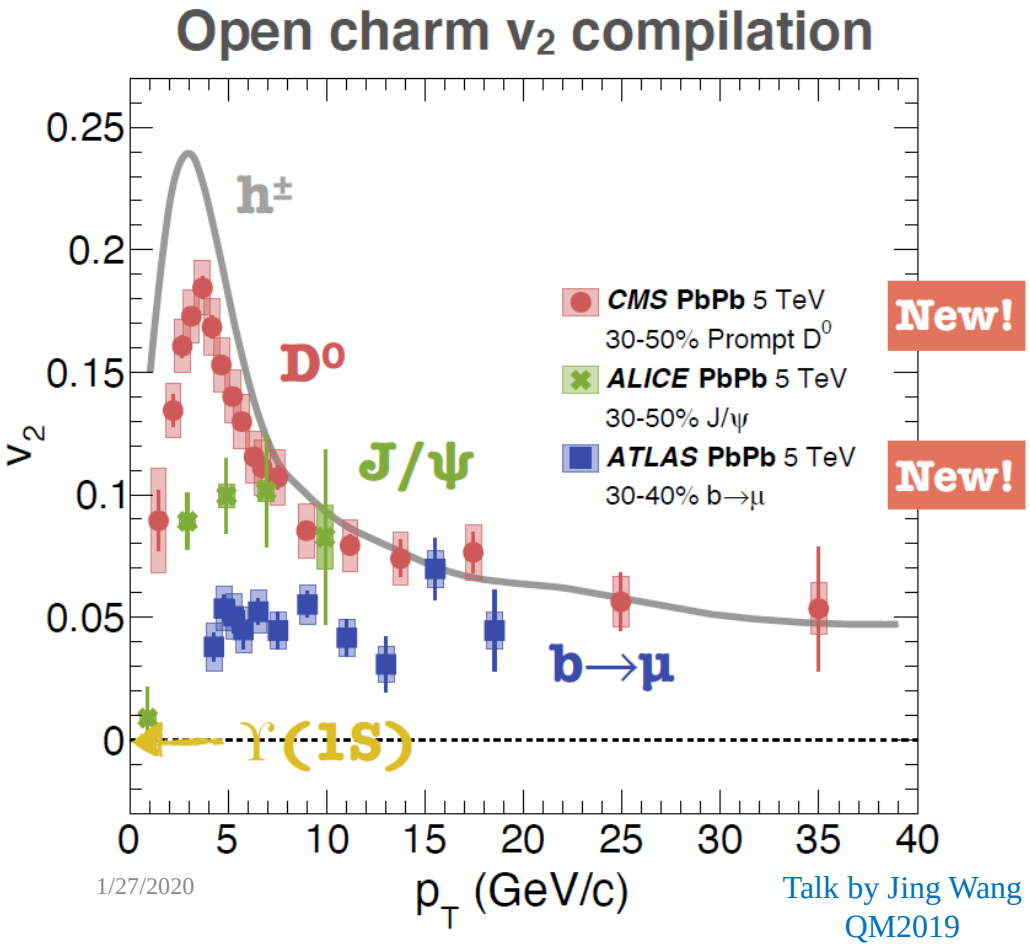


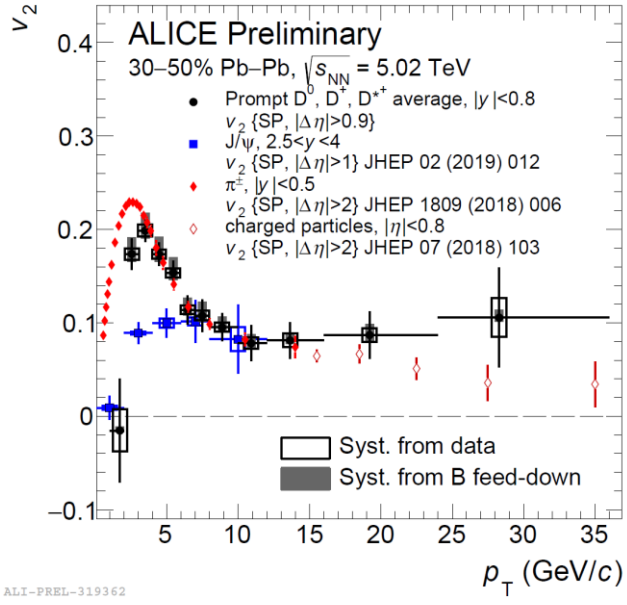
Collective flow in PbPb

- $v_2(h^{\pm}) > v_2(D) > v_2(J/\psi)$
- $v_2(\text{charm}) > v_2(\text{open bottom}) > 0$
- $v_2(\Upsilon) \sim 0$





