Recent heavy-flavor measurements with the ATLAS detector

Qipeng Hu (LLNL)

Quark-Gluon Plasma Characterisation with Heavy Flavour Probes

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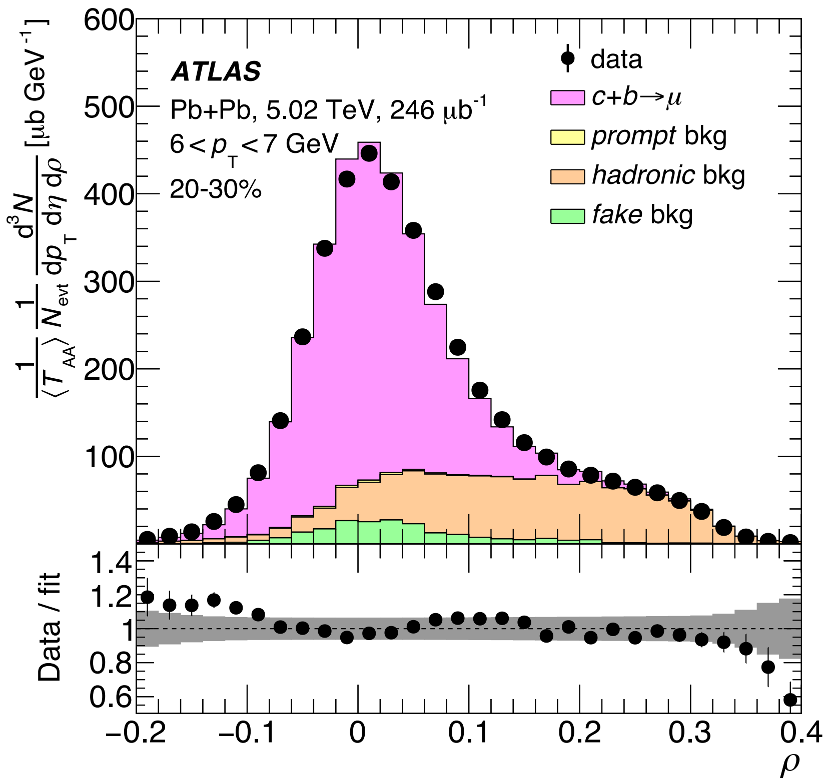
Lawrence Livermore National Laboratory

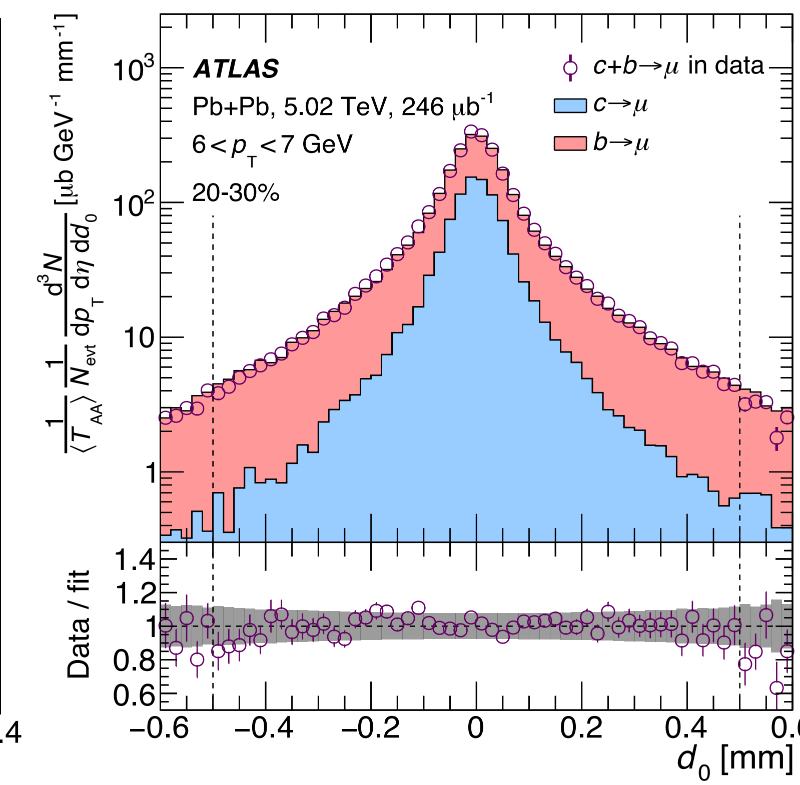
Heavy flavors in heavy ion collisions

- Two of the most important phenomena in HIC: collective flow and jet quenching, quantified by v_n and R_{AA}
- Open heavy flavors (charm and bottom) are produced early in the collision. Heavy flavor production in vacuum can be calculated perturbatively.
- Heavy flavor production in HIC is a complicated business: transport property, energy loss, hadronization, etc. More detailed/differential R_{AA} and v_n measurements could help to constrain modeling of each part.

Why heavy flavor (HF) muon

arXiv:2109.00411



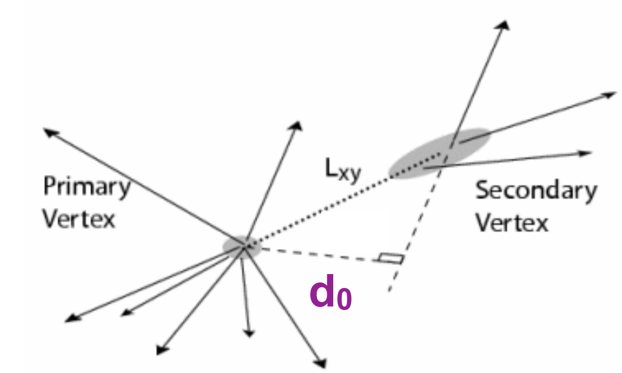


- Clean in central collisions
- Easy to collect with muon trigger
- Charm/bottom extracted at the same time in a correlated way

Keep in mind the hadron to muon decay

Background removed using momentum imbalance:
$\rho = (p_T^{ID} - p_T^{MS})/p_T^{ID}$

Charm/bottom separation via impact parameter (DCA): d_0



ATLAS HF muon program

Inclusive HF muon:

- HF muon (b+c) v_n and R_{AA} at 2.76 TeV — PRC 98 (2018) 044905, arXiv, web
- HF muon (b+c) v_2 in *p*+Pb — ATLAS-CONF-2017-006

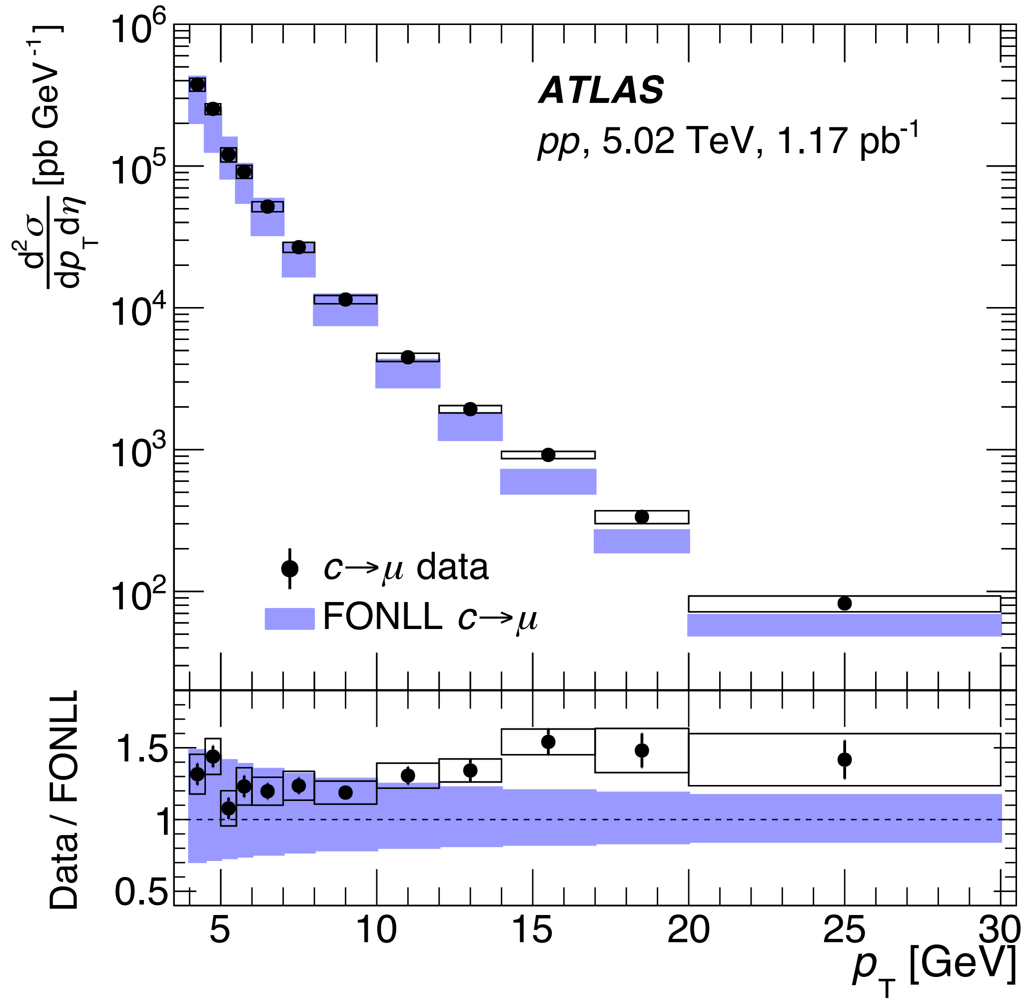
Charm/bottom muon separated:

- HF muon (b/c) v_2 in *pp* — PRL 124 (2020) 082301, arXiv, web
- HF muon (b/c) v_n in Pb+Pb — PLB 807 (2020) 135595, arXiv, web
- HF muon (b/c) R_{AA} at 5.02 TeV — arXiv, web

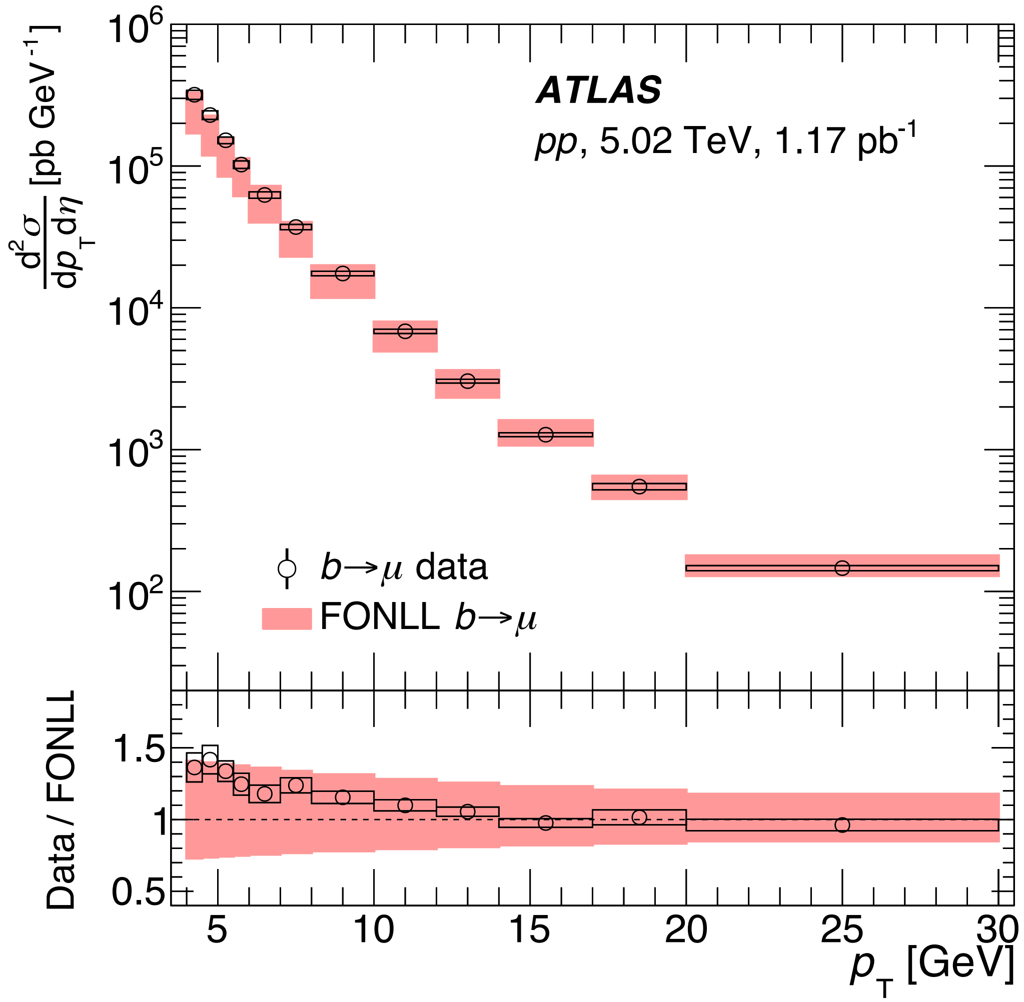
- Visit https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults for more ATLAS heavy ion results
- Check out ATLAS publication web for auxiliary materials

