Recent heavy-flavor measurements with the ATLAS detector

EPS-HEP Conference 2021
European Physical Society conference on high energy physics 2021
Online conference, July 26-30, 2021

James Nagle, University of Colorado Boulder
For the ATLAS Collaboration

Wealth of ATLAS results on **open heavy flavor***
In these 12 minutes, focus on three recent measurements

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS EXPERIMENT

Phys. Lett. B 807 (2020) 135595
DOI: 10.1016/j.physletb.2020.135595
CERN-EP-2019-274
24th July 2020

Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the ATLAS detector

ATLAS EXPERIMENT

ATLAS CONF Note

ATLAS-CONF-2021-020
14th May 2021

Measurement of nuclear modification factor for muons from charm and bottom hadrons in Pb+Pb collisions at 5.02 TeV with the ATLAS detector

The ATLAS Collaboration

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS EXPERIMENT

Phys. Rev. Lett. 124 (2020) 082301
DOI: 10.1103/PhysRevLett.124.082301
CERN-EP-2019-166
March 9, 2020

Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in *pp* collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

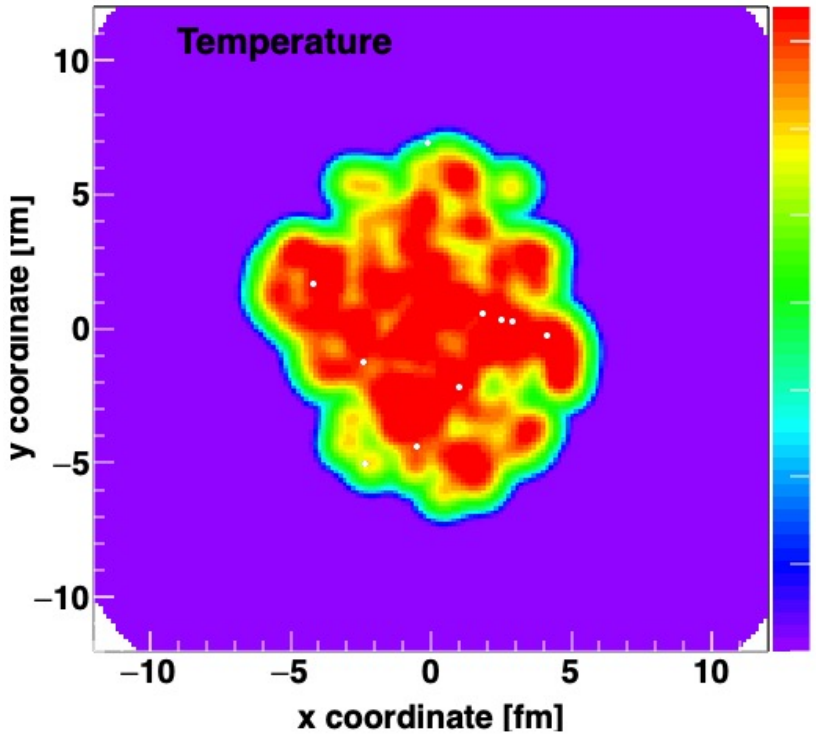
* https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults
HF muon+hadron correlations in 13 TeV pp, Phys.Rev.Lett. 124 (2020) 8, 082301
HF muon flow in 5 TeV PbPb, Phys. Lett. B 807 (2020), 135595
HF muon nuclear modification in 5 TeV PbPb, CONF Note
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2021-020/

Key features of heavy-ion collisions

Hydrodynamic described "collectivity" of the bulk (p_T < 5-6 GeV)

Jet quenching suppresses particles at high p_T > 5-6 GeV

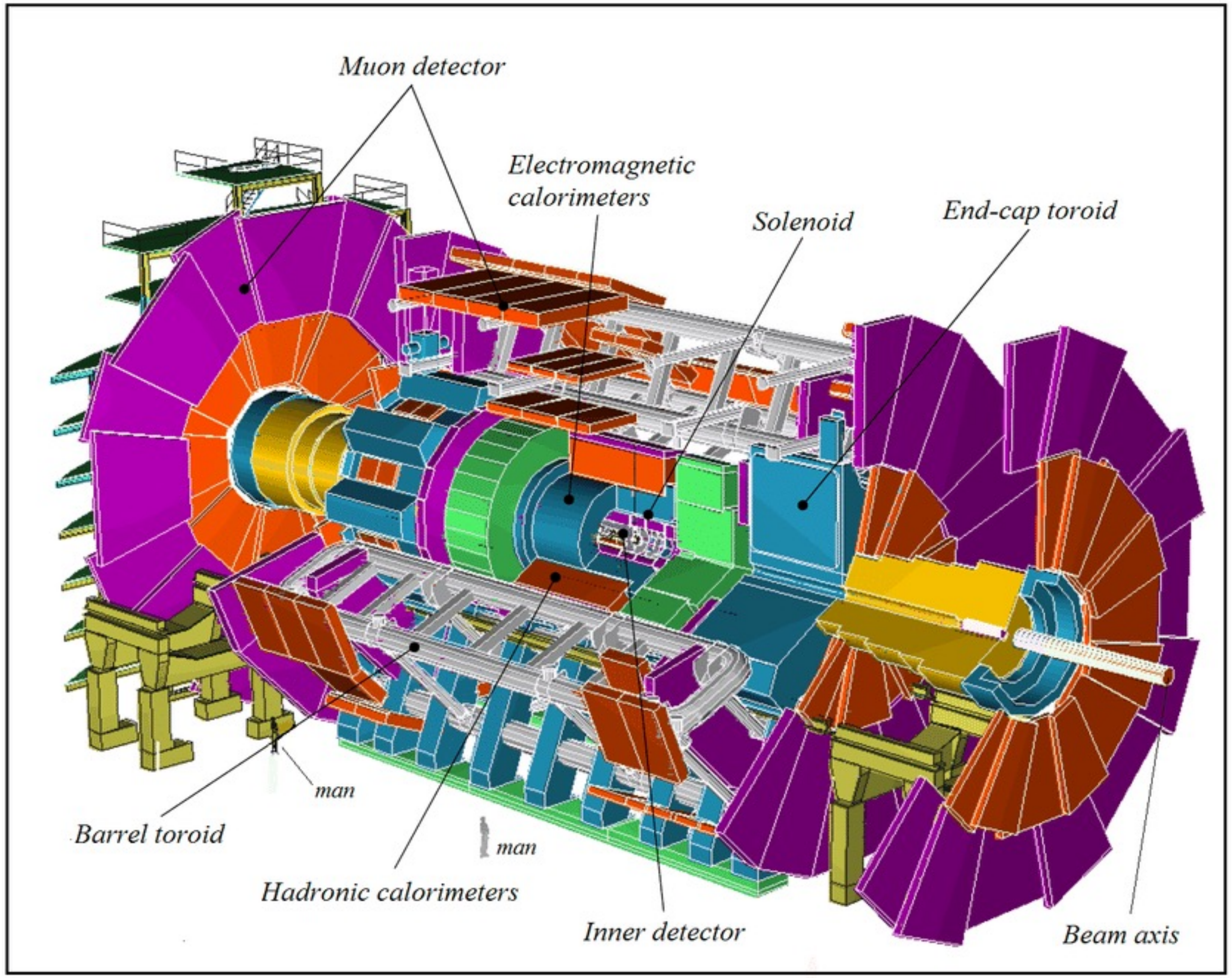
A. Adare et al., Phys.Rev.C 90 (2014) 2, 024911



Langevin Drag & Diffusion Modeling

- Heavy quarks "flow" with the bulk
- Suppression in high p_T heavy quarks

ATLAS Detector at the LHC



Data Sets

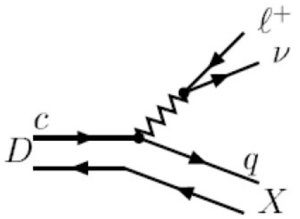
pp 5.02 TeV (2017)

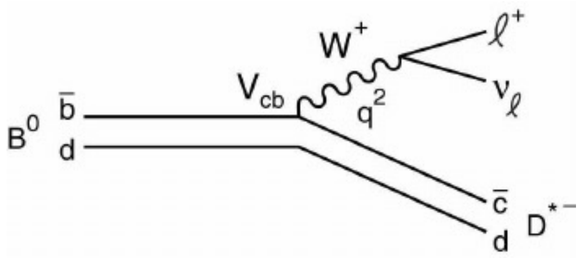
pp 13 TeV (2017)

PbPb 5.02 TeV (2015 & 2018)