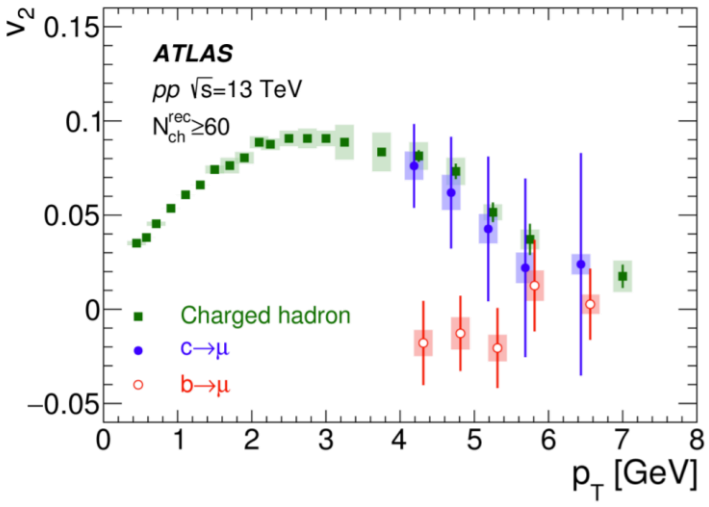


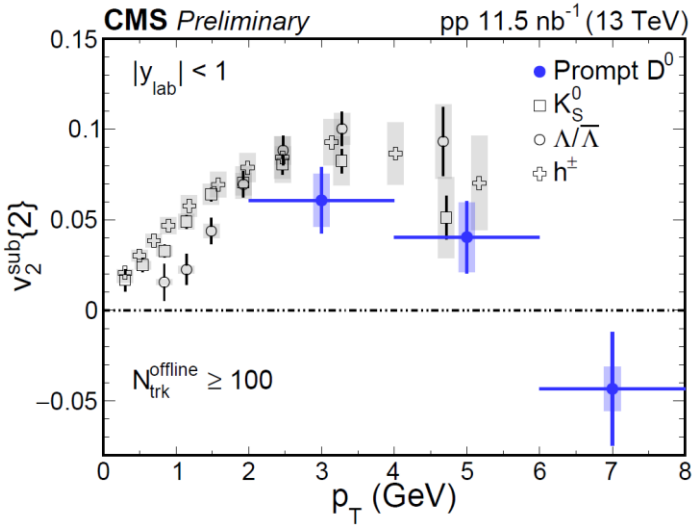


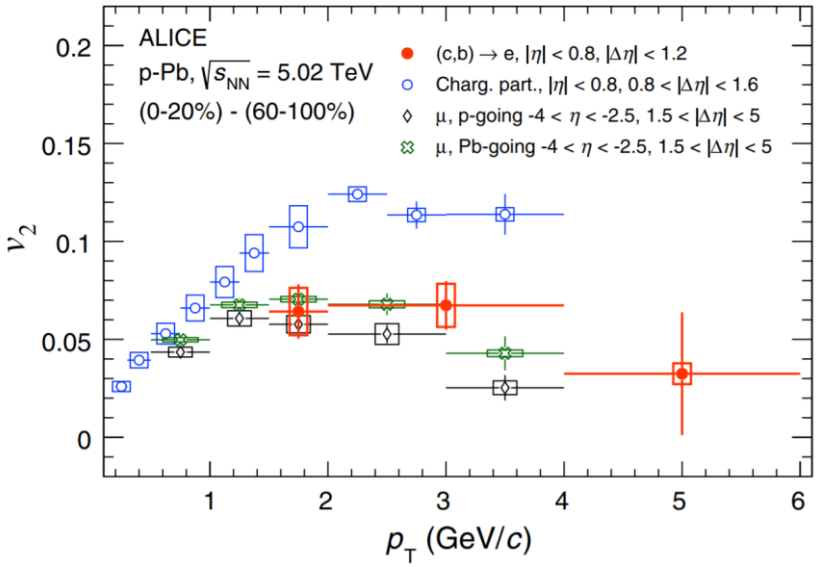
Collectivity in small systems

- *pp*:
  - $v_2(c) \lesssim v_2(h^{\pm})$
  - $v_2(b) \sim 0$
- *p*Pb:
  - $v_2(h^{\pm}) > v_2(c)$ $\quad v_2(D^0) \sim v_2(J/\psi)$
  - $v_2(b) \sim 0$