HF production in *pp* collisions

arXiv:2109.00411



Charm muon

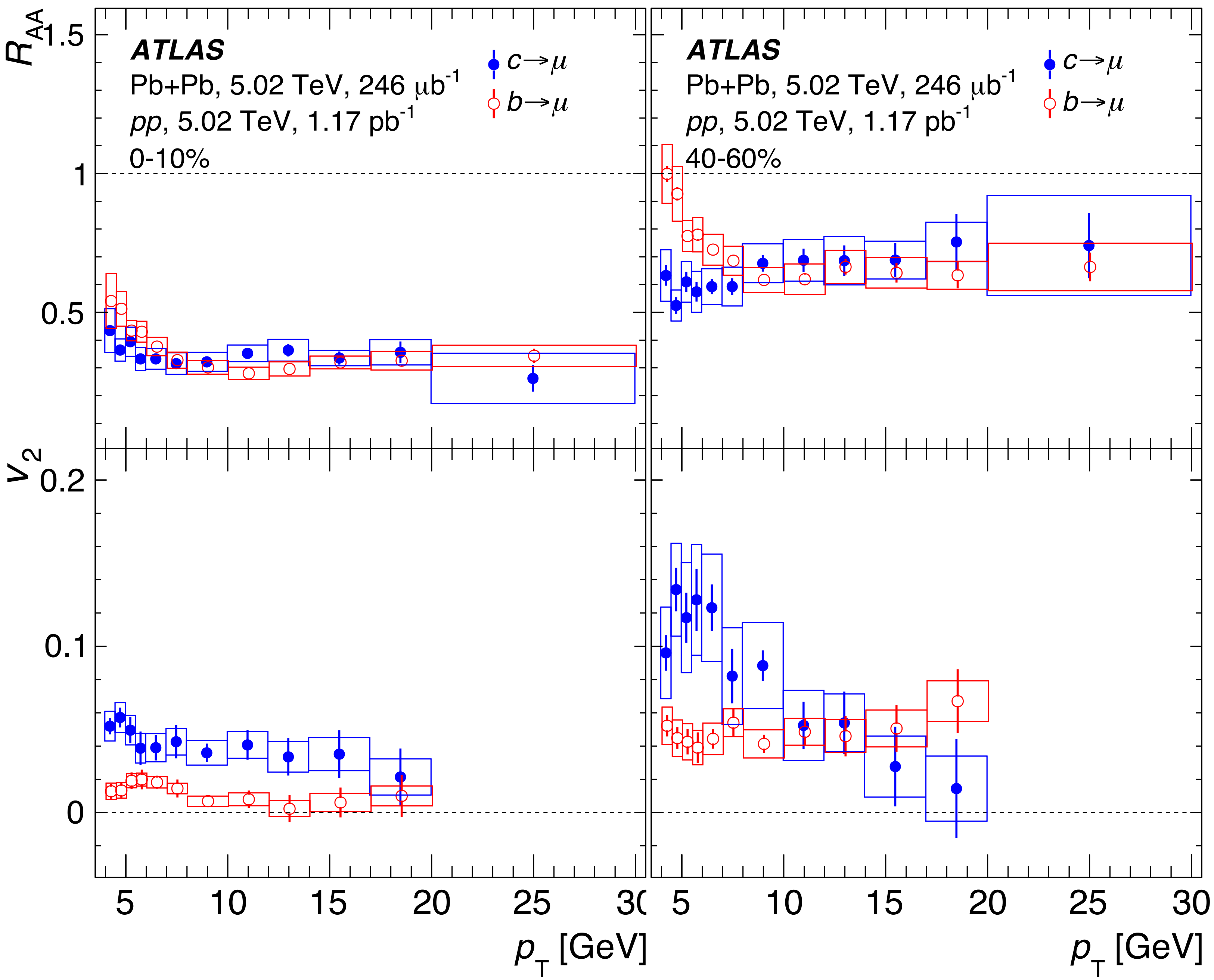


Bottom muon

- L) Charm muon data lies at upper bond of FONLL uncertainty
- R) Bottom muon data agrees with FONLL at high p_T
- Consistent with other HF measurements (e.g. ALICE *D*'s: arXiv:2102.13601)

Charm and bottom muon R_{AA} vs. v_2

arXiv:2109.00411
PLB 807 (2020) 135595



0-10%

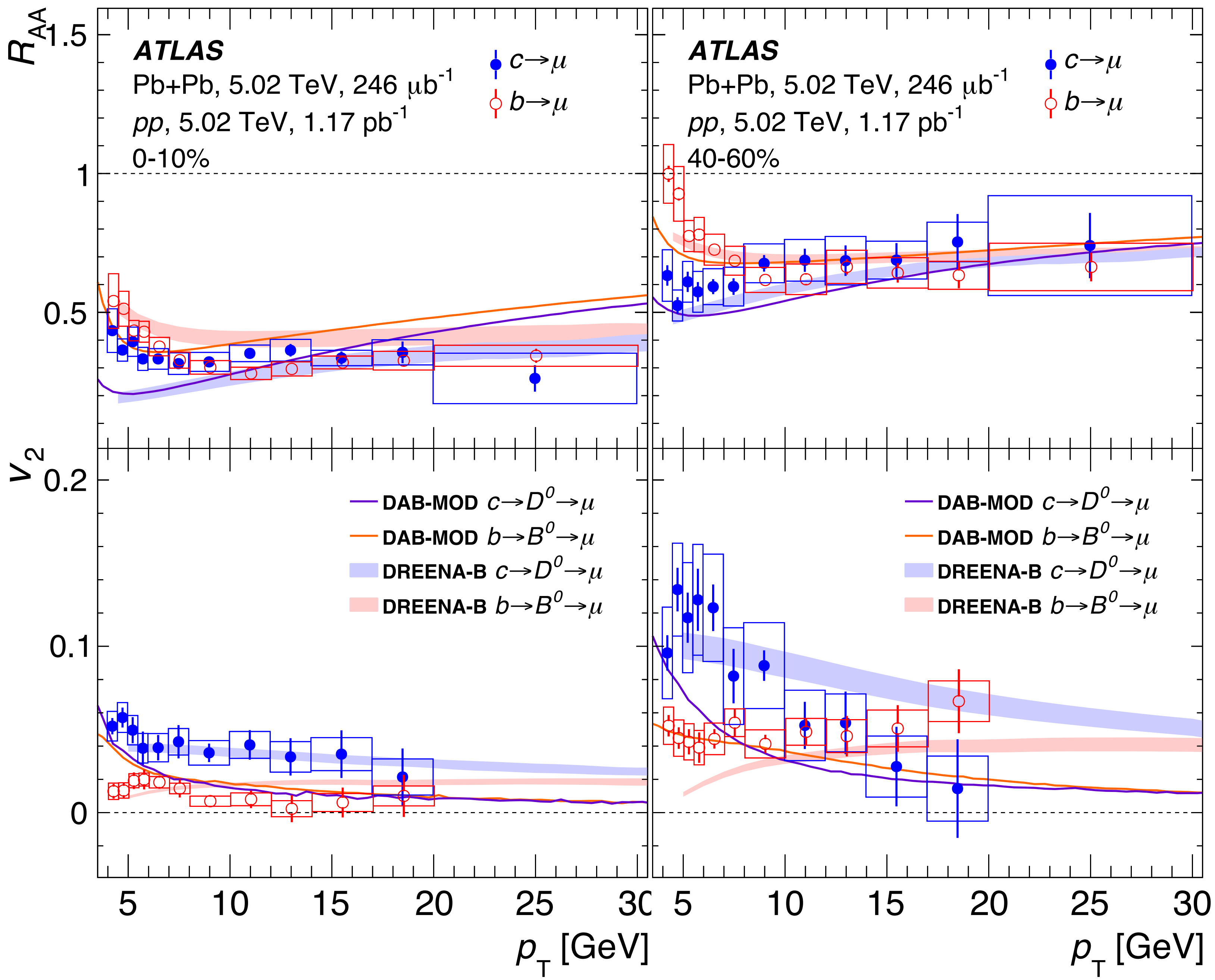
40-60%

- $R_{AA}(c \to \mu) < R_{AA}(b \to \mu)$ at low p_T. Difference becomes insignificant above 10 GeV
- EP method based: $v_2(c \to \mu) > v_2(b \to \mu)$
- Both R_{AA} and v_2 show strong centrality dependence

Other centrality bins can be found at web

Charm and bottom muon R_{AA} vs. v_2

arXiv:2109.00411
[PLB 807 (2020) 135595](PLB 807 (2020) 135595)



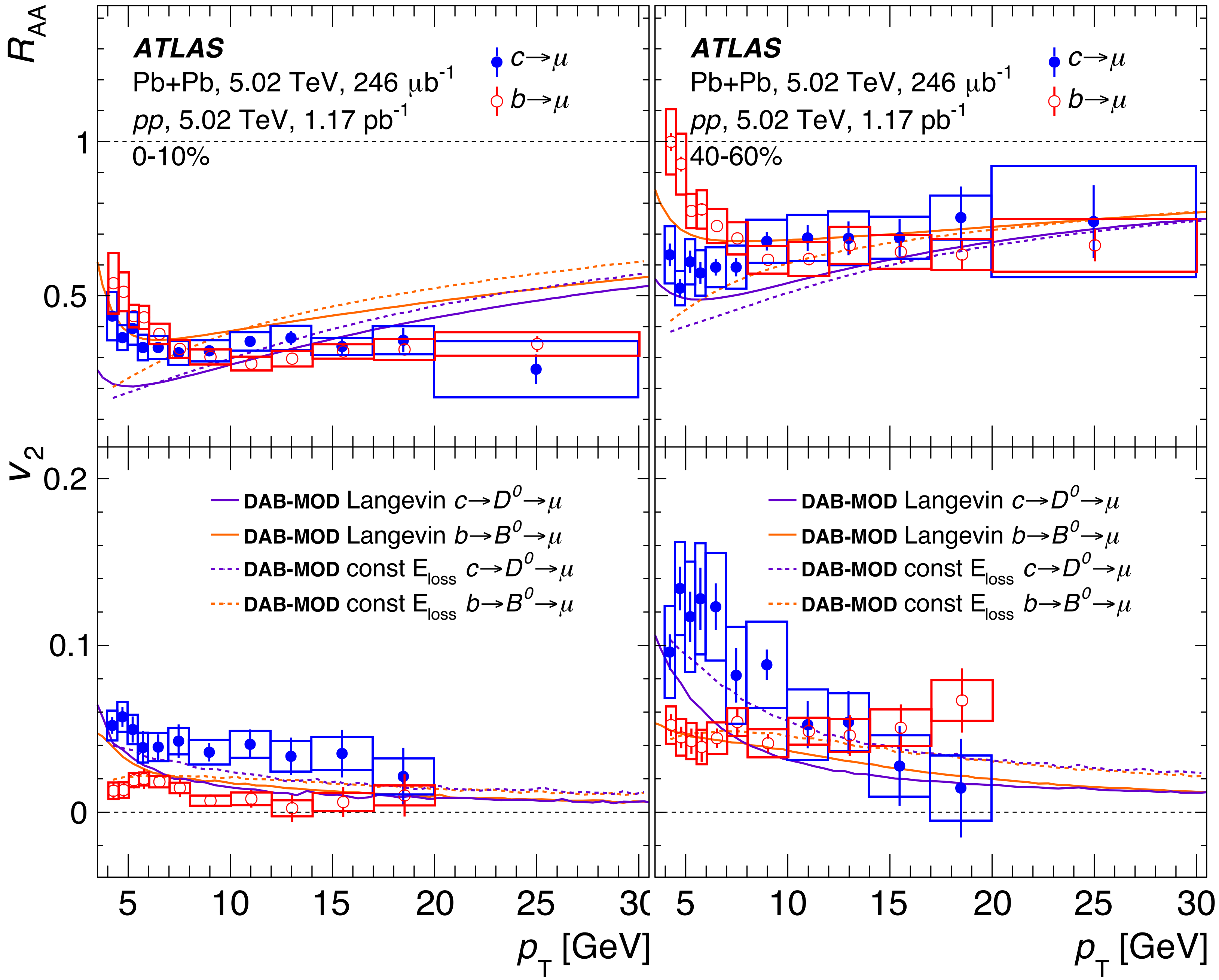
0-10% **40-60%**

- **DAB-MOD** (arXiv:1906.10768): 2+1D medium, Langevin
- **DREENA-B** (arXiv:1805.04786): 1+1D medium, dynamical radiative + collisional E_{loss}
- Both models describe R_{AA}, **DREENA-B** better describes v_2