Open heavy flavor measurements via decay muons

Muons from open charm and bottom

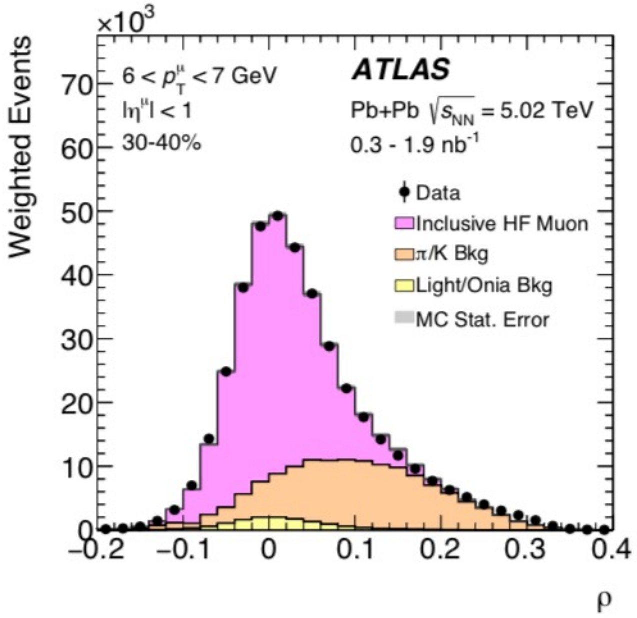


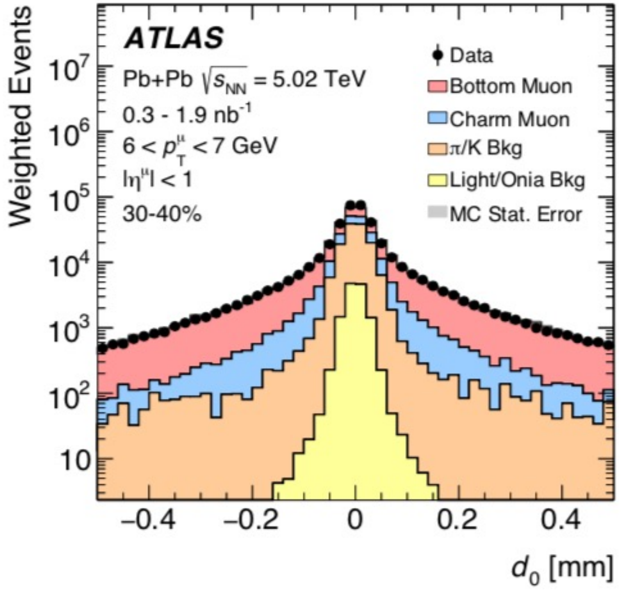


Are separated from light flavor decay muons and from each other via:

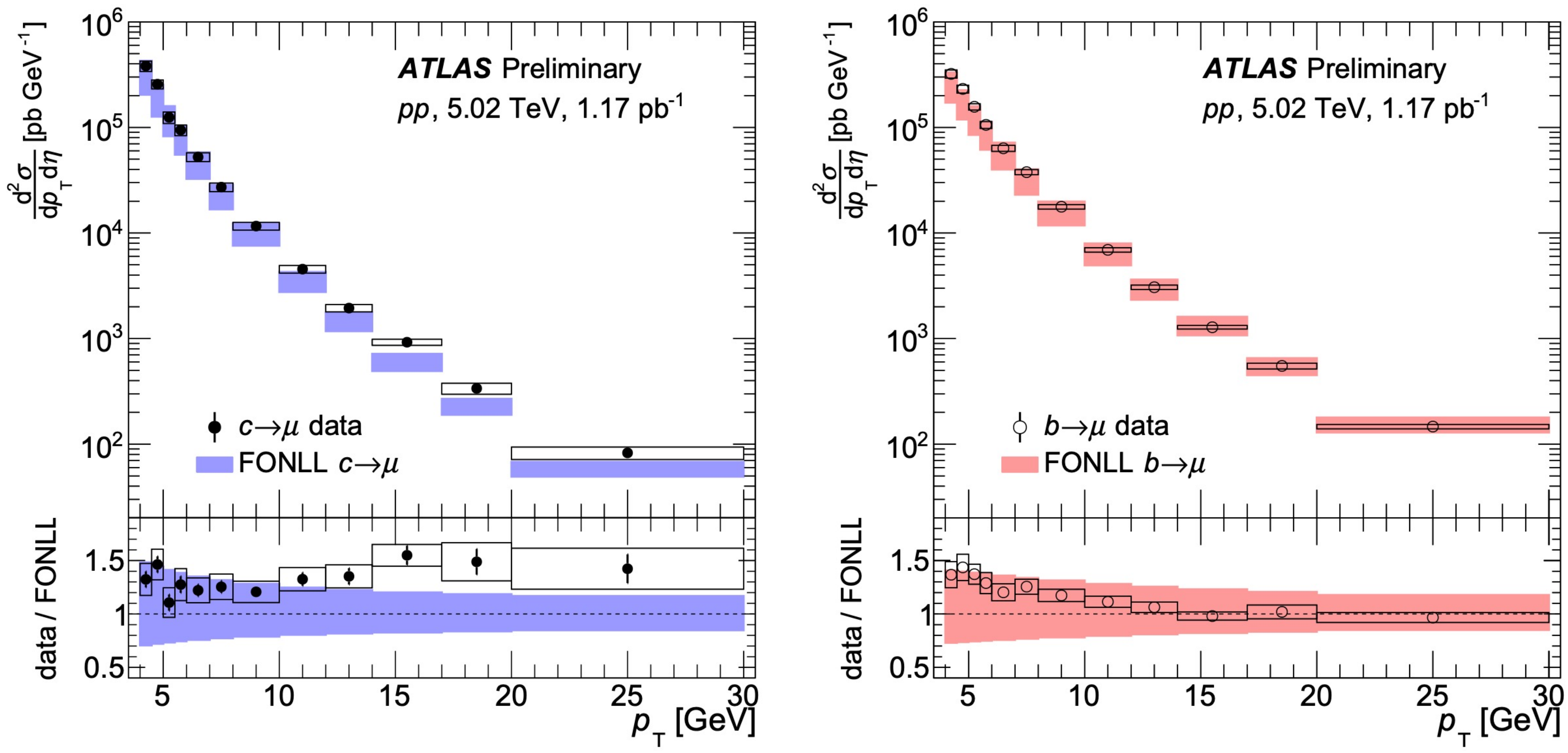
a) Momentum imbalance between the measurements in the inner tracking detector and the muon spectrometer