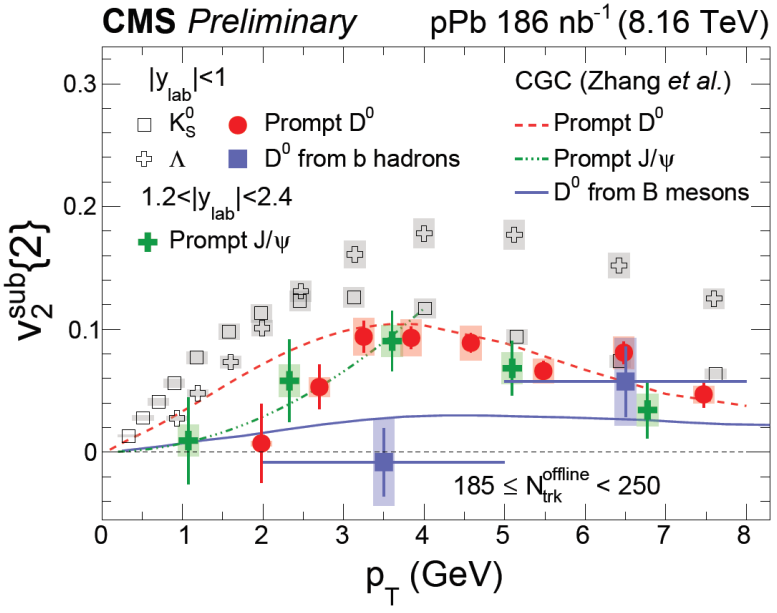
arXiv:1909.01650







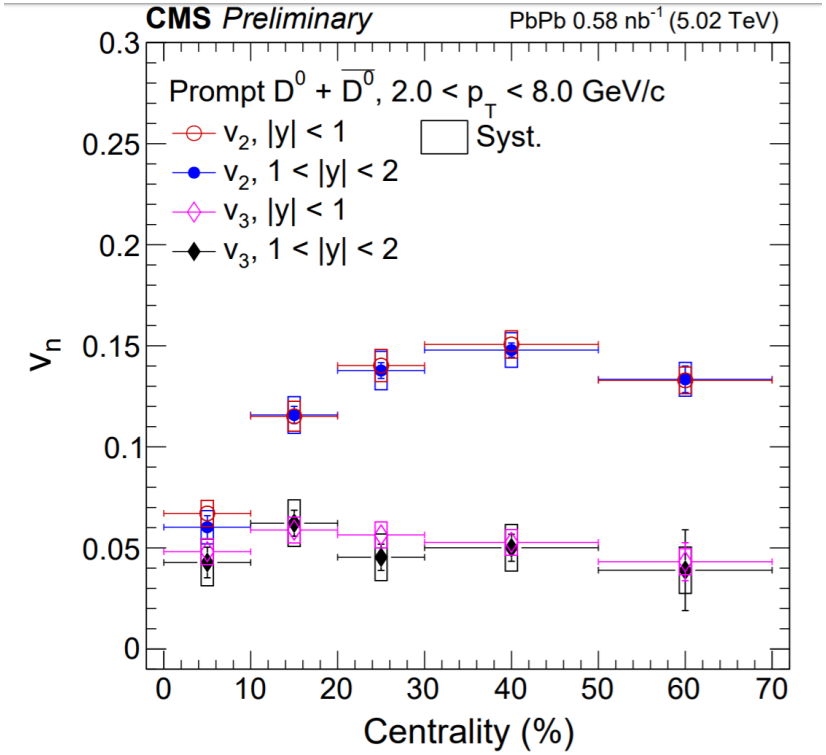
PhysRevLett.122.072301

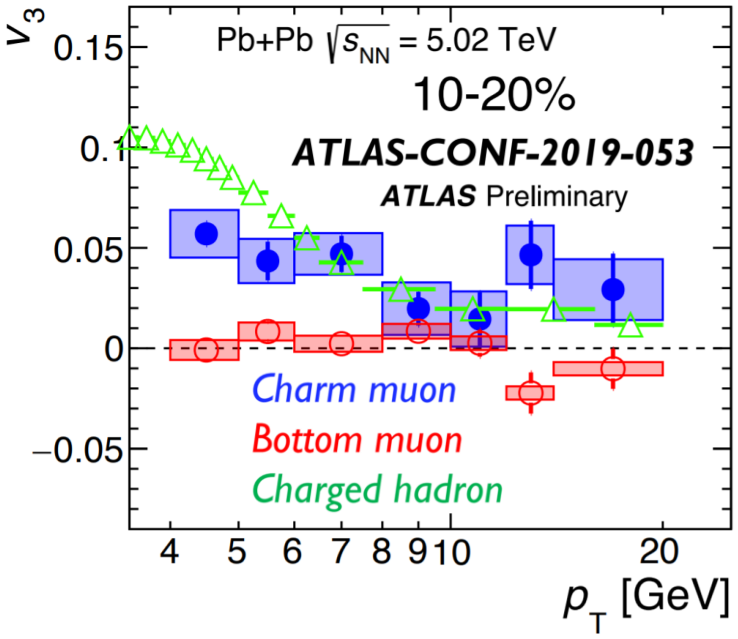


CMS PAS HIN-19-009

Initial fluctuation v_3 in PbPb

- D^0 v_3: no strong centrality dependence
- $v_3(h^{\pm}) > v_3(\text{charm}) > v_3(\text{bottom})$
- $v_3(\text{bottom}) \sim 0$

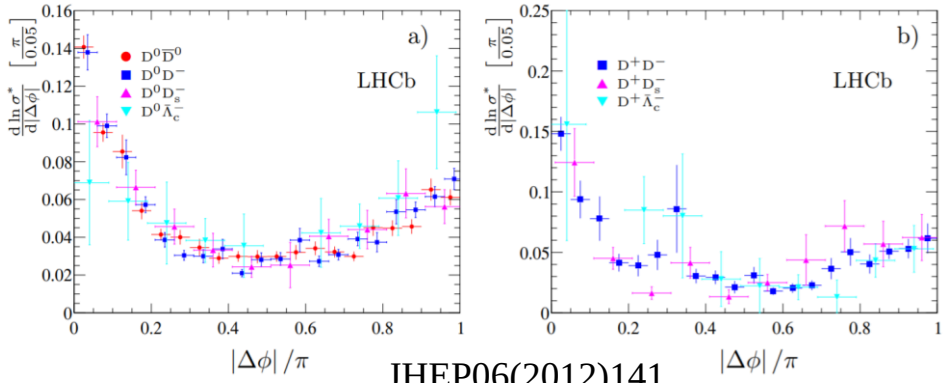




CMS-PAS-HIN-19-008

Outlook

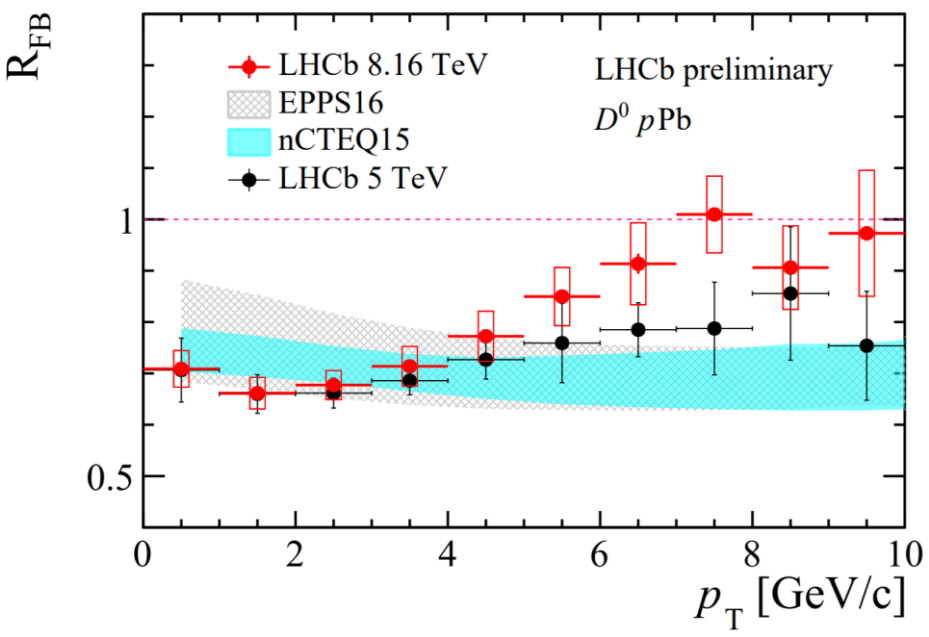
- LHCb upcoming results:
  - Double charm correlations in *p*Pb collisions
  - Open charm production in mid-peripheral to peripheral PbPb collisions
- A wishlist…