Other centrality bins can be found at web

R_{AA} vs. v_2 — DAB-MOD comparisons

arXiv:2109.00411
PLB 807 (2020) 135595



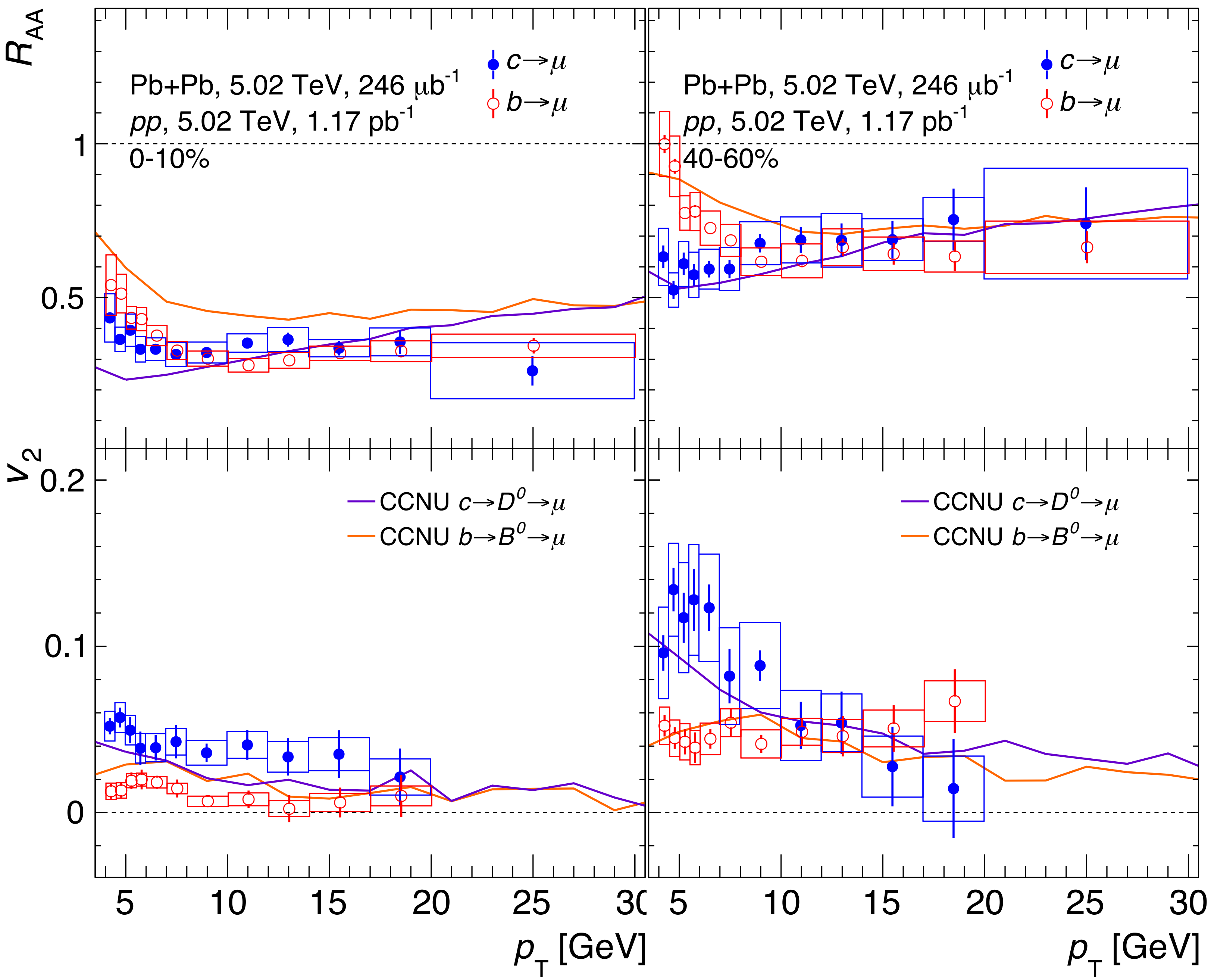
0-10% **40-60%**

- **DAB-MOD** Langevin vs. constant E_{loss} (dashed lines)
- Constant E_{loss} shows a better agreement in v_2 but larger discrepancy with R_{AA} in the measured low p_T region

Other centrality bins can be found at web

Comparison with CCNU model

arXiv:2109.00411
PLB 807 (2020) 135595

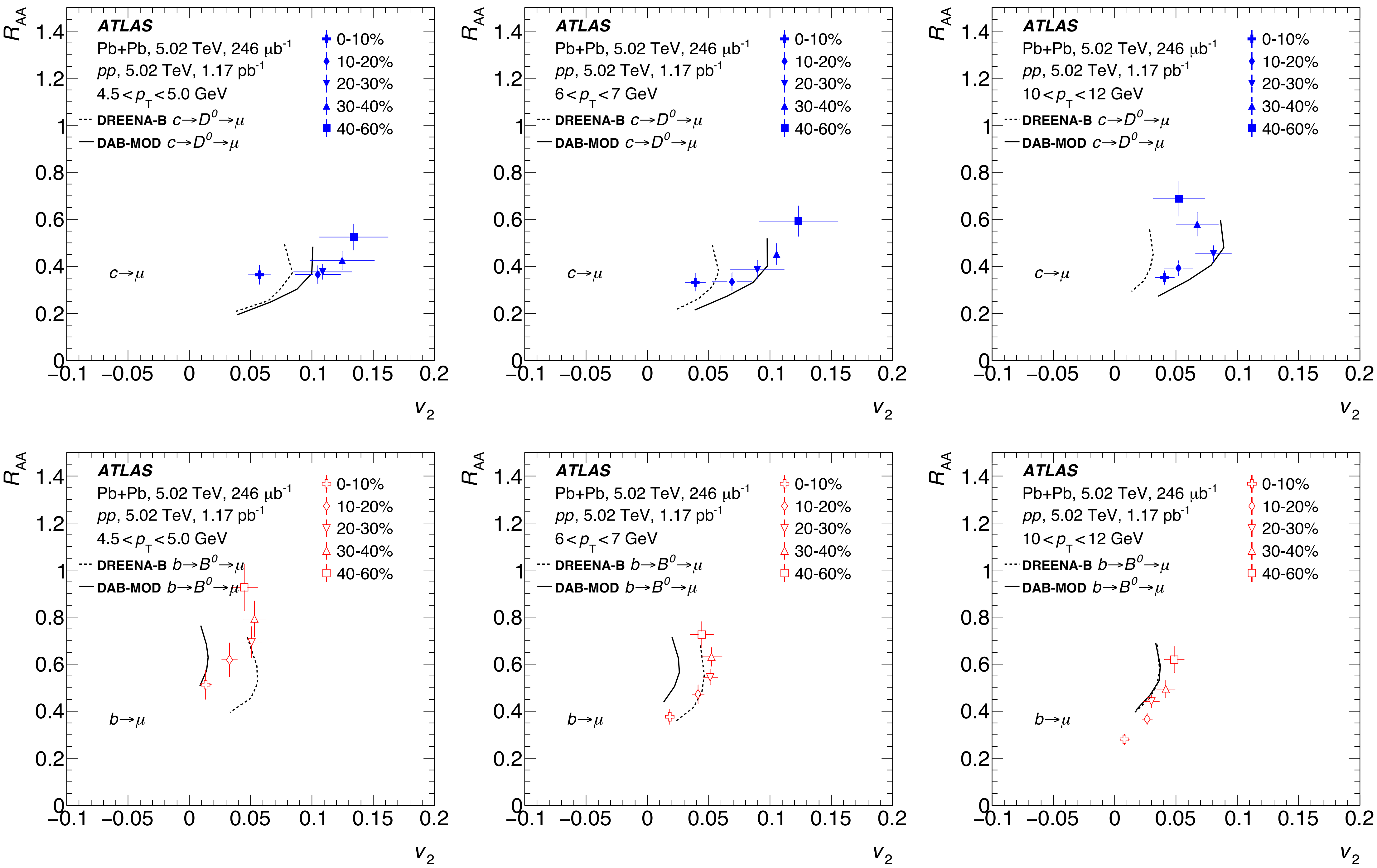


0-10% **40-60%**

- **CCNU model** (2005.03330): Langevin-hydrodynamics framework + hybrid fragmentation-coalescence hadronization
- Modified Langevin with radiative E_{loss}
- Good agreement with data in 40-60%, while overestimate bottom muon R_{AA} and v_2 in 0-10%