b) Distance of Closest Approach distribution and template fitting

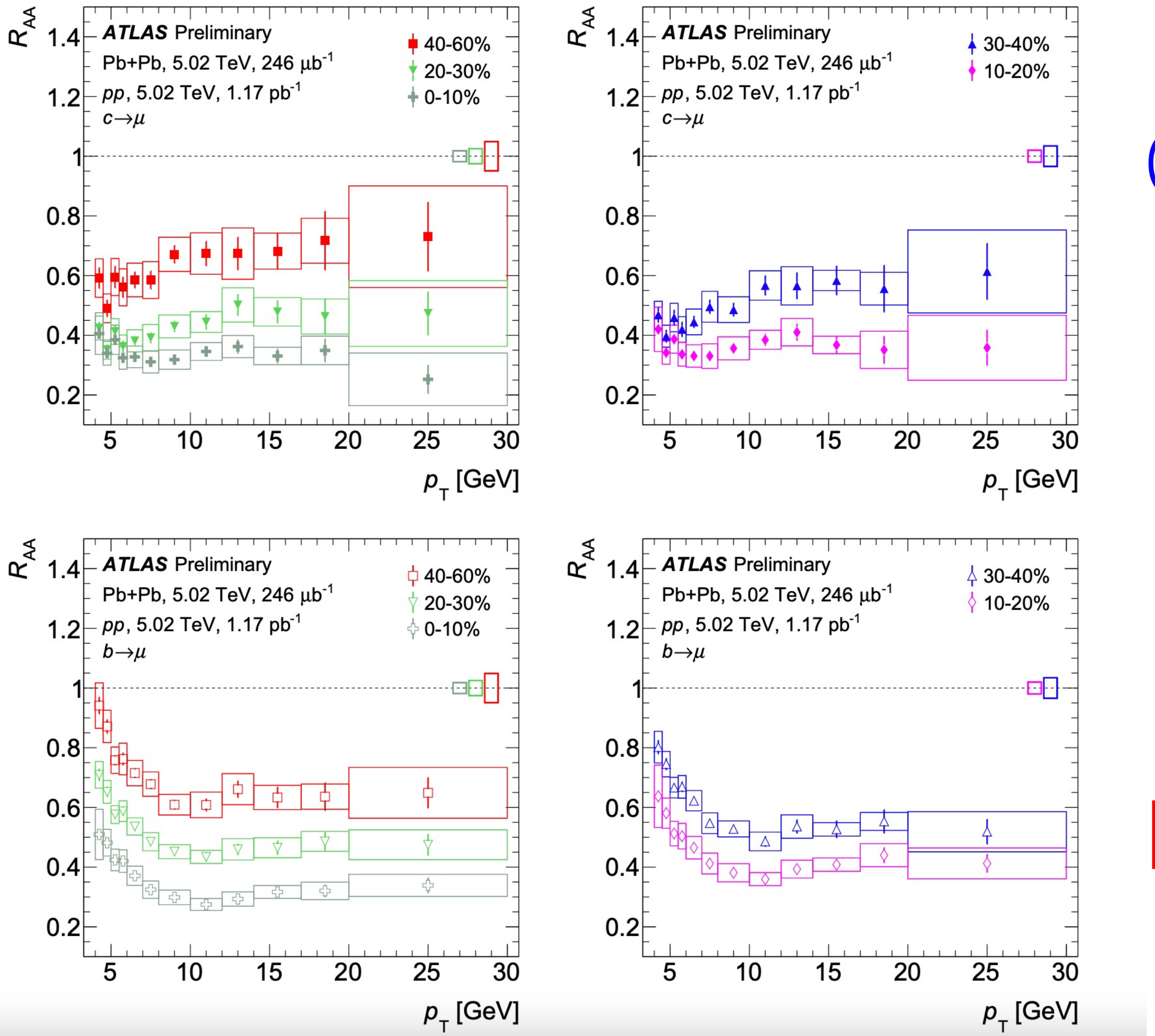




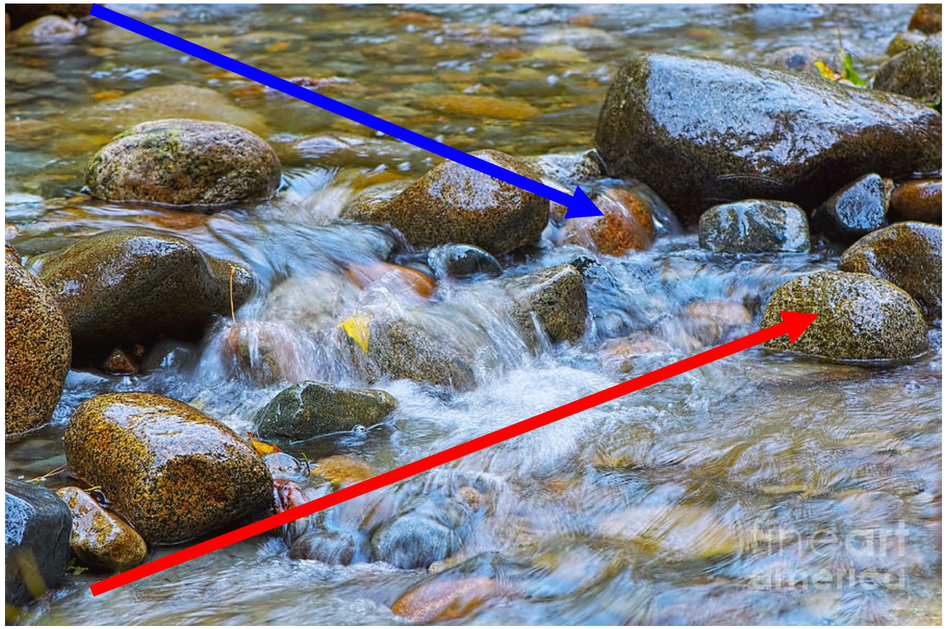
Proton-Proton Spectra and FONLL Comparison