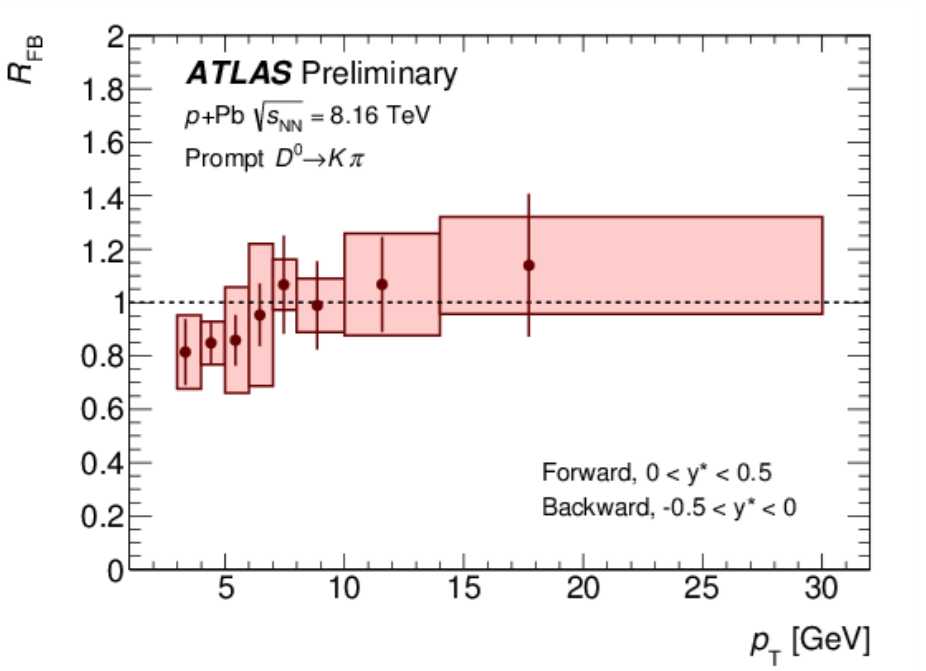


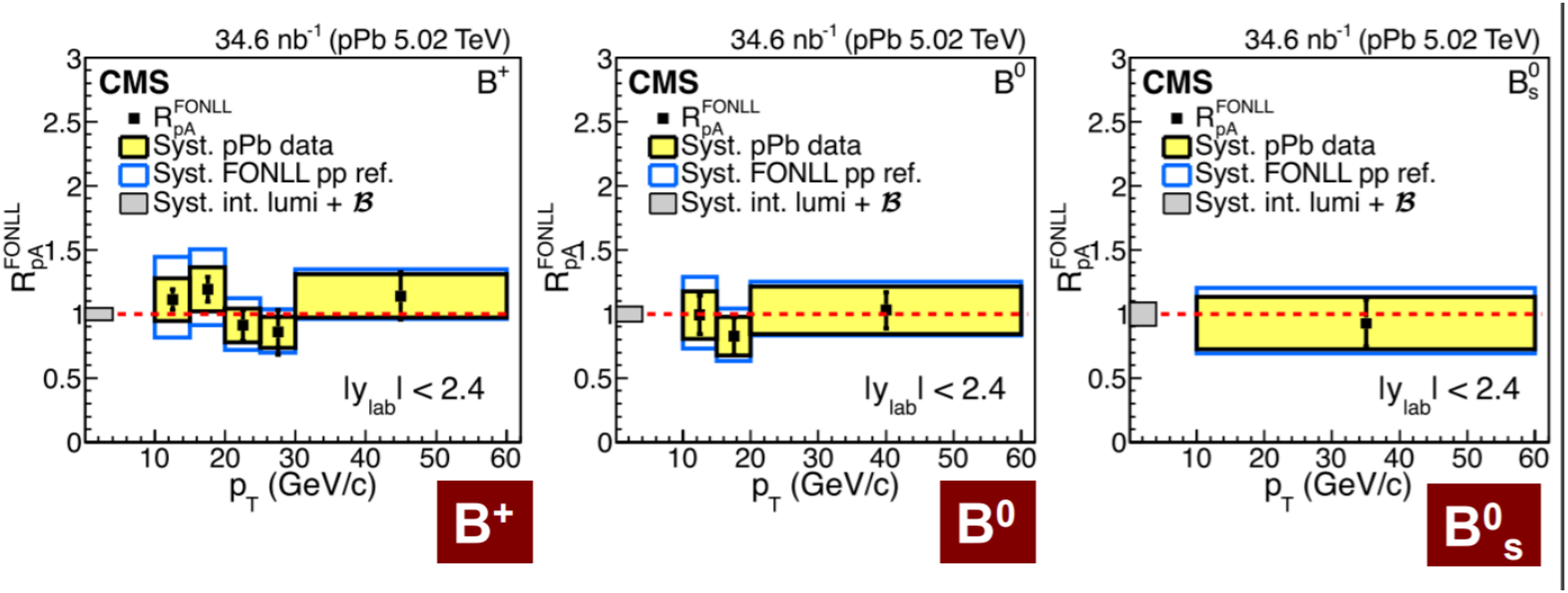
JHEP06(2012)141

	LHCb	ALICE	ATLAS	CMS
Open charm in *p*Pb	R_{FB} > nPDF at high p_T preliminary	midrapidity	High p_T	High p_T
Open beauty in *p*Pb	Statistically limited result $2<p_T<20$, $2<\eta<5$	Midrapidity $\|y\|<0.5$	$20<p_T<40$ GeV/c $\|y\|<2$	Statistically limited $10<p_T<60$ GeV/c $\|y\|<2.4$
Double charm	Upcoming *p*Pb	SAME	SAME	SAME