R_{AA} vs. v_2 in centralities

arXiv:2109.00411
PLB 807 (2020) 135595



Charm muon

Bottom muon

$4.5 < p_T < 5$ GeV

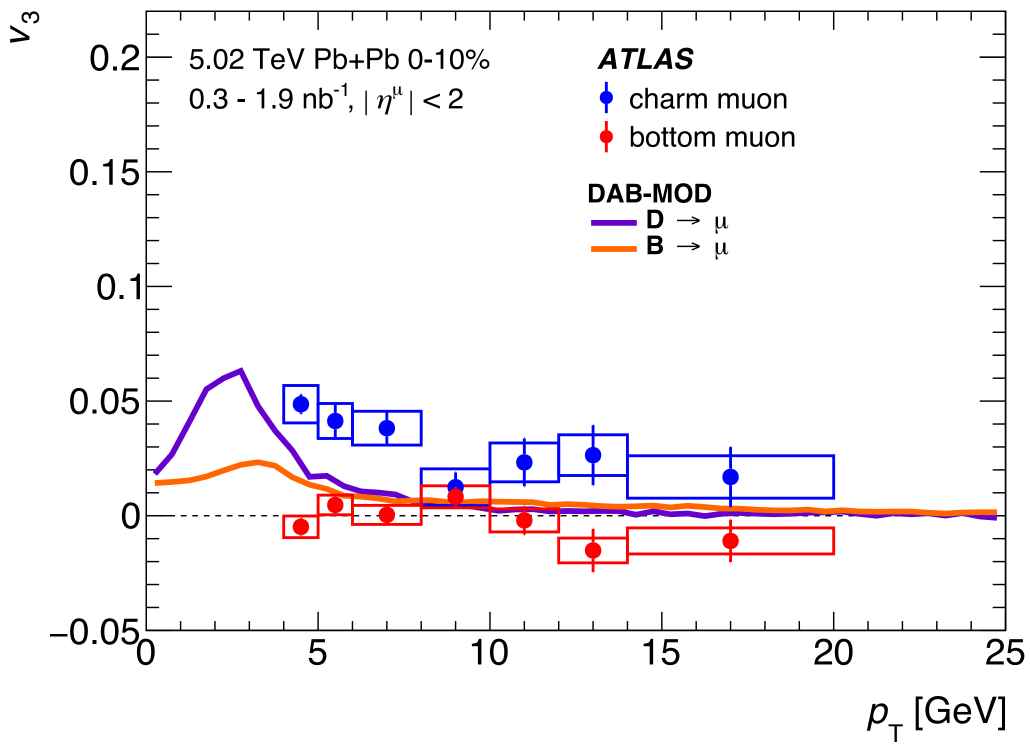
$6 < p_T < 7$ GeV

$10 < p_T < 12$ GeV

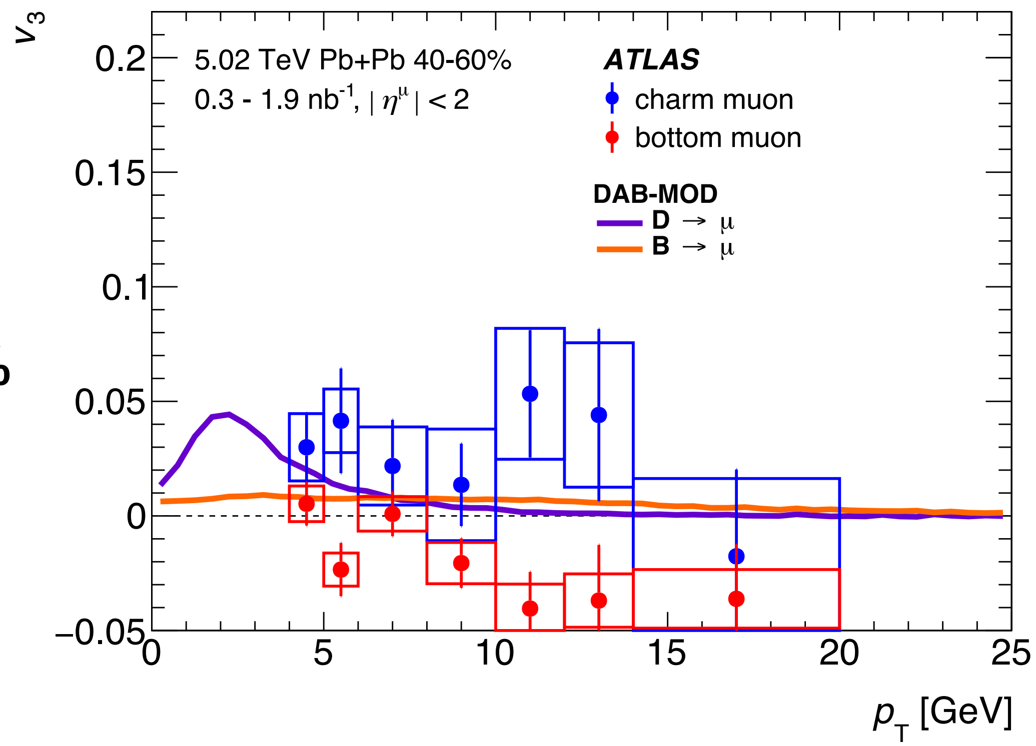
v_3 — DAB-MOD comparisons

PLB 807 (2020) 135595

0-10%



40-60%



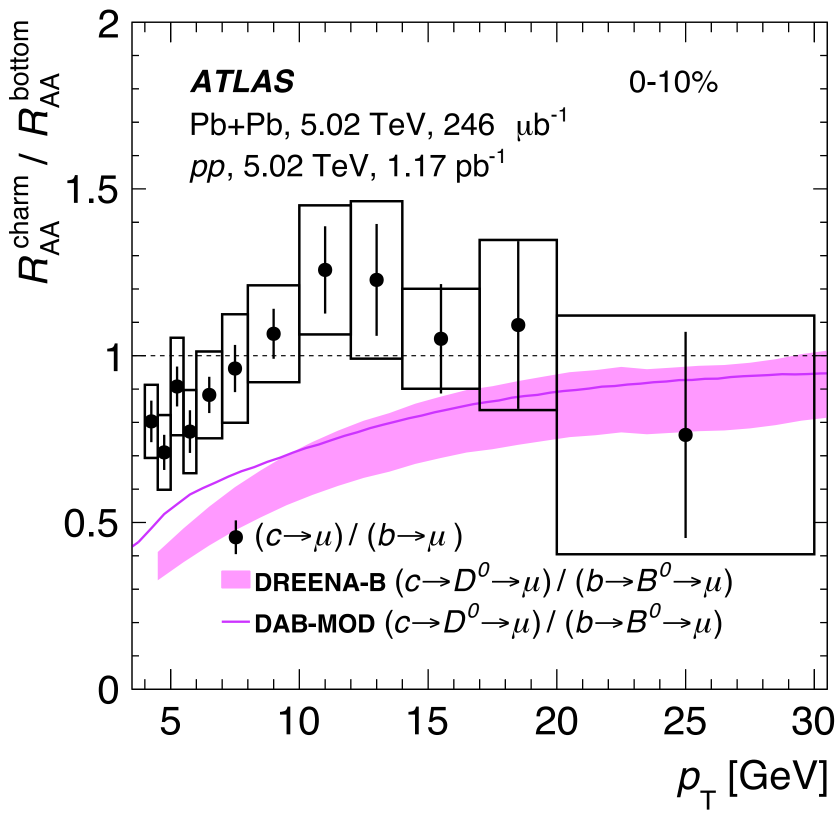
- $v_3(c \to \mu) > 0$
- $v_3(b \to \mu) \sim 0$
- **DAB-MOD Langevin** with fluctuating medium under predicts charm muon v_3 in the measured p_T range in central events

Other centrality bins can be found at web

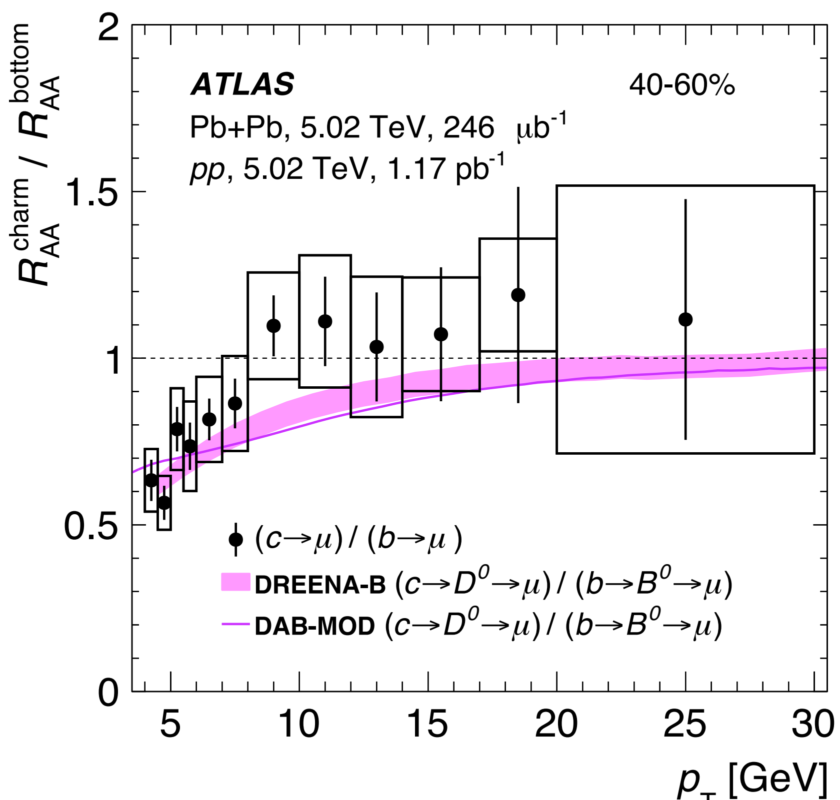
Charm to bottom double ratio

arXiv:2109.00411

0-10%



40-60%

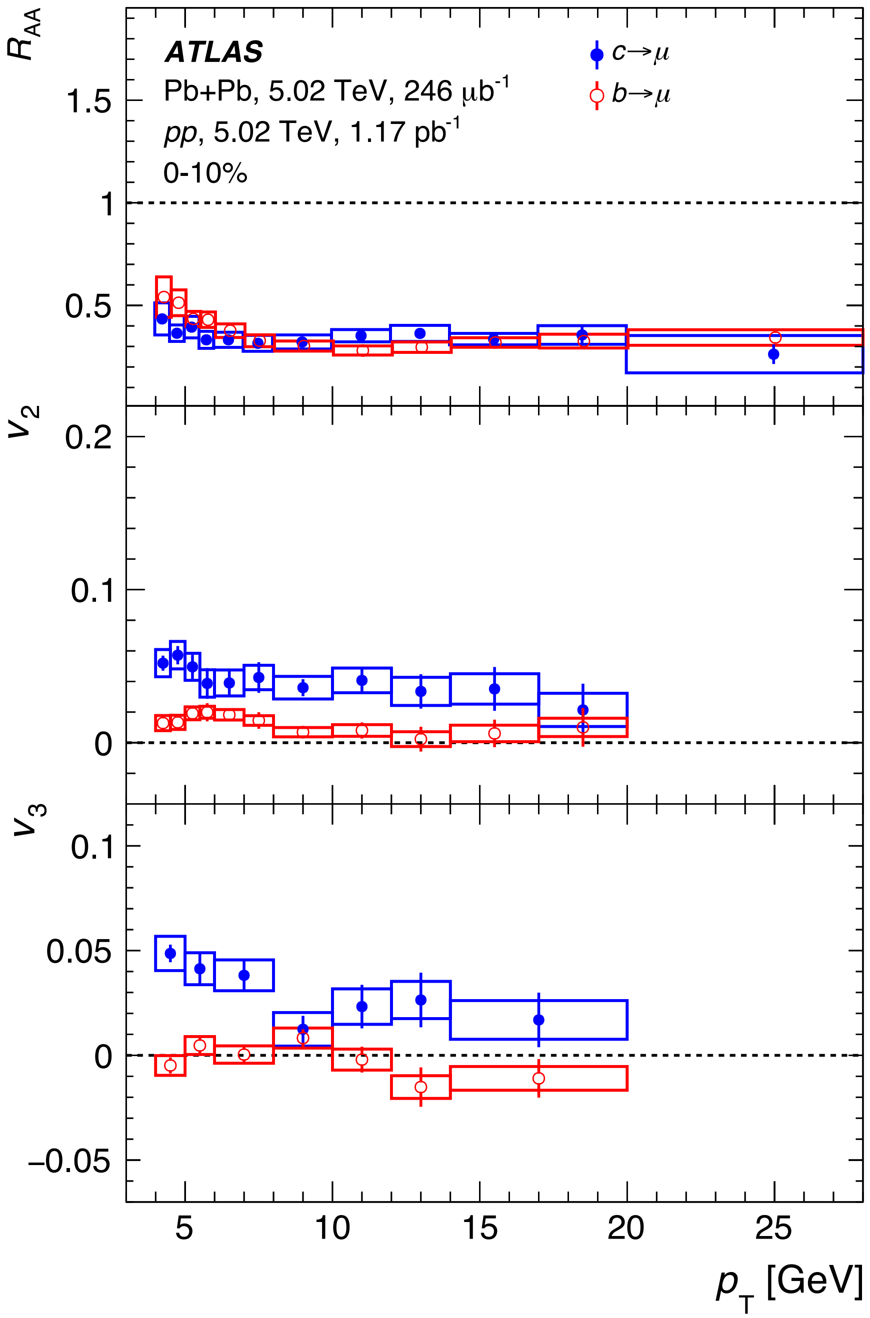


- Large uncertainties on data results due to strong anti-correlation between charm and bottom muon results
- Charm is more suppressed than bottom at low p_T in both 0-10% and 40-60%
- Comparable at high p_T
- **DAB-MOD** and **DREENA-B** predict similar charm-bottom difference, larger model-data discrepancy in 0-10%