Nuclear Modification Factors



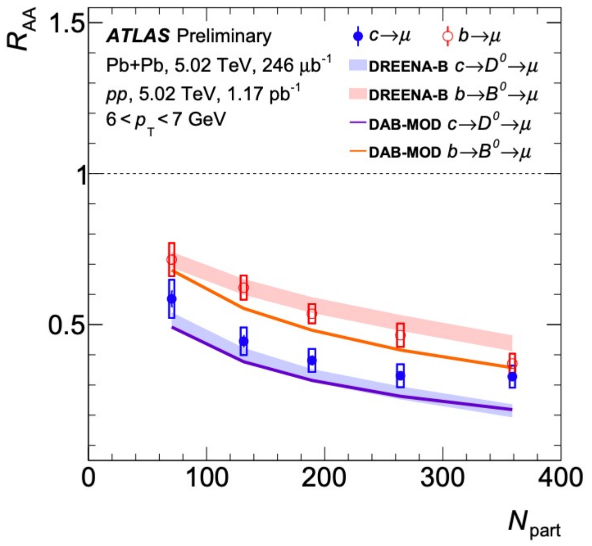
Charm



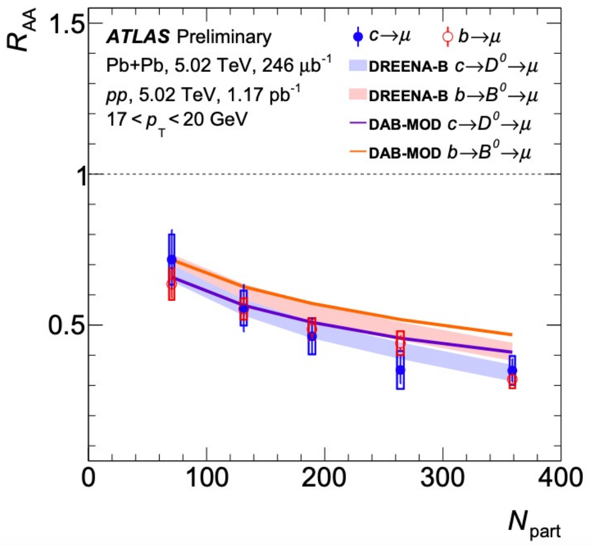
Bottom

Nuclear Modification Factors

Muon p_T = 6-7 GeV

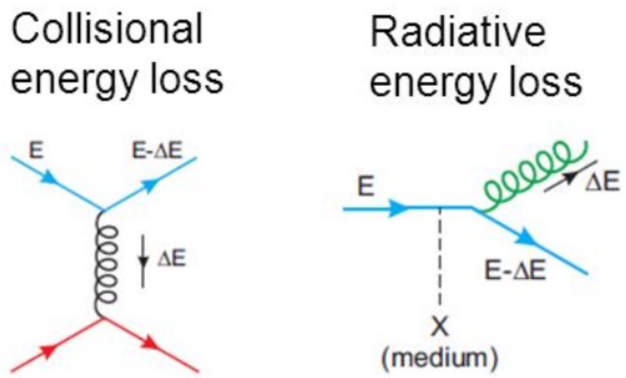


Muon p_T = 17-20 GeV

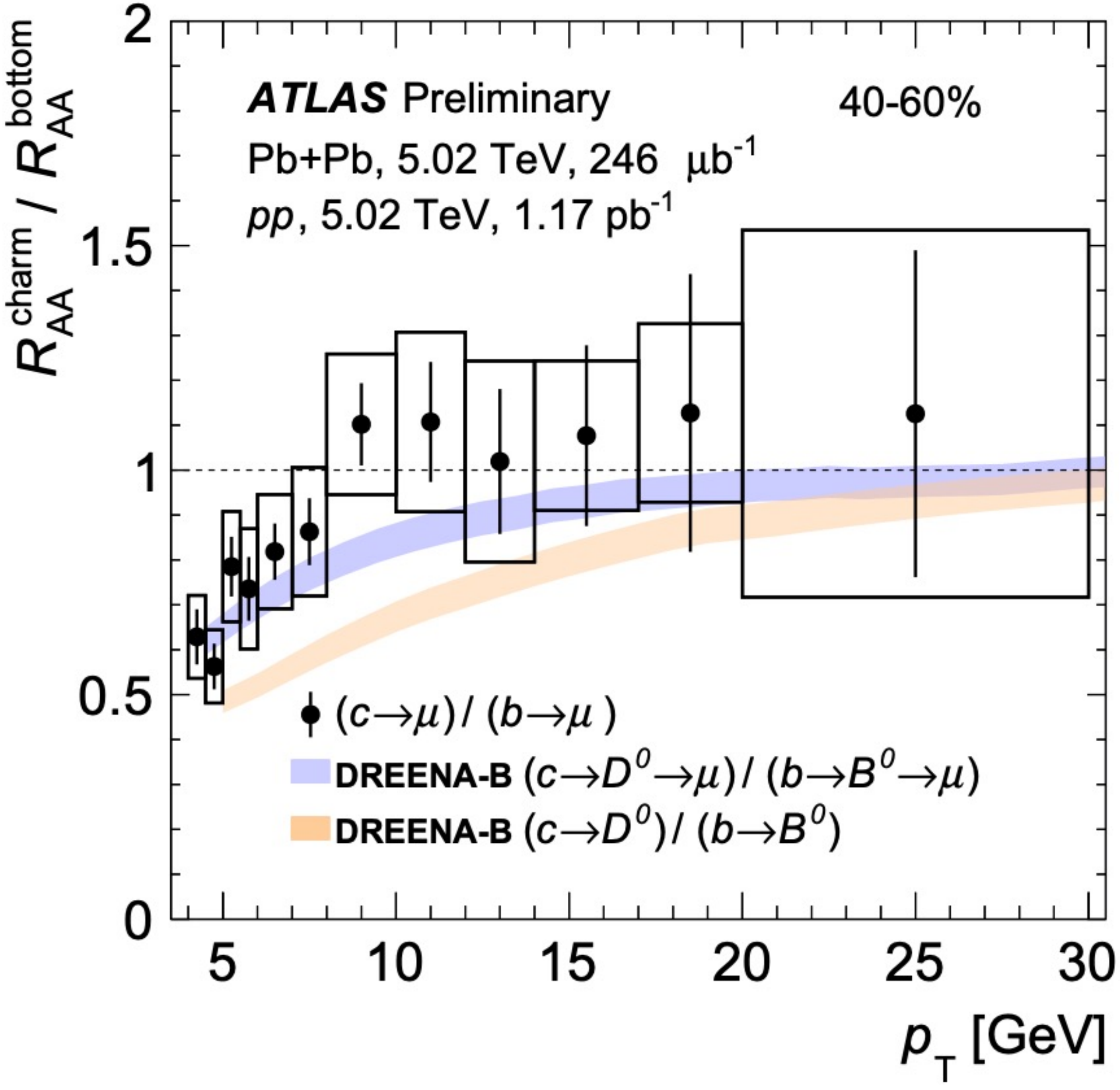


Charm has larger suppression than bottom at lower p_T, but similar at higher p_T

Radiative energy loss reduced by "dead-cone" effect when $p_T << m_{c,b}$

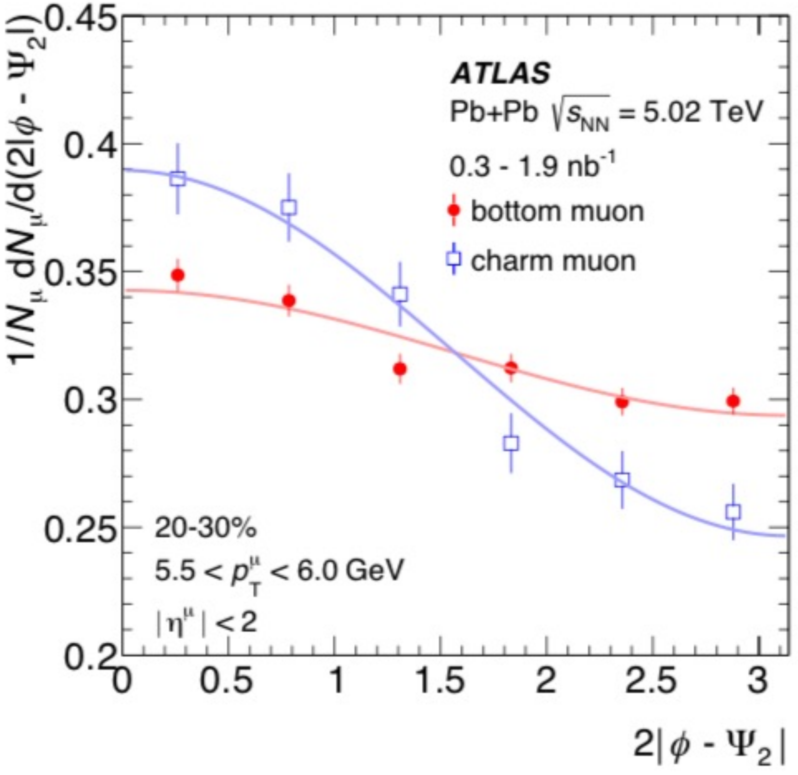


Hence larger energy loss for charm compared to bottom at lower p_T

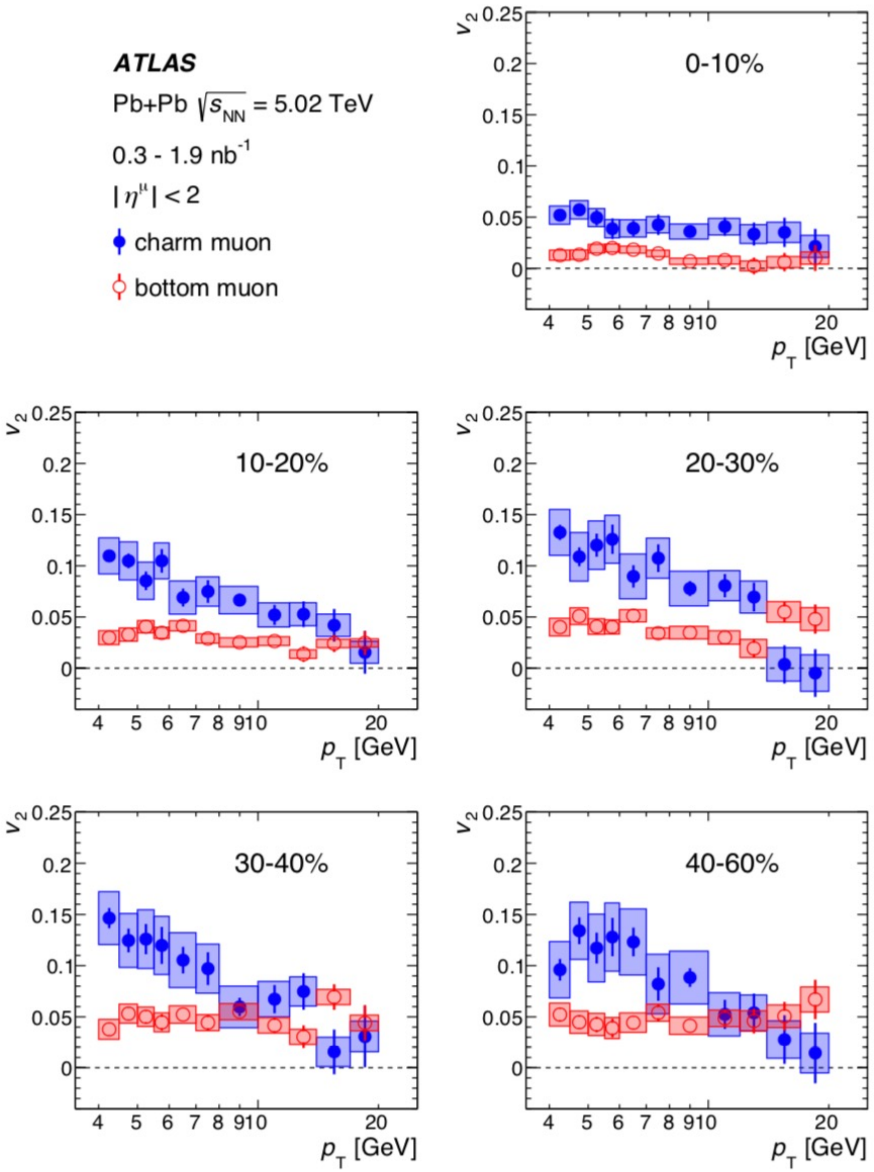


ATLAS Preliminary
40-60%
Pb+Pb, 5.02 TeV, 246 μb^{-1}
pp, 5.02 TeV, 1.17 pb^{-1}
$R_{AA}^{charm} / R_{AA}^{bottom}$
(c→μ) / (b→μ)
DREENA-B (c→D^0→μ) / (b→B^0→μ)
DREENA-B (c→D^0) / (b→B^0)
p_T [GeV]