Λ_c^+/D^0 ratio	Upcoming mid-peripheral PbPb result	*pp*, *p*Pb, PbPb results midrapidity	?	*pp*, PbPb results High p_T
Open charm v_1, v_2	forward $2<\eta<5$ v_2: in progress	v_1 positive slope $\|\eta\|<0.8$	v_1: $\|y\|<2$	v_1: $\|y\|<2.4$
Open beauty v_2 in small system	HF flow in forward rapidity		~ 0, large uncertainty	~ 0, large uncertainty

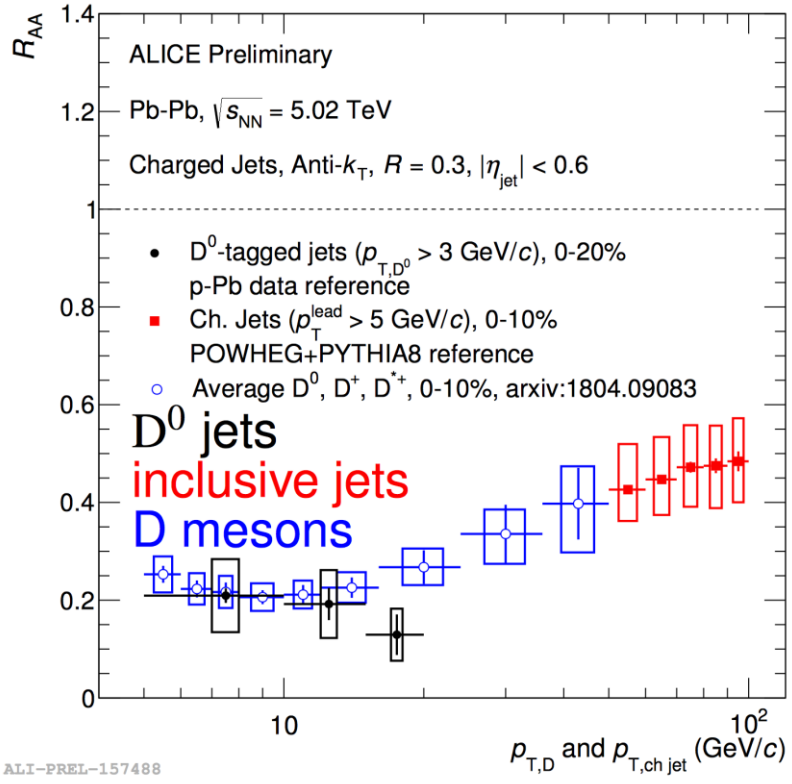
backup

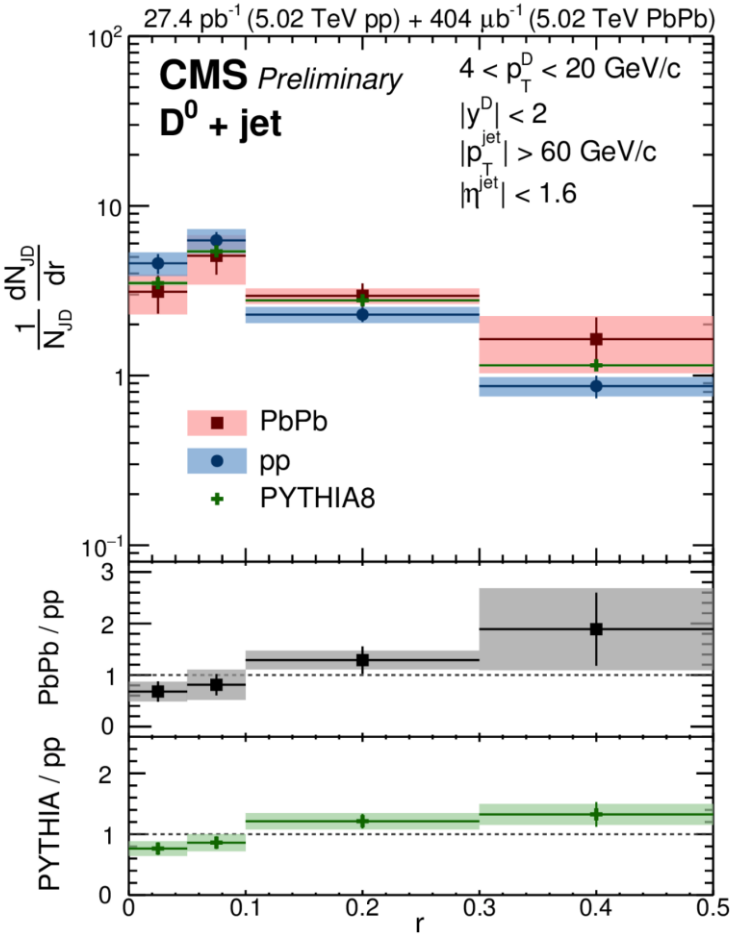

R_{FB}
LHCb 8.16 TeV
EPPS16
nCTEQ15
LHCb 5 TeV
LHCb preliminary
D^0 pPb
1
0.5
0
2
4
6
8
10
p_T [GeV/c]