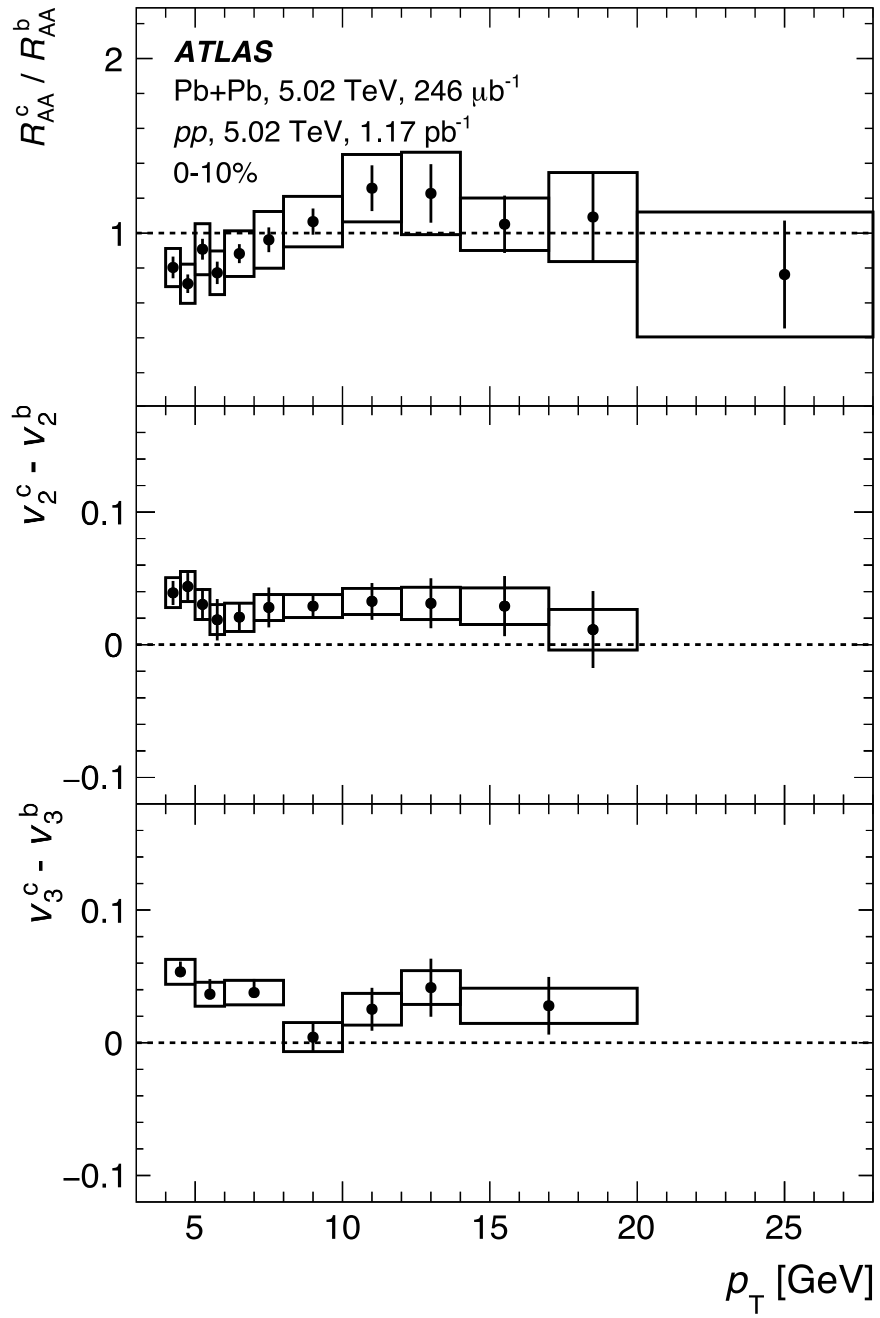
Other centrality bins can be found at web

Charm-bottom difference

arXiv:2109.00411
[PLB 807 (2020) 135595](PLB 807 (2020) 135595)



Charm/bottom muon measurements



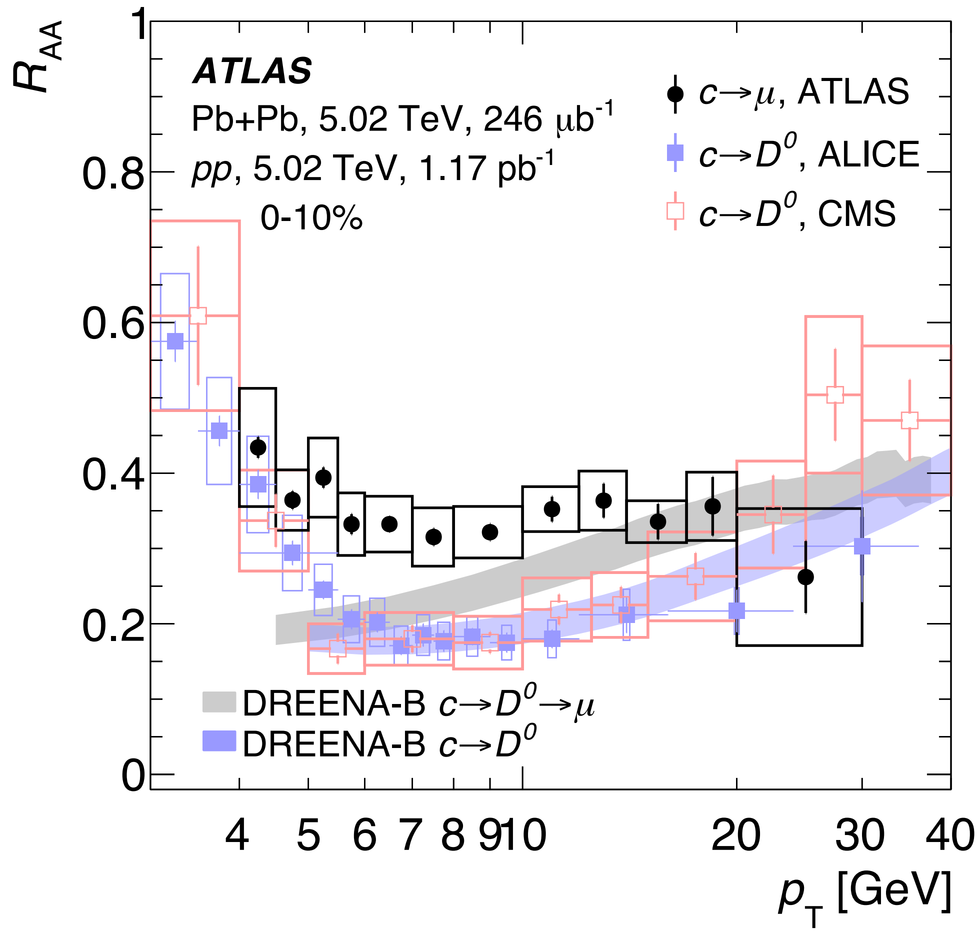
Charm/bottom muon difference

Other centrality bins can be found at web

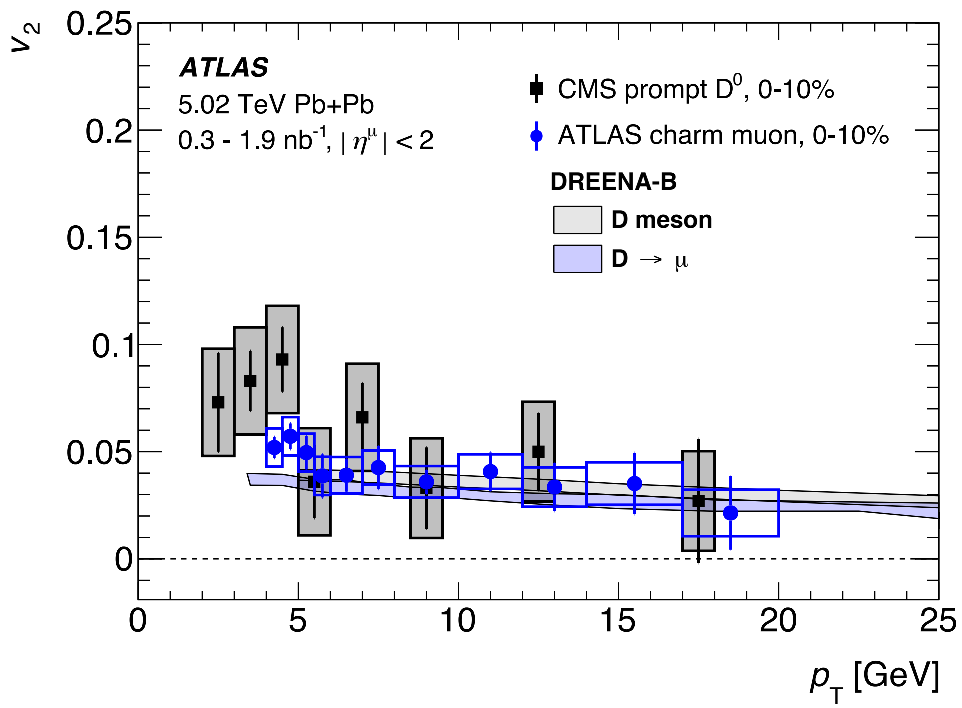
Compare to other experiments

arXiv:2109.00411
[PLB 807 (2020) 135595](PLB 807 (2020) 135595)

R_{AA}



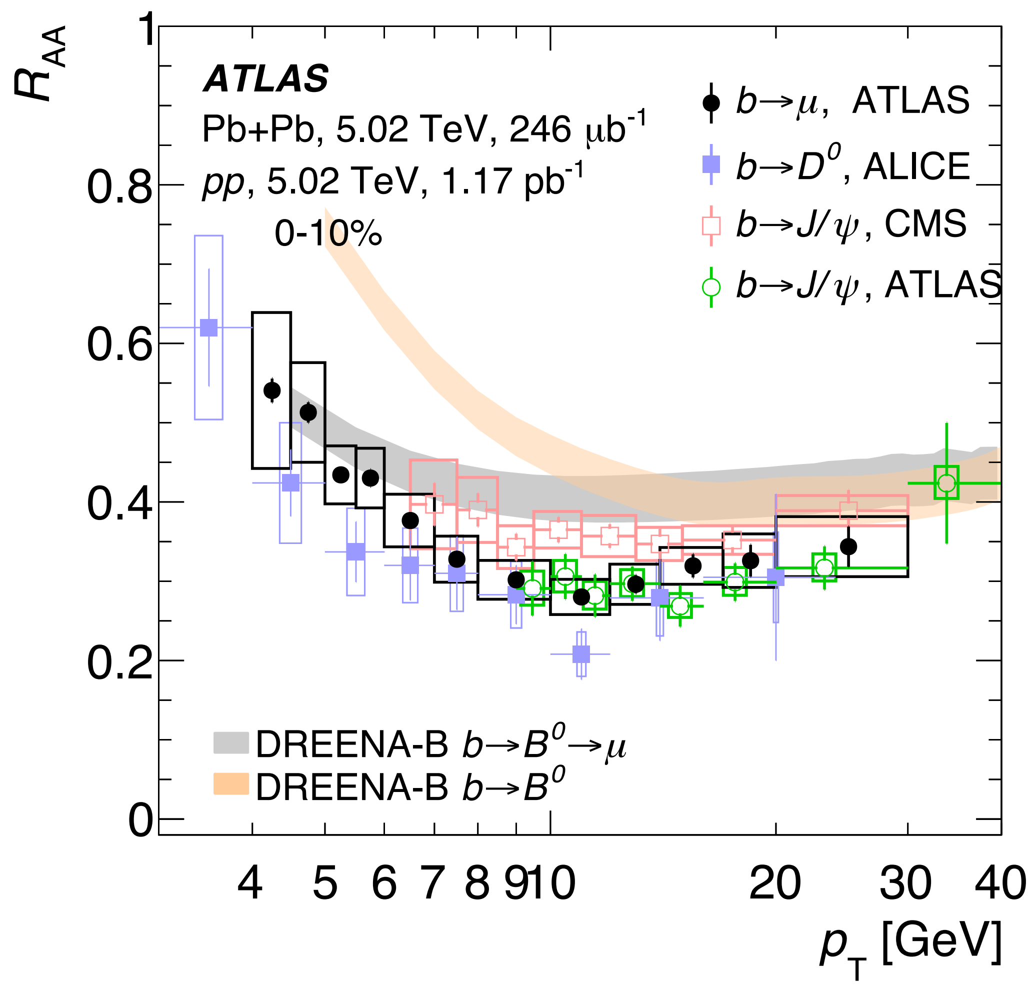
v_2



- Charm muon vs. prompt D^0 in 0-10% in comparison to **DREENA-B** predictions for both
- Difference between charm muon and prompt D^0 R_{AA} (CMS: arXiv:1708.04962, ALICE: arXiv:1804.09083) is larger than DREENA-B predicts
- Small difference between charm muon and prompt D^0 v_2 (CMS: arXiv:1708.03497)