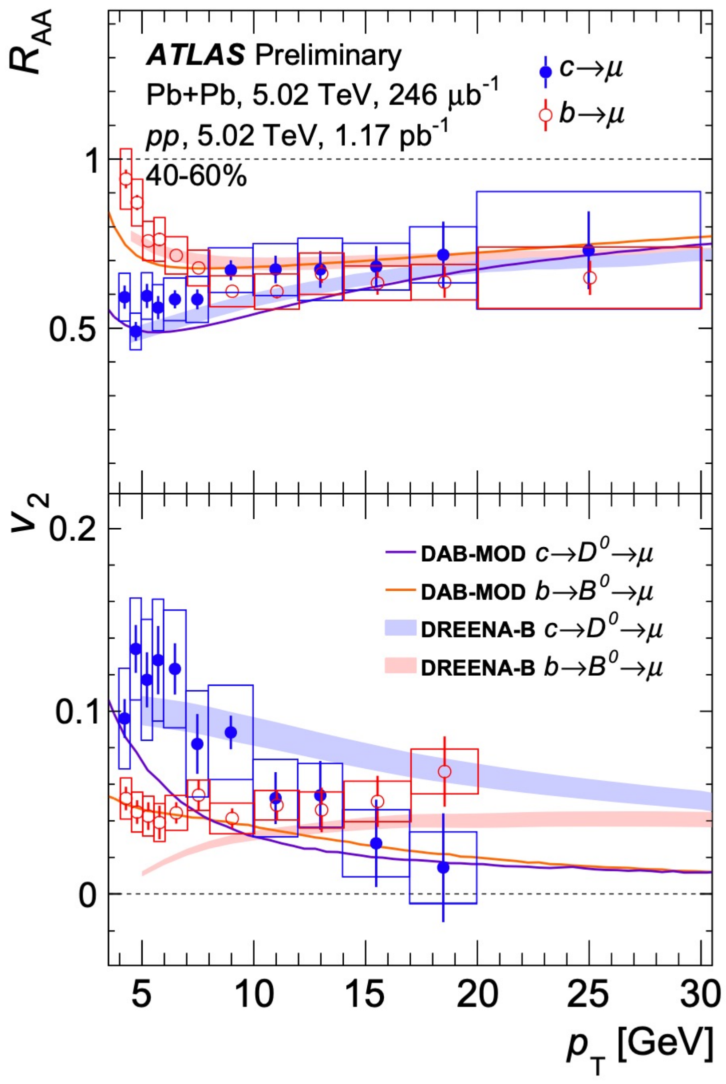
What about flow of heavy quarks?



Measure the yield of charm/bottom muons relative to the reaction plane



Is this a consistent picture?



State-of-the-art calculations

DREENA-B (arXiv:1805.04786)

Dusan Zigic, Igor Salom, Jussi Auvinen, Marko Djordjevic, Magdalena Djordjevic

Dynamic energy loss in 1+1D expanding QCD medium

DAB-MOD (arXiv: 1906.10768)

Roland Katz, Caio A. G. Prado, Jacquelyn Noronha-Hostler, Jorge Noronha, Alexandre A. P. Suaide

2D+1 viscous hydrodynamic expansion with event-by-event fluctuations

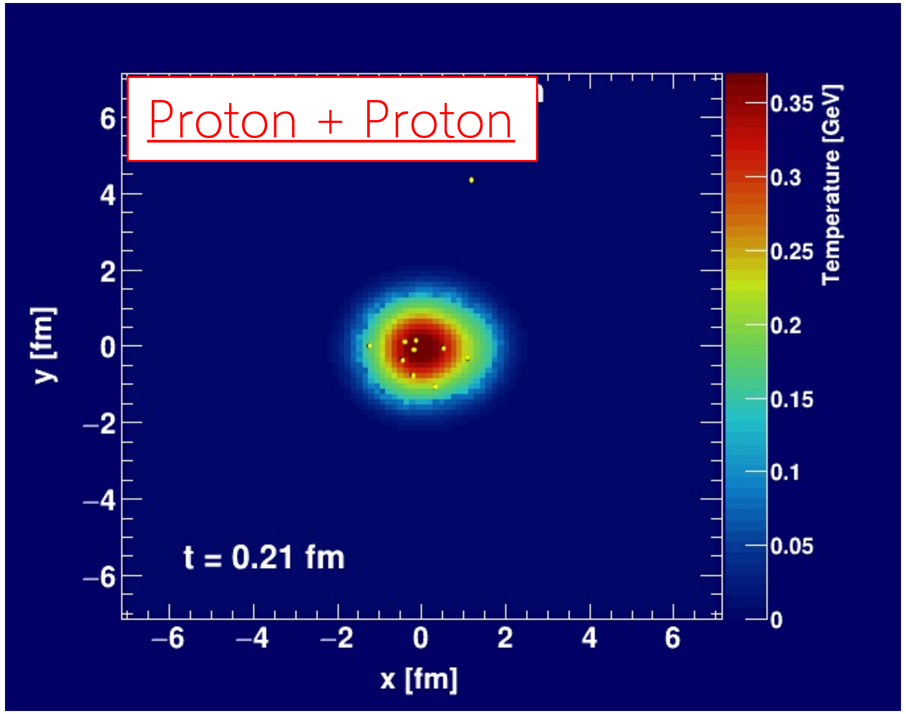
Both match mass splitting in R_{AA} at low p_T

DREENA-B has closer match to elliptic flow v_2

It would be ideal to test both energy loss calculations on identical expanding QGP background (challenge to the theorists)

What about a mini-QGP droplet in proton+proton collisions?

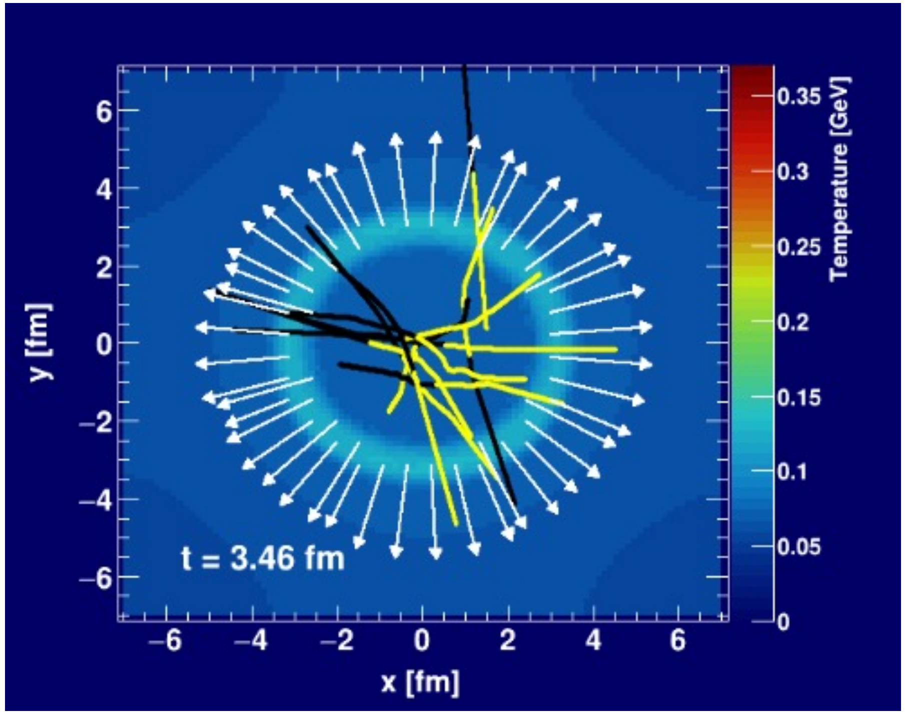
A. Adare et al., Phys.Rev.C 90 (2014) 2, 024911



SONIC Hydrodynamics
with proton (3 quark) geometry

Heavy Quark Langevin

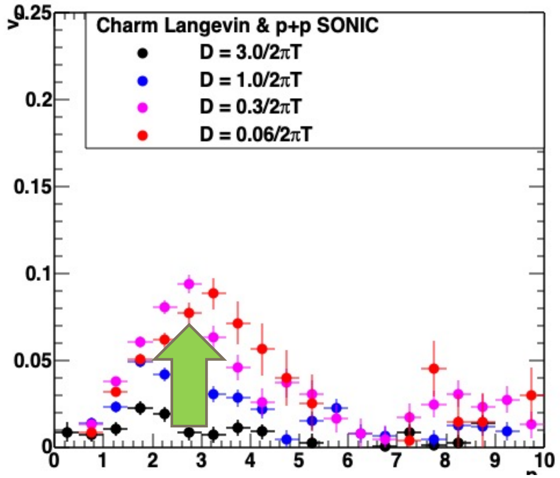
What about a mini-QGP droplet in proton+proton collisions?