R_{FB}
ATLAS Preliminary
p+Pb $\sqrt{s_{NN}}$ = 8.16 TeV
Prompt $D^0 \to K\pi$
Forward, 0 < y* < 0.5
Backward, -0.5 < y* < 0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
p_T [GeV]

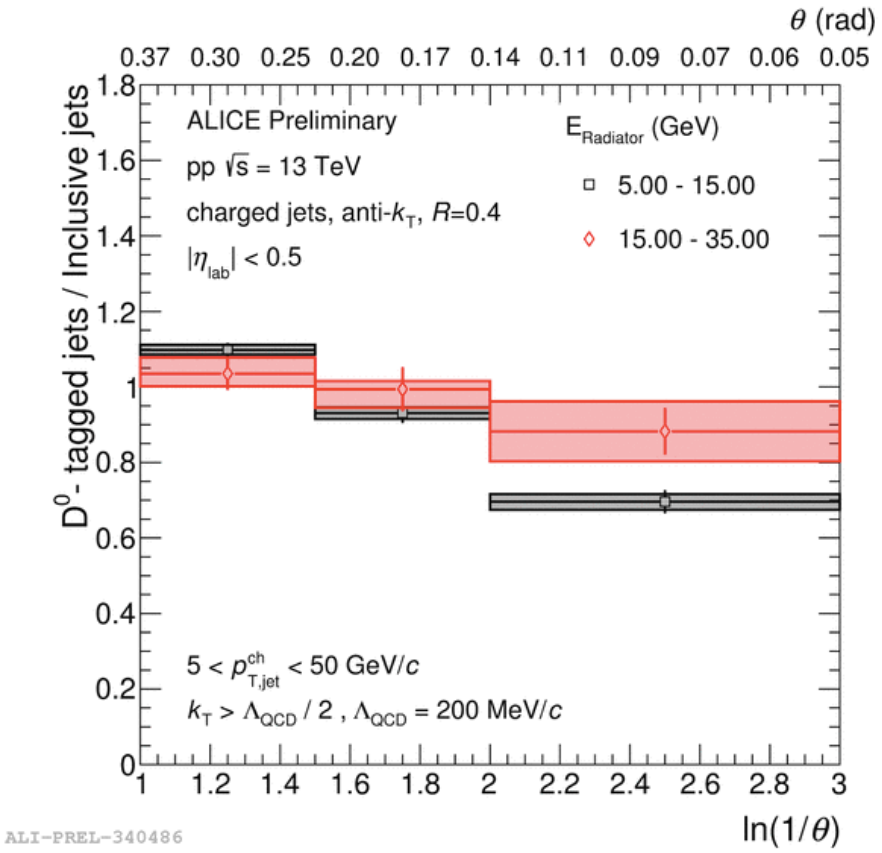

34.6 nb-1 (pPb 5.02 TeV)
CMS
B+
RpAFONLL
Syst. pPb data
Syst. FONLL pp ref.
Syst. int. lumi + B
|ylab| < 2.4
RpAFONLL
pT (GeV/c)
B+
34.6 nb-1 (pPb 5.02 TeV)
CMS
B0
RpAFONLL
Syst. pPb data
Syst. FONLL pp ref.
Syst. int. lumi + B
|ylab| < 2.4
RpAFONLL
pT (GeV/c)
B0
34.6 nb-1 (pPb 5.02 TeV)
CMS
B0s
RpAFONLL
Syst. pPb data
Syst. FONLL pp ref.
Syst. int. lumi + B
|ylab| < 2.4
RpAFONLL
pT (GeV/c)
B0s