Compare to other experiments

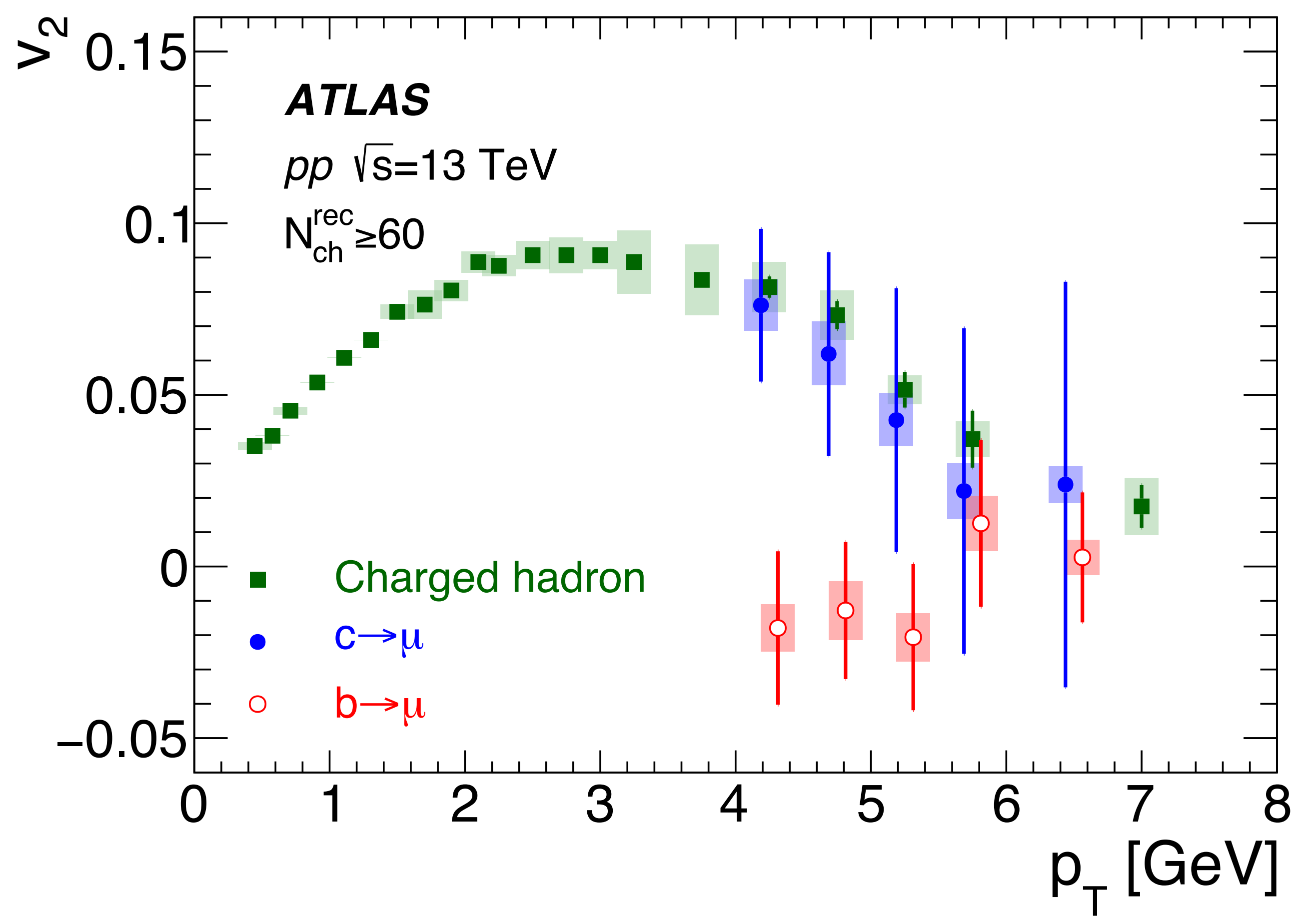
arXiv:2109.00411



- Bottom muon vs. non-prompt D^0 / non-prompt J/ψ (CMS: arXiv:1712.08959, ATLAS: arXiv:1805.04077) in 0-10% in comparison to **DREENA-B** predictions
- All B-decay results are comparable with each other, and significantly smaller than **DREENA-B** prediction

HF muon v_2 in *pp*

PRL 124 (2020) 082301



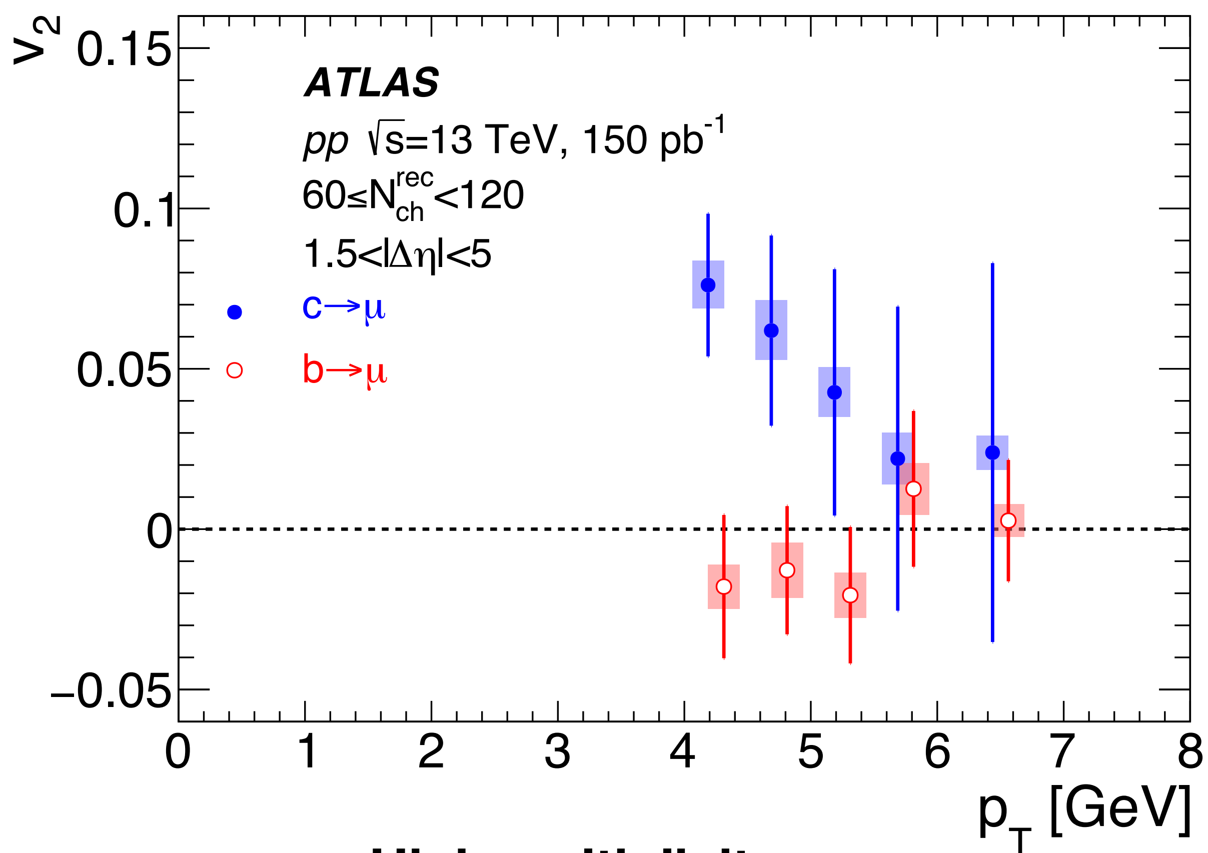
- HF muon v_2 measured in 2017 *pp* collisions at 13 TeV using muon-hadron 2PC with non-flow subtraction