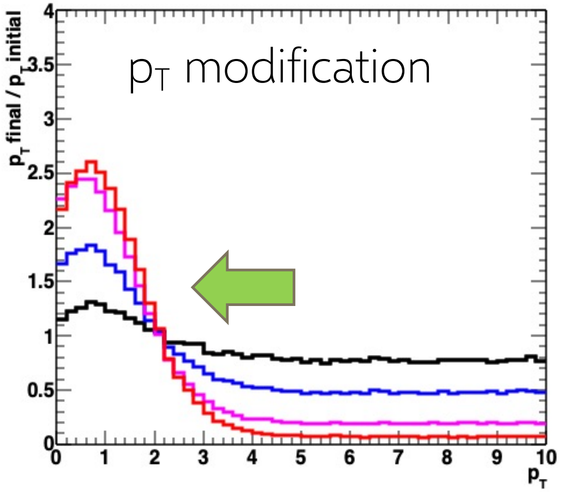


SONIC Hydrodynamics
with proton (3 quark) geometry

Heavy Quark Langevin

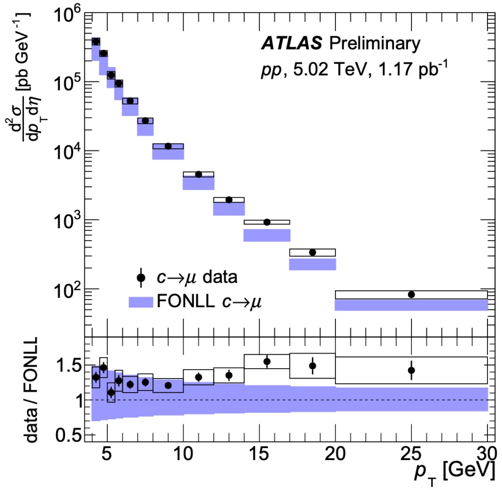
elliptic flow v_2





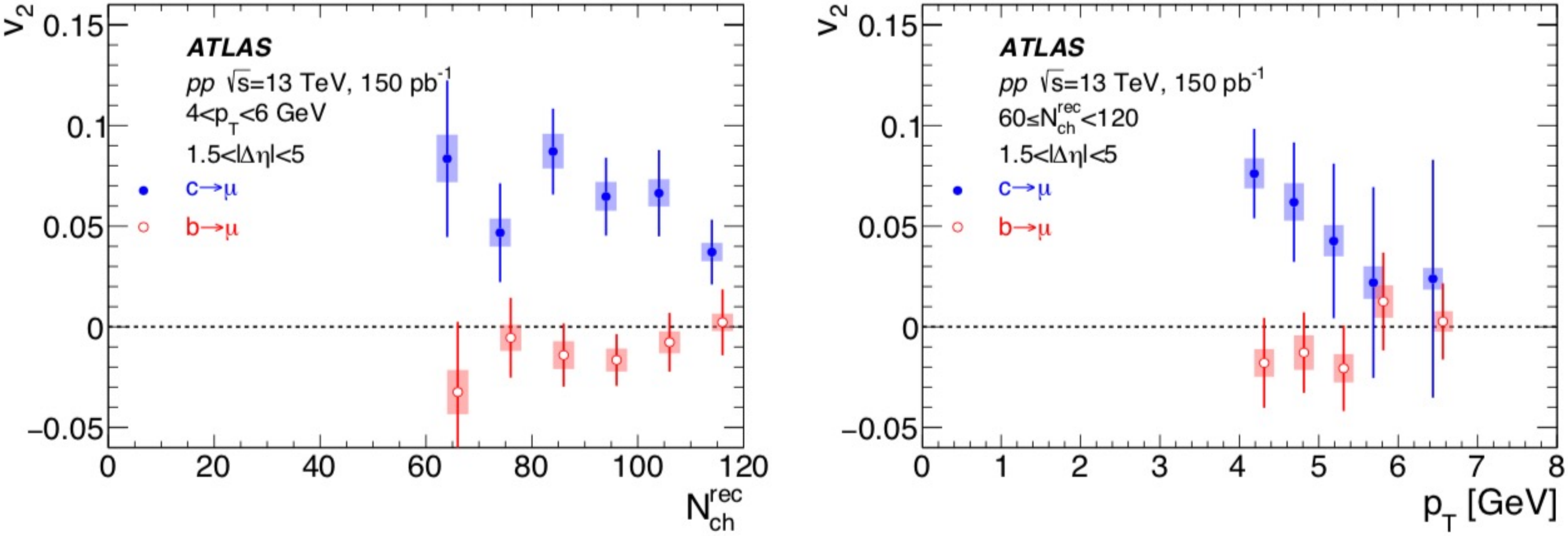
Heavy quark flow might not be so surprising

However,
such calculations also predict very significant p_T modifications
(not seen ?)



In pp, charm also "flows" ($v_2 > 0$) !
i.e. azimuthal correlation with low p_T hadrons...

Bottom consistent with $v_2 = 0$ in pp.



Summary

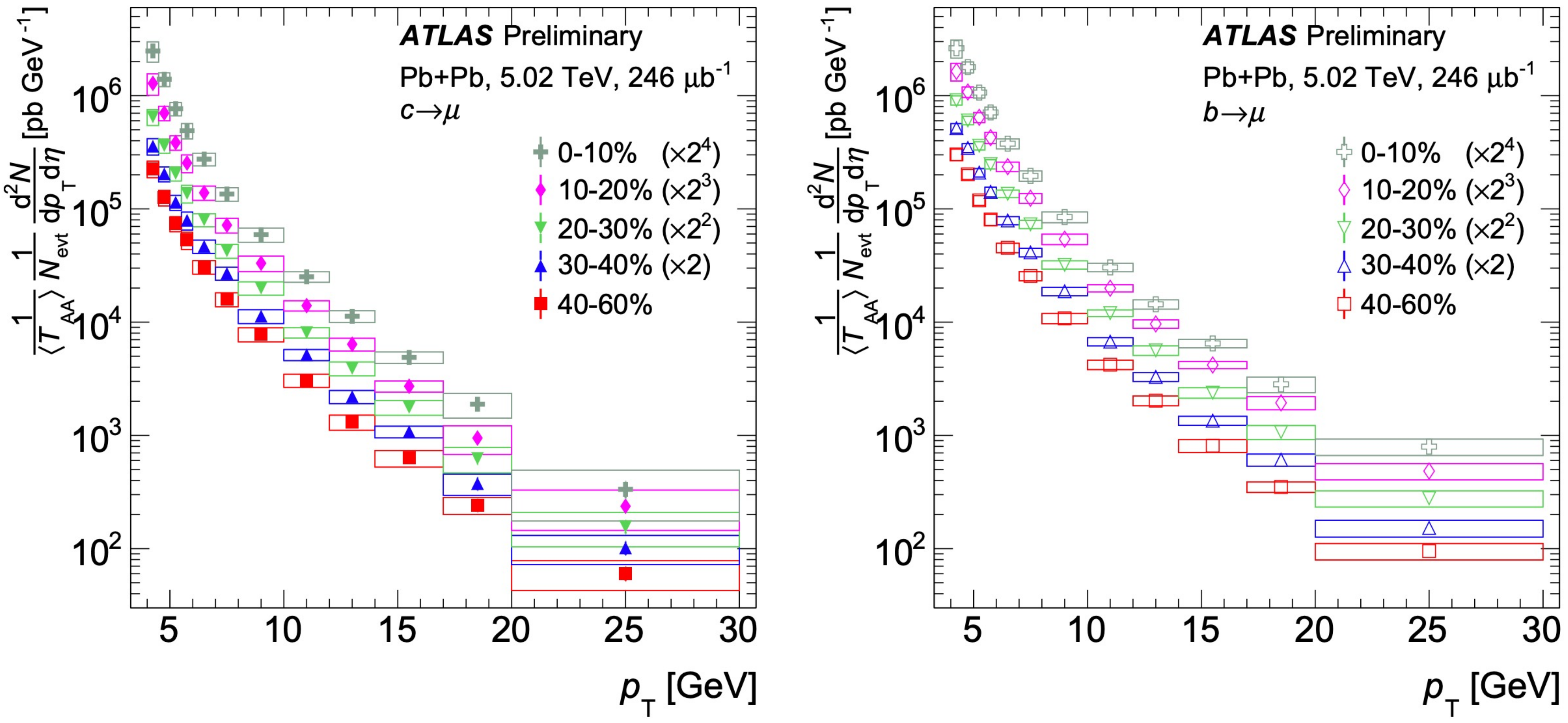
- New ATLAS results on charm/bottom muon R_{AA} presented

- Combined with previously published v_2, v_3 for charm/bottom muons gives strong constraints on energy loss mechanisms (radiative/collisional) and QGP expansion modeling

