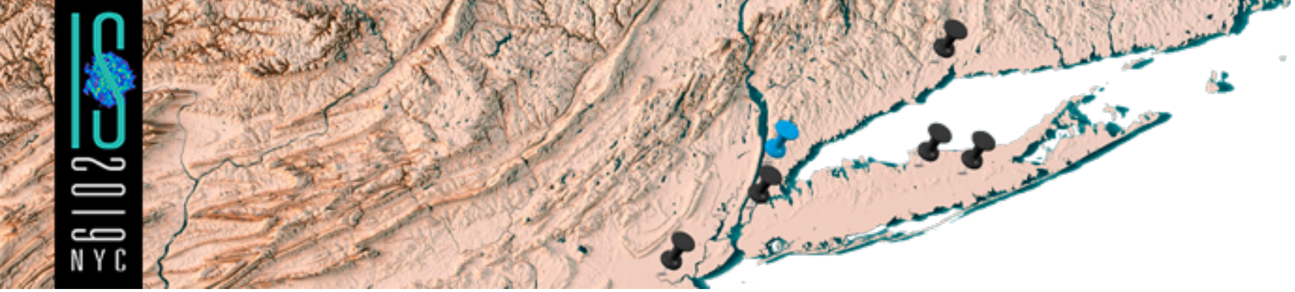

ATLAS measurements of azimuthal anisotropy of heavy flavor hadrons in Pb+Pb, *p*+Pb and *pp* collisions

Kurt Hill
University of Colorado Boulder
for the ATLAS Collaboration

ATLAS EXPERIMENT

Do charm and bottom quarks flow with the quark-gluon fluid?

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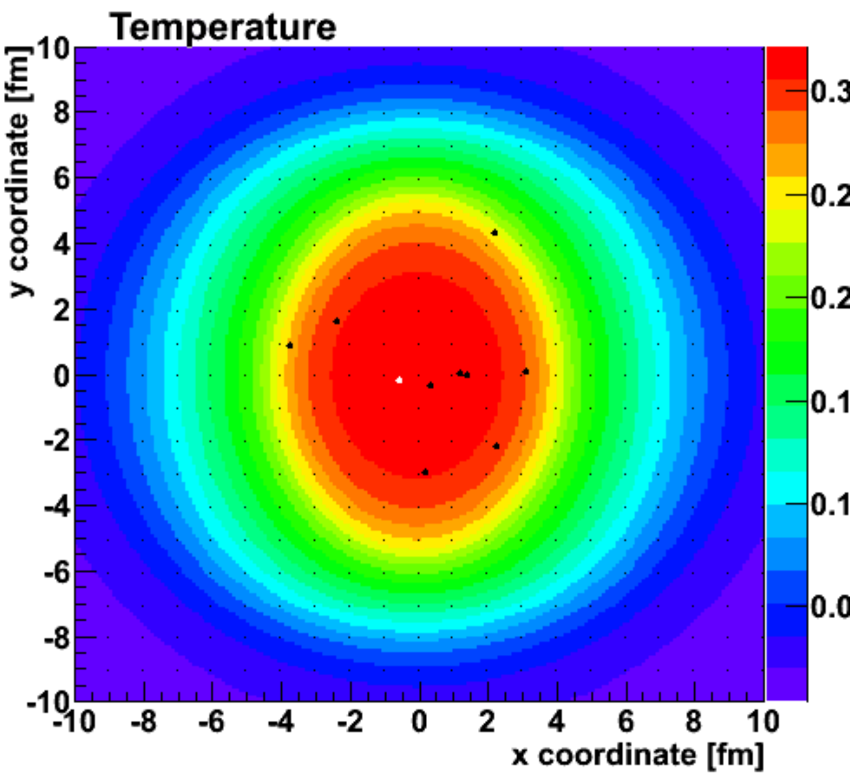
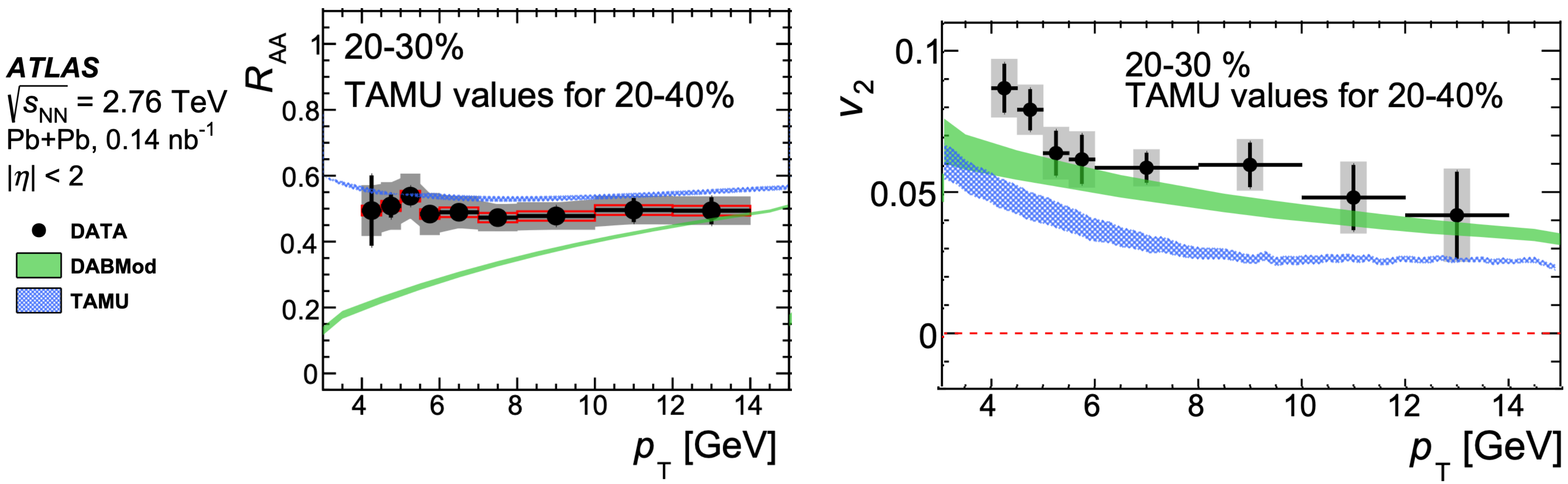


Phys. Rev. C 90, 024911

Langevin (drag & diffusion) type calculations indicate they should “flow”

ATLAS Heavy-Flavor Muons in Pb+Pb

Significant modification of HF muon p_T distribution (R_{AA} suppression)
Significant non-zero elliptic flow (v_2) event at high p_T



ATLAS : Phys Rev. C 98, 044905

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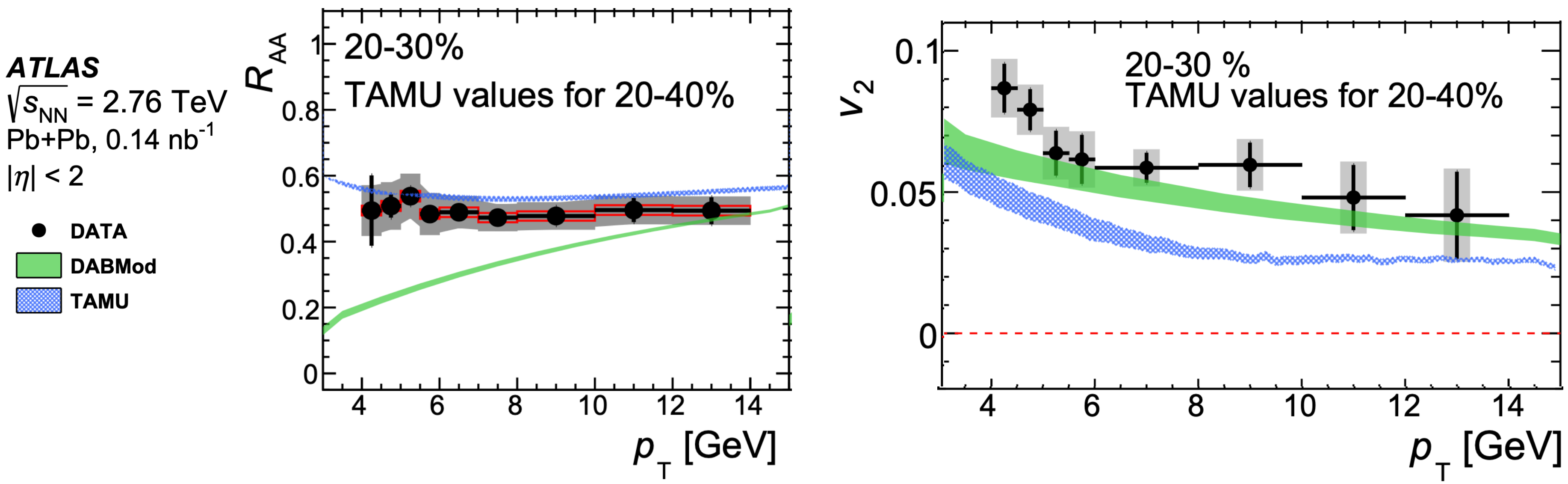