- $v_2(c \to \mu) \sim v_2(\text{light})$

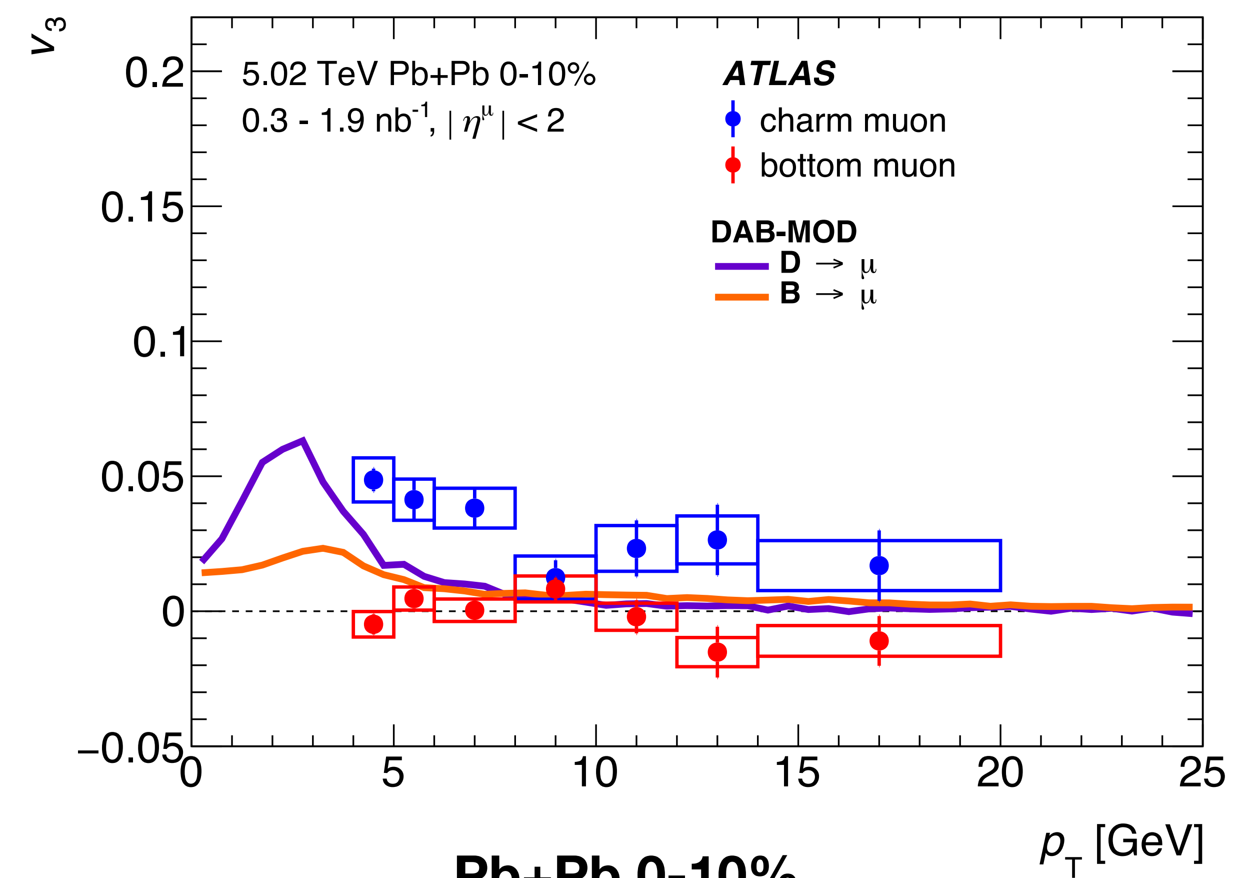
- $v_2(b \to \mu) \sim 0$

HF muon flow in *pp*

PRL 124 (2020) 082301
arXiv:1909.01650



High multiplicity *pp*



Pb+Pb 0-10%

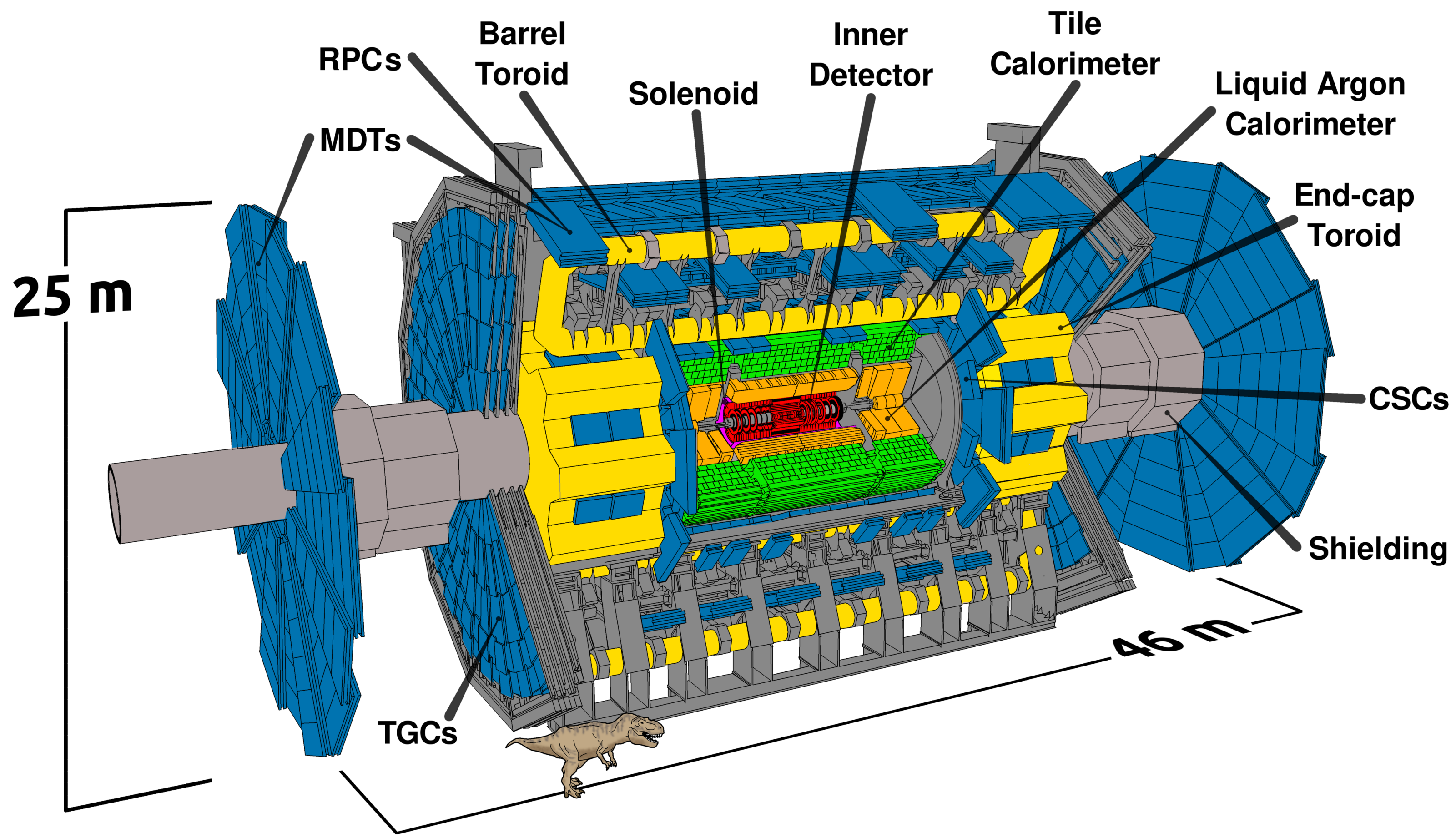
- v_2 in *pp* looks similar to v_3 in Pb+Pb
- Small droplet of QGP in high multiplicity *pp* collisions?
- Different interpretation for *pp* and Pb+Pb?
- Why so different for charm and bottom in *pp*?

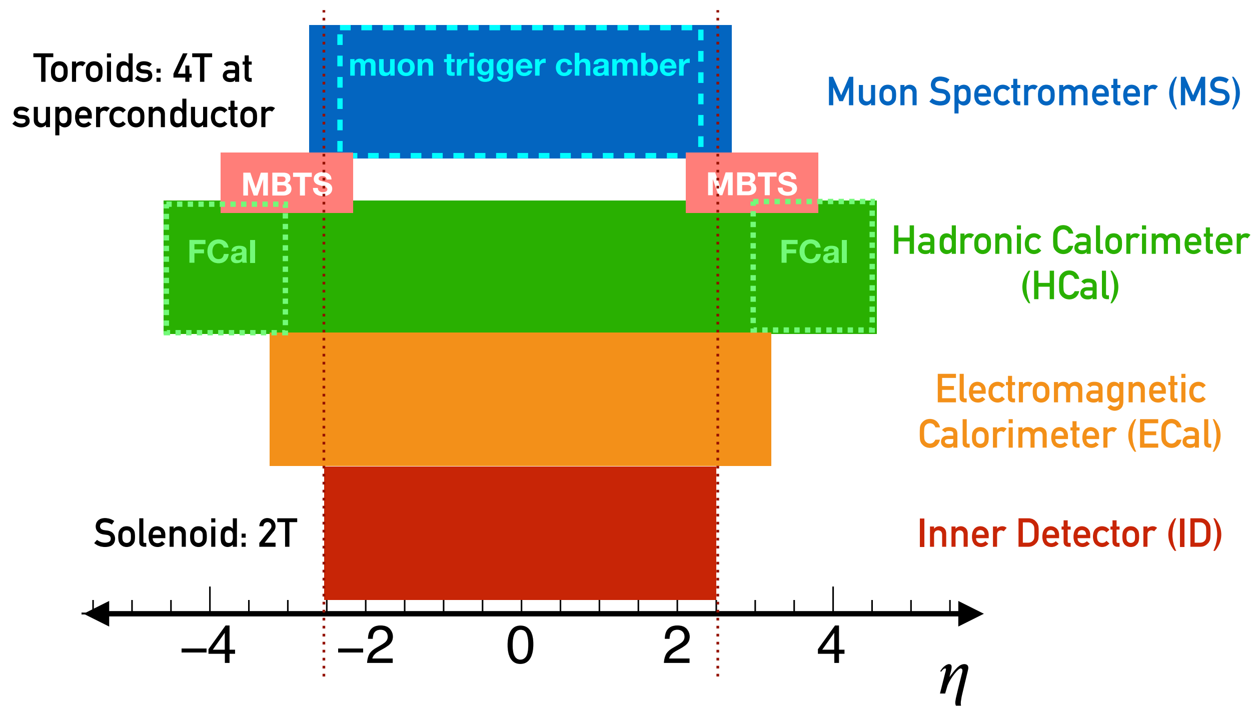
Summary

- Decay muon serves as a powerful HF probe in HIC
- Detailed differential ATLAS results are available
- Don't hesitate to send us your calculations. We could do hadron to muon decay, and make figures for you
- What's next? Use HF muon as tool for other HF studies; a closer look at *p*+Pb collisions before new data collected

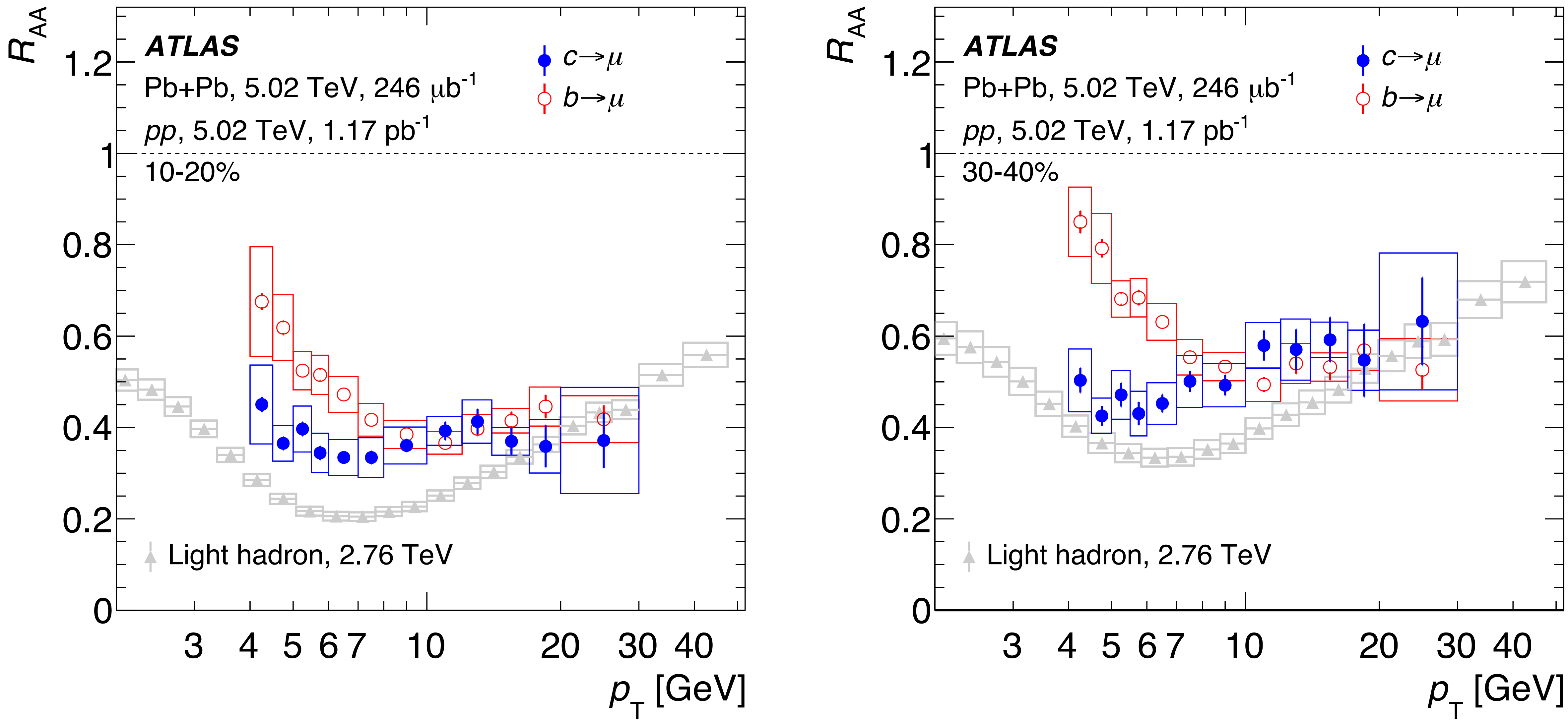
Backup Slides

ATLAS detector





Compare to light hadrons



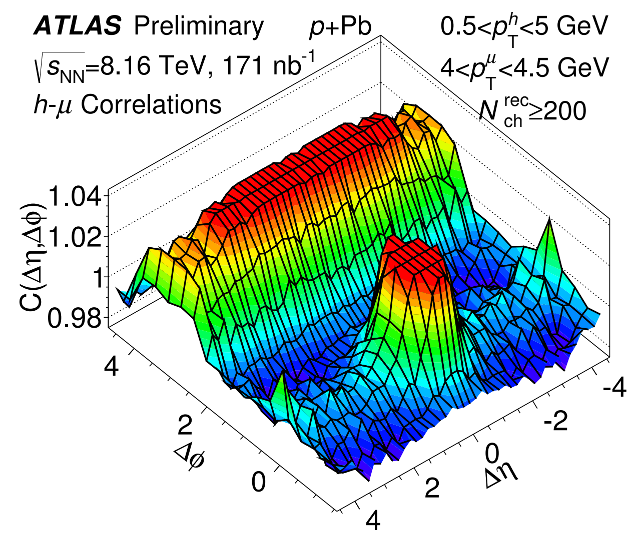
HF muon flow in small systems

In small systems (*pp* and *p*+Pb):

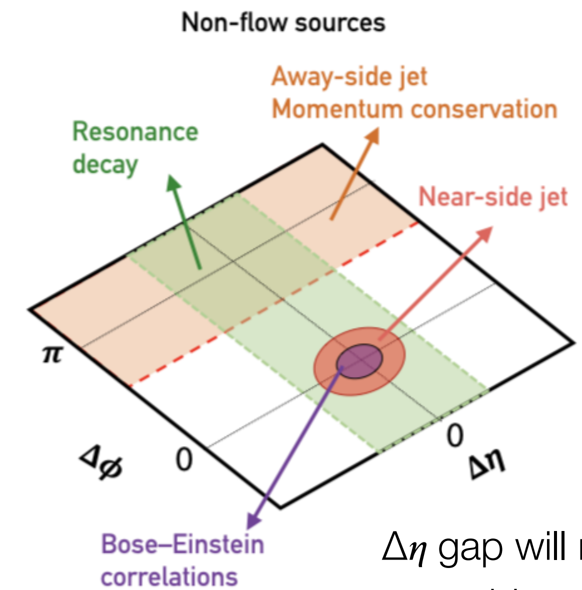
2PC + $\Delta\eta$ gap + non-flow subtraction

$$C(\Delta\phi) = FC^{\text{periph}}(\Delta\phi) + G\left\{1 + 2\sum v_{n,n}\cos(n\Delta\phi)\right\}$$

$v_{n,n}$ factories and v_n is extracted.