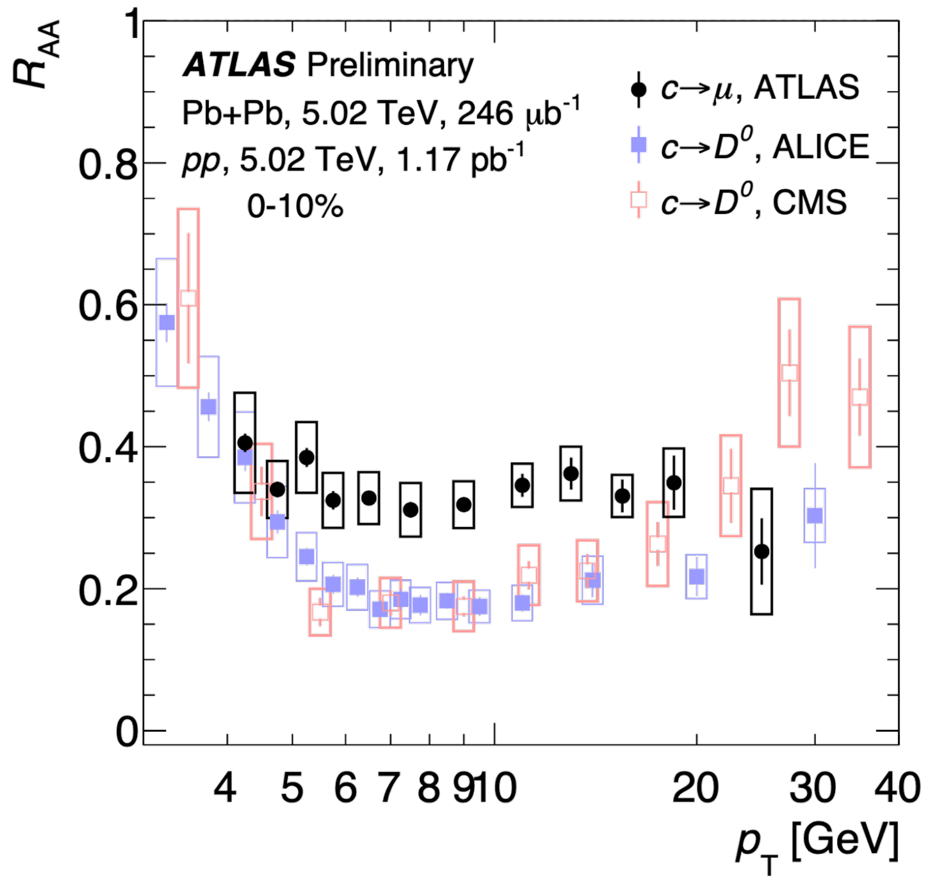
- Published v_2 for charm/bottom muons in pp 13 TeV remains a significant puzzle