D meson tagged jets



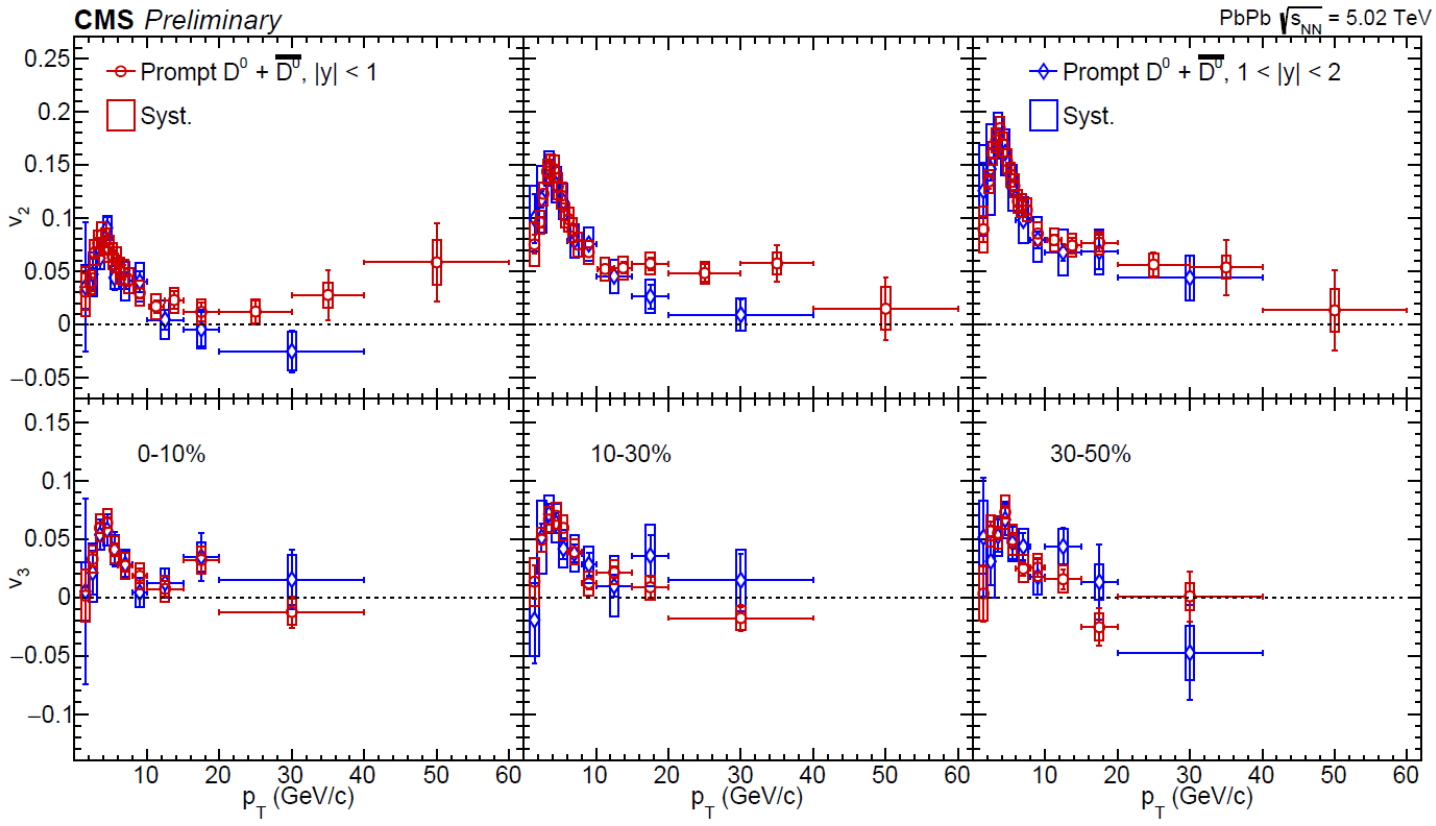


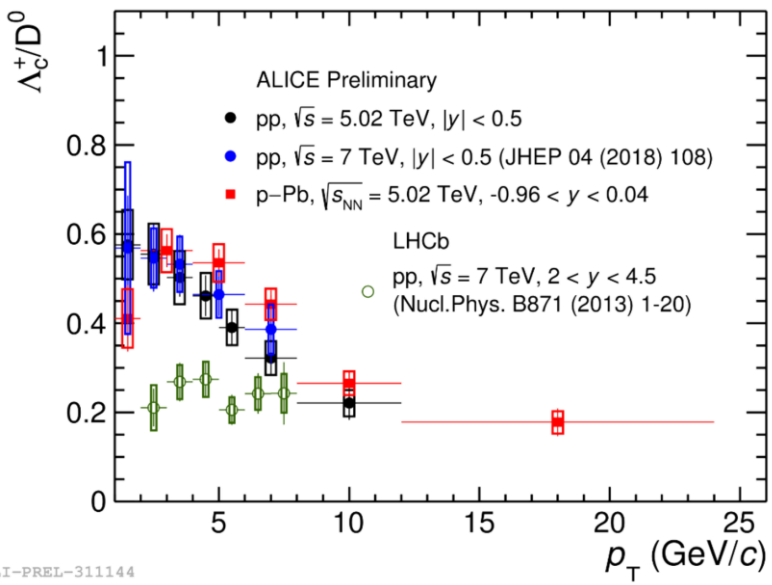
Dead cone effect observed in pp

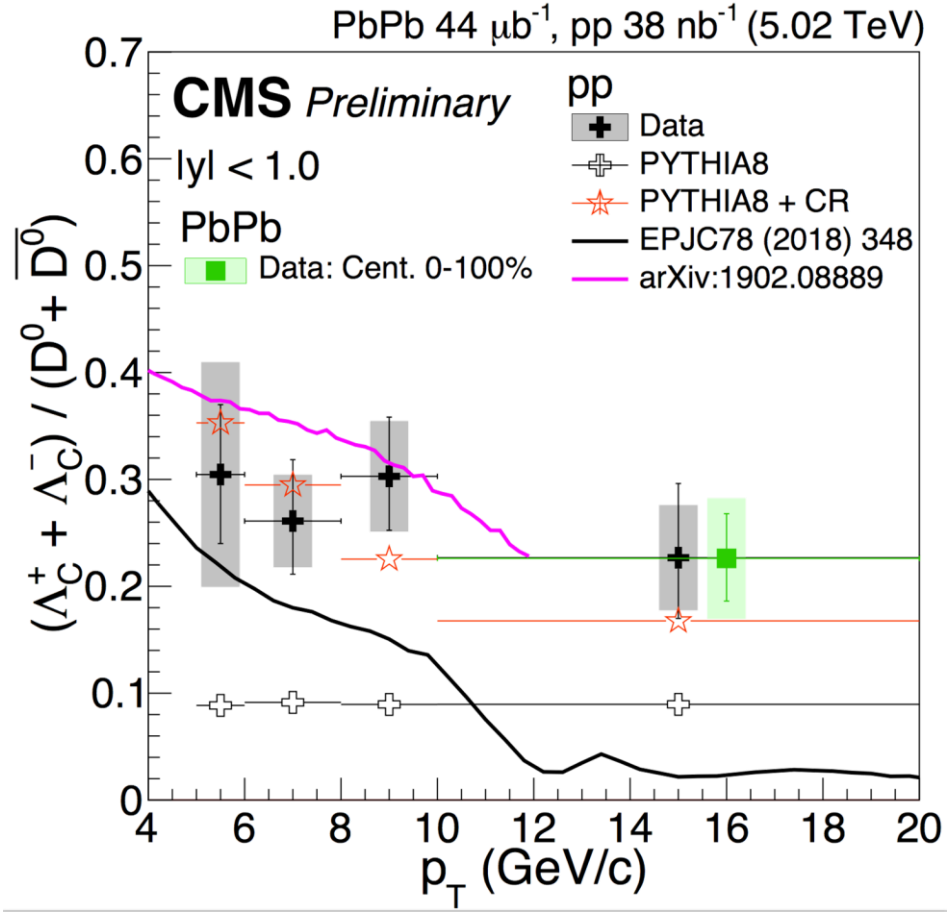


D0 v2

- CMS


CMS Preliminary
PbPb √s_NN = 5.02 TeV
Prompt D⁰ + D̄⁰, |y| < 1
Syst.
Prompt D⁰ + D̄⁰, 1 < |y| < 2
Syst.
v2
v3
0-10%
10-30%
30-50%
p_T (GeV/c)