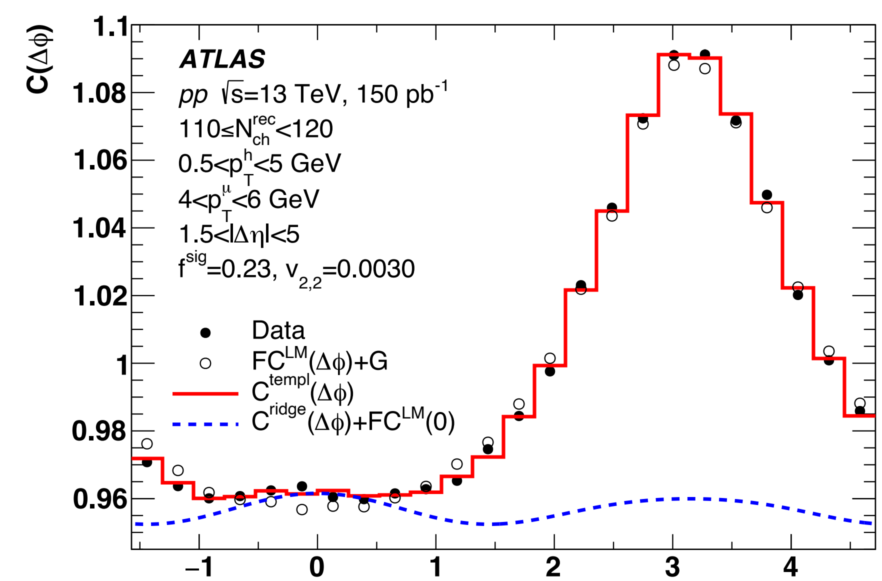
ATLAS-CONF-2017-006



$\Delta\eta$ gap will remove near-side non-flow

Assumptions of non-flow subtraction:

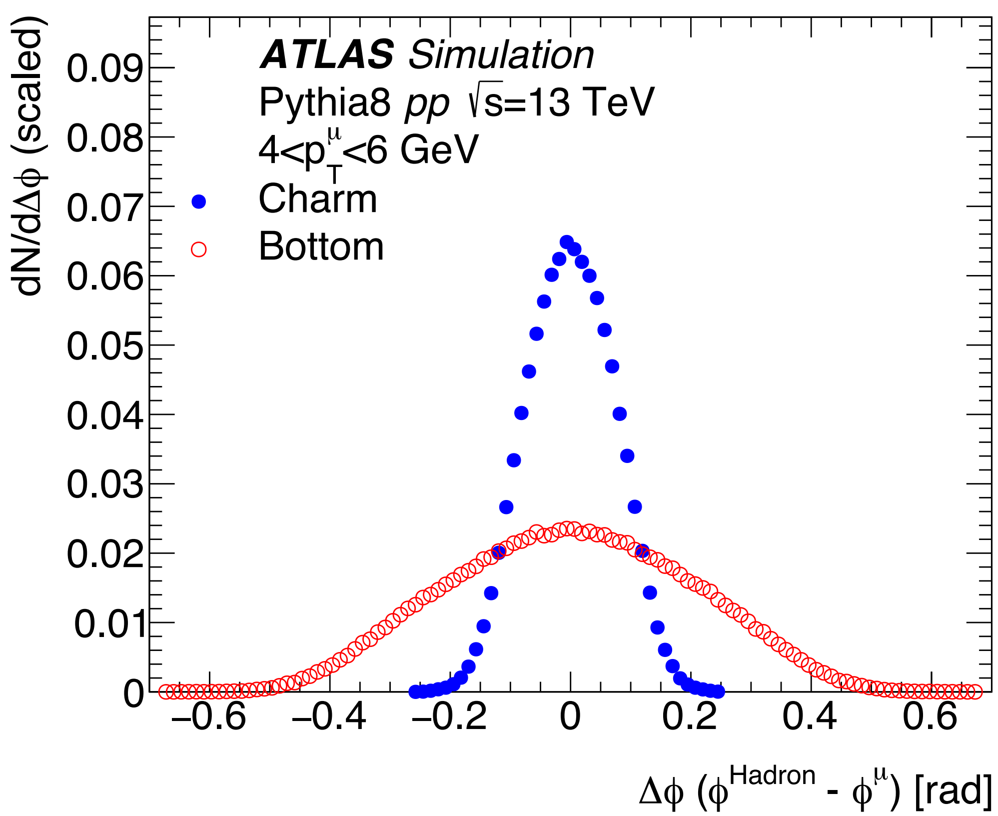
- Universal jet-correlation shape
- Non-zero flow for low multiplicity (difference wrt. CMS)



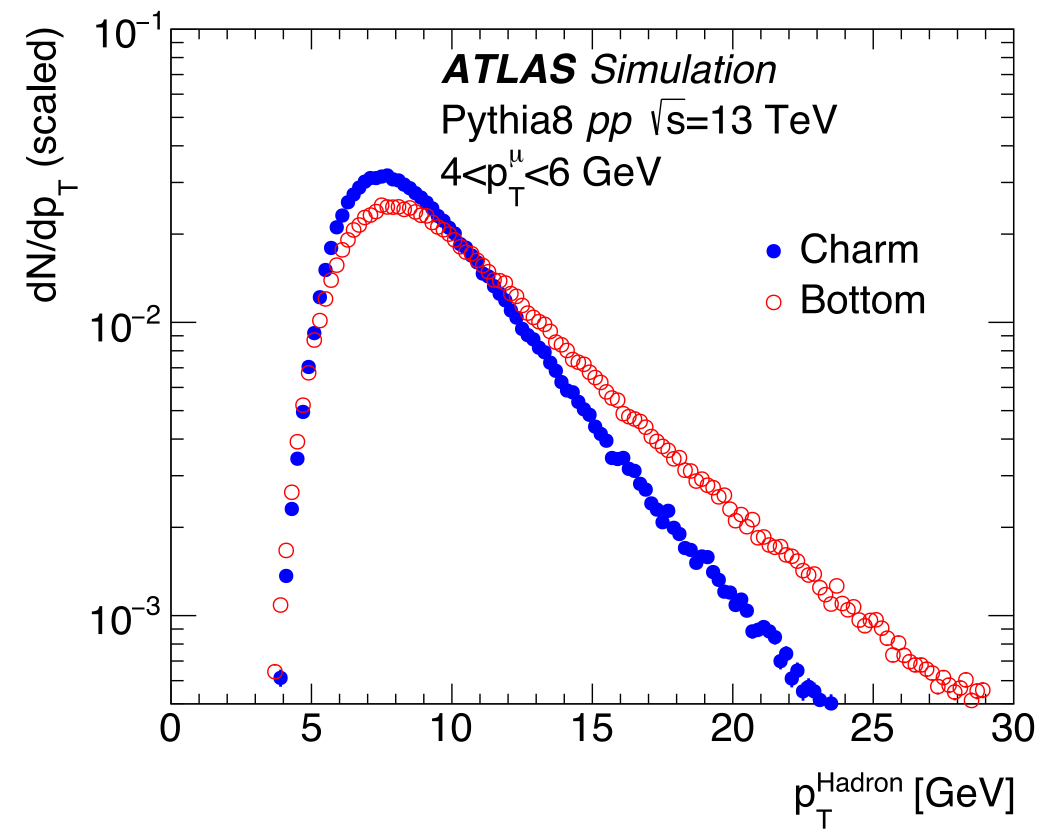
https://arxiv.org/abs/1909.01650

v_n is called “flow” coefficient in this talk just for simplicity.
Hydrodynamic flow is not the only explanation of the results

Hadron to muon smearing in Pythia



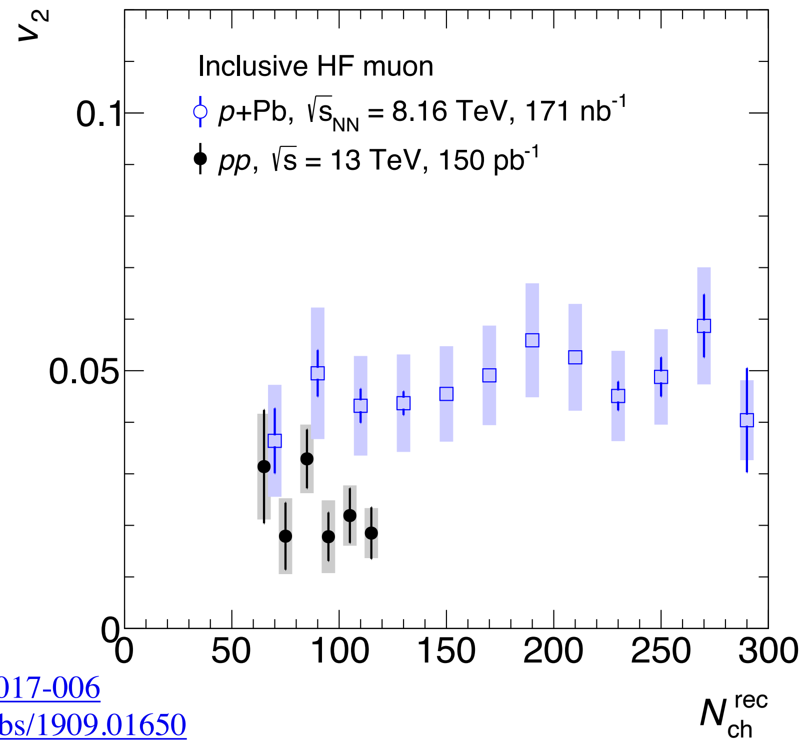
azimuthal angle smearing



p_T shift and smearing

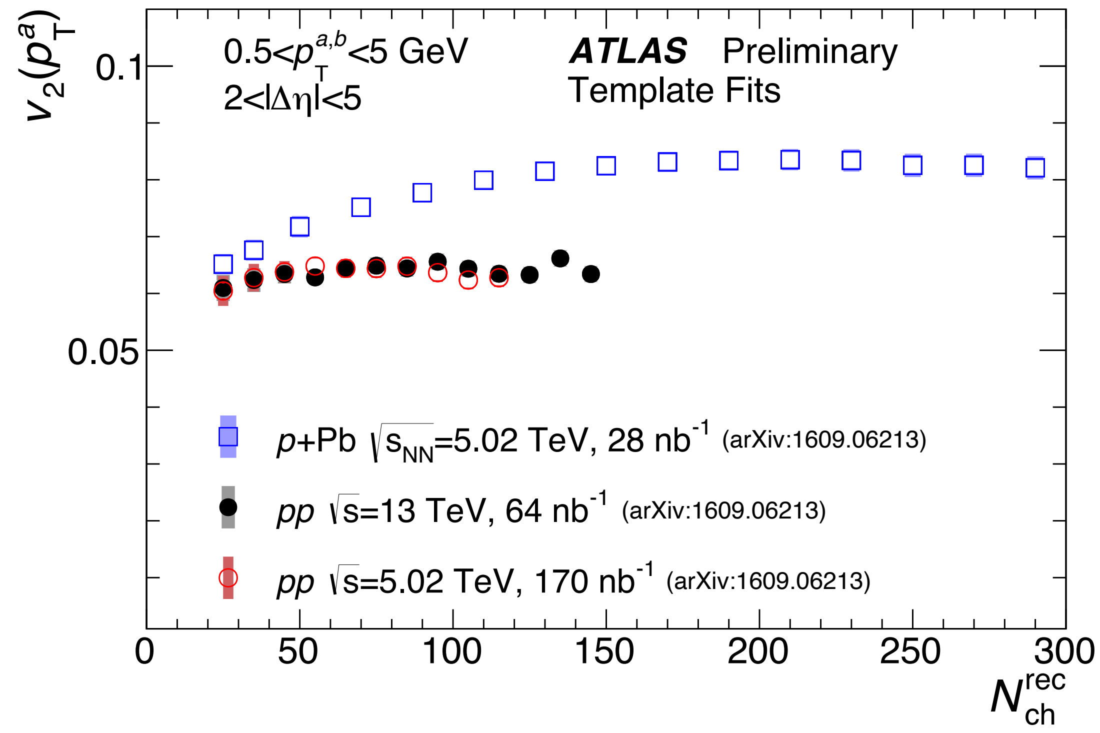
pp vs. *p*+Pb

HF muon



ATLAS-CONF-2017-006
https://arxiv.org/abs/1909.01650

Inclusive charged particle



- Smaller v_2 for muons than charged hadron in *pp* and *p*+Pb
- Similar difference between *pp* and *p*+Pb