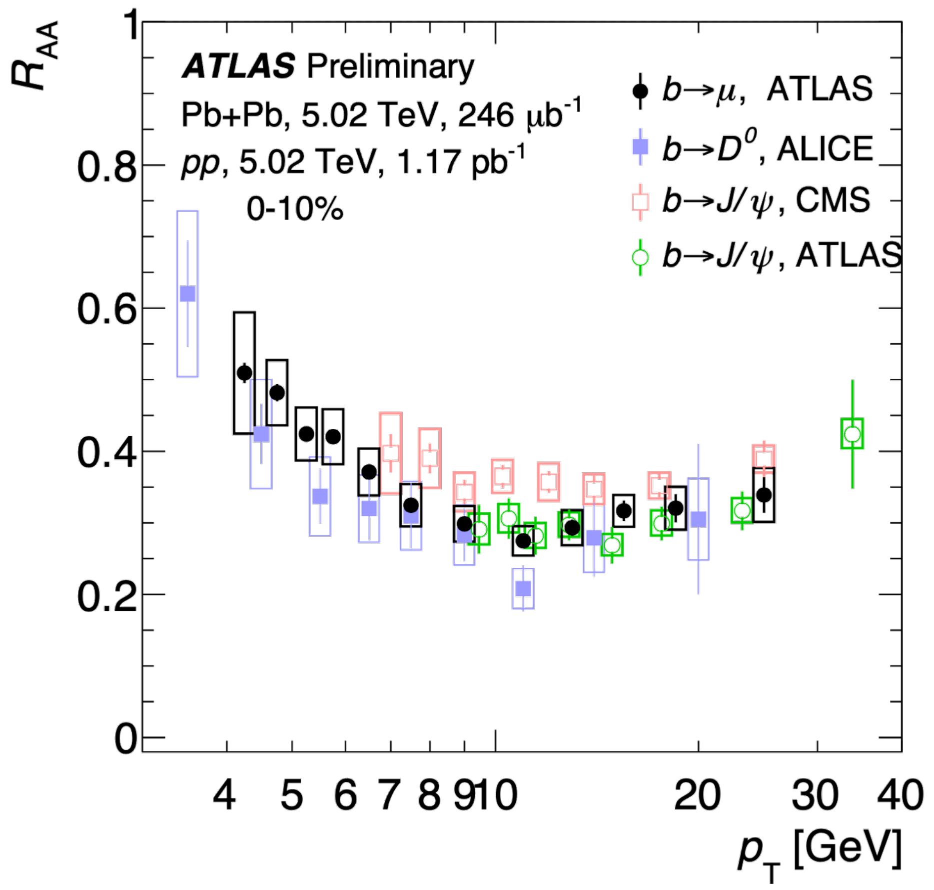
Extra

Pb+Pb 5 TeV Spectra

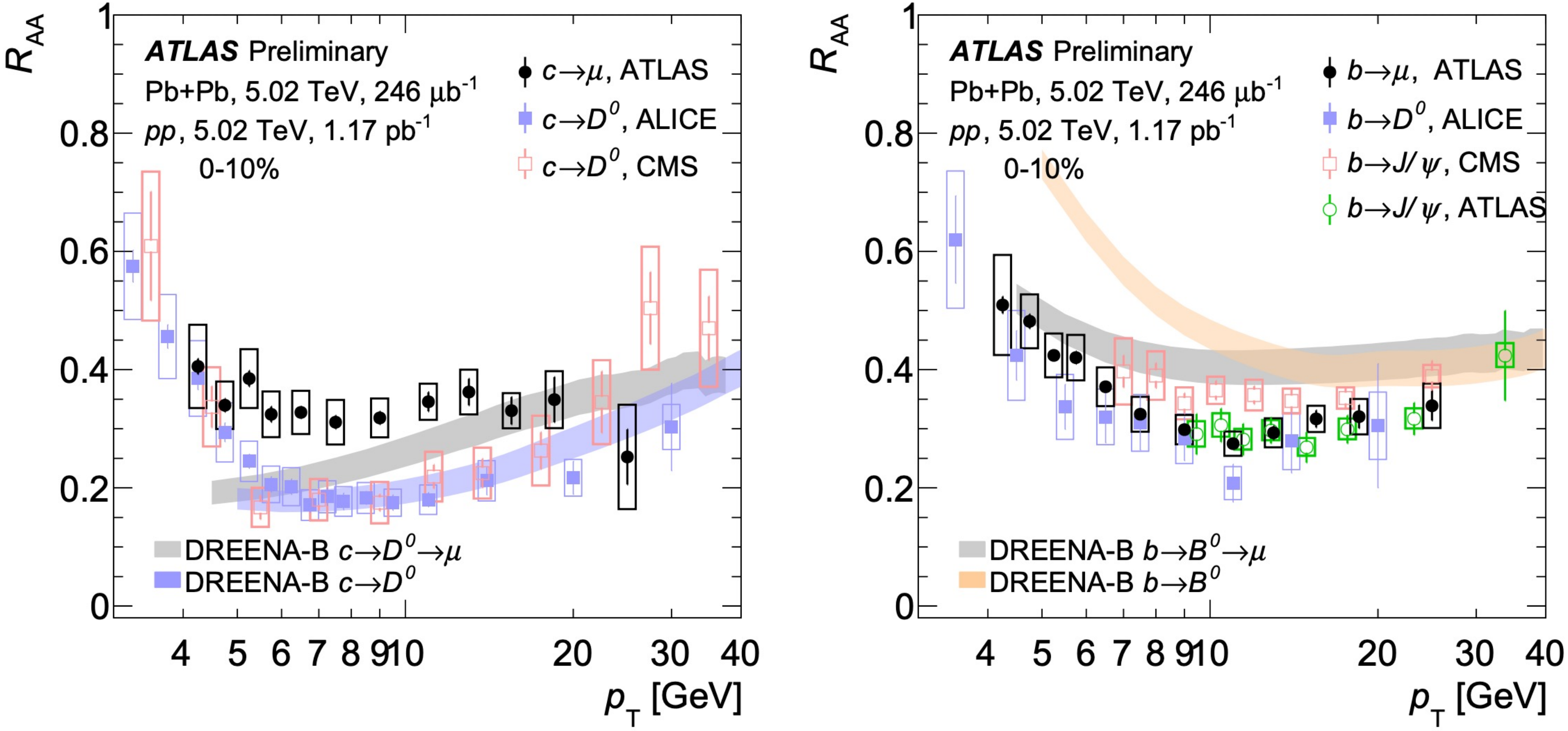


Comparison with other measurements

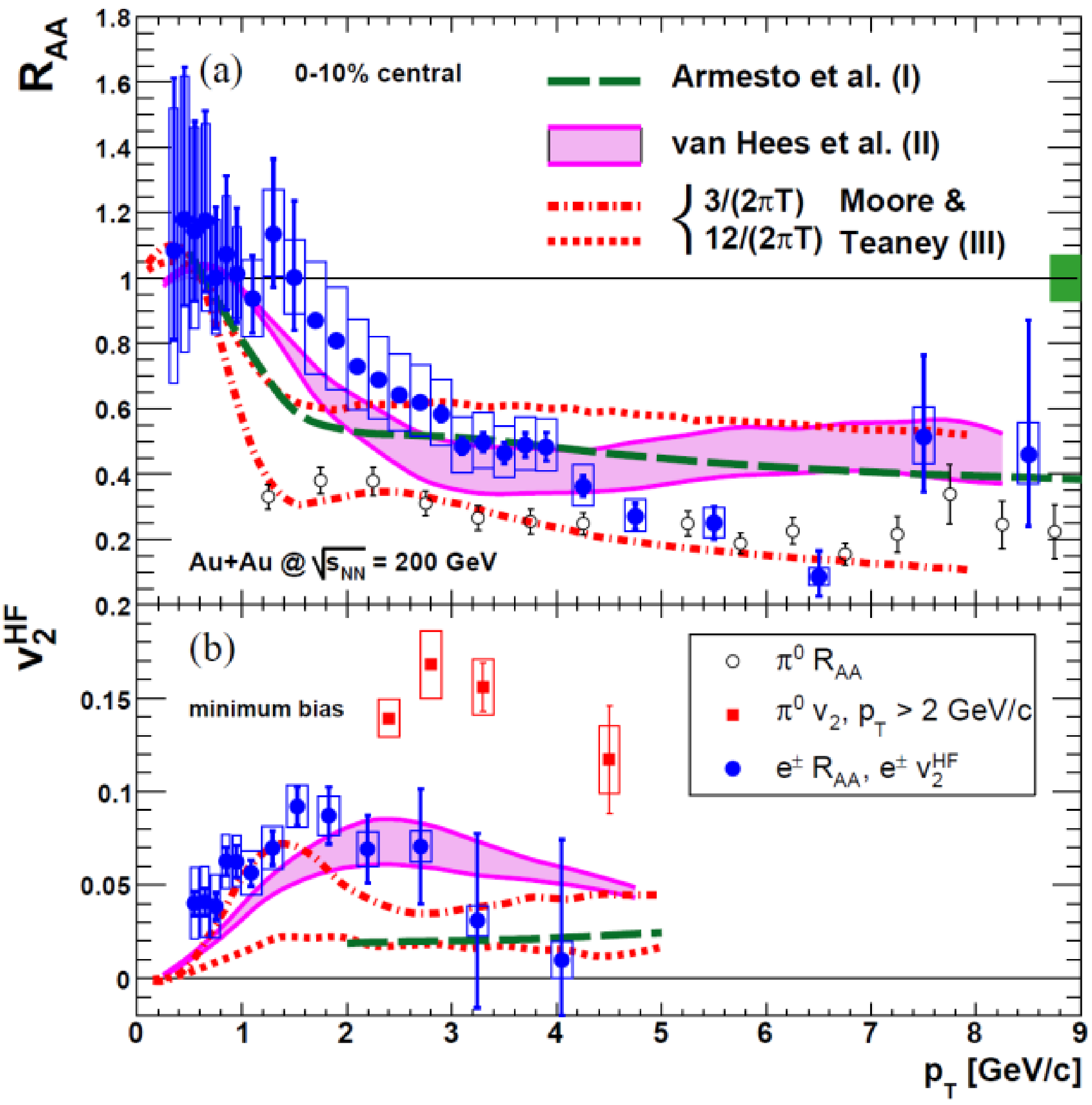




Comparison with other measurements



Heavy flavor channel matters – decay kinematics



Does the charm flow at RHIC?

Phys.Lett.B 557 (2003) 26-32

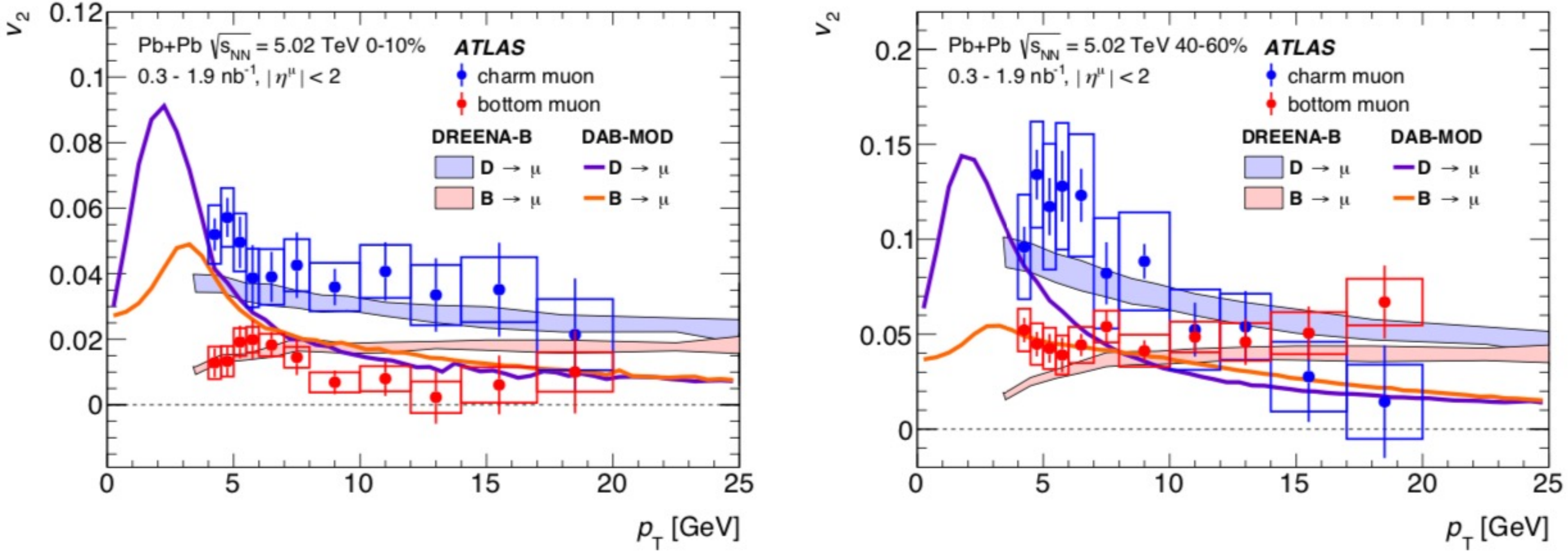
Charm quarks dragged and diffused in QGP suppresses high p_T hadrons (R_{AA} ↓)

And push generates "flow" (v_2 ↑)

PHENIX Collaboration, *Phys.Rev.Lett.* 98 (2007) 172301

749 citations to date

Yes, but what about bottom quarks?



Pb+Pb √sNN = 5.02 TeV 0-10%
0.3 - 1.9 nb-1, |η^μ| < 2
ATLAS
charm muon
bottom muon
DREENA-B
DAB-MOD
D → μ
B → μ
D → μ
B → μ
v2
pT [GeV]
Pb+Pb √sNN = 5.02 TeV 40-60%
0.3 - 1.9 nb-1, |η^μ| < 2
ATLAS
charm muon
bottom muon
DREENA-B
DAB-MOD
D → μ
B → μ
D → μ
B → μ
v2
pT [GeV]

Model Variations

State-of-the-art calculations

DAB-MOD (arXiv: 1906.10768)

2D+1 viscous hydrodynamic expansion with event-by-event fluctuations

Langevin versus constant E_{loss}