ALICE Preliminary
pp, $\sqrt{s}$ = 5.02 TeV, |y| < 0.5
pp, $\sqrt{s}$ = 7 TeV, |y| < 0.5 (JHEP 04 (2018) 108)
p–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV, -0.96 < y < 0.04
LHCb
pp, $\sqrt{s}$ = 7 TeV, 2 < y < 4.5
(Nucl.Phys. B871 (2013) 1-20)
Λ_c^+/D^0
p_T (GeV/c)
ALI-PREL-311144

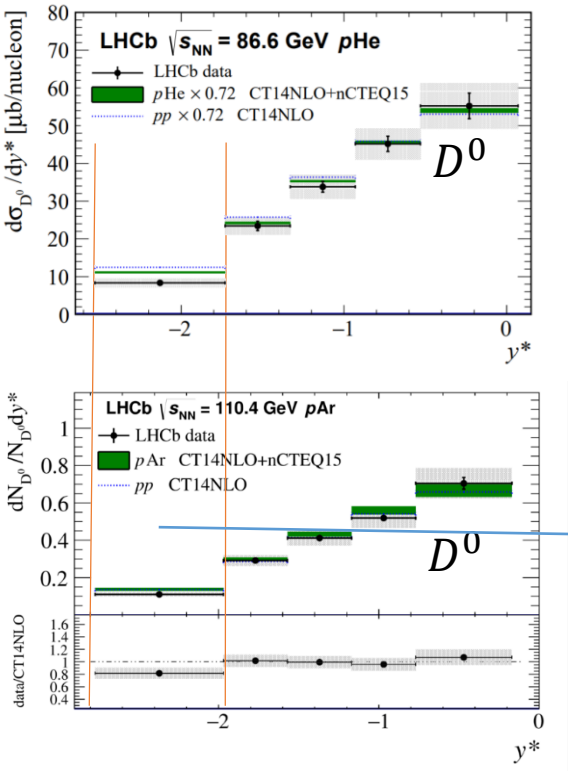

PbPb 44 μb^{-1}, pp 38 nb^{-1} (5.02 TeV)
CMS Preliminary
|y| < 1.0
PbPb
Data: Cent. 0-100%
pp
Data
PYTHIA8
PYTHIA8 + CR
EPJC78 (2018) 348
arXiv:1902.08889
$(\Lambda_c^+ + \bar{\Lambda}_c^-) / (D^0 + \bar{D}^0)$
p_T (GeV/c)

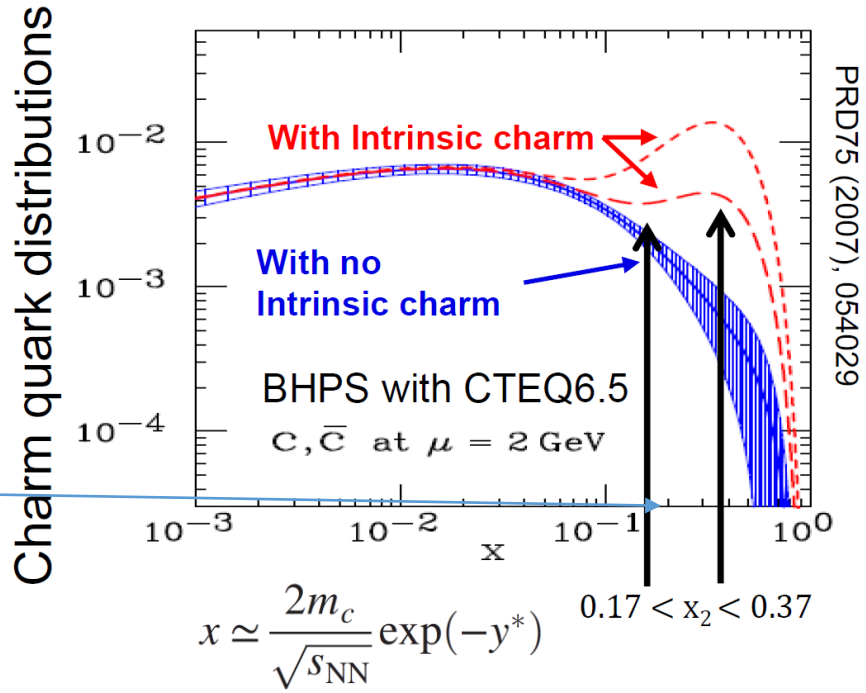
Charm production in fixed-target *p*A collision

PRL 122 (2019) 132002

*p*Ne @ 86.6 GeV

*p*Ar @ 110.4 GeV





- Differential D^0 cross-section (*p*He @ 86.6 GeV), differential yields (*p*Ar @ 110.4 GeV)
- Reasonable agreement with Helac-Onia predictions in rapidity shape
- -2.53<y*<-1.73 → 0.17<*x*<0.37
- No evidence of strong intrinsic charm contribution observed

Models:
Eur. Phys. J. C77 (2017) 1
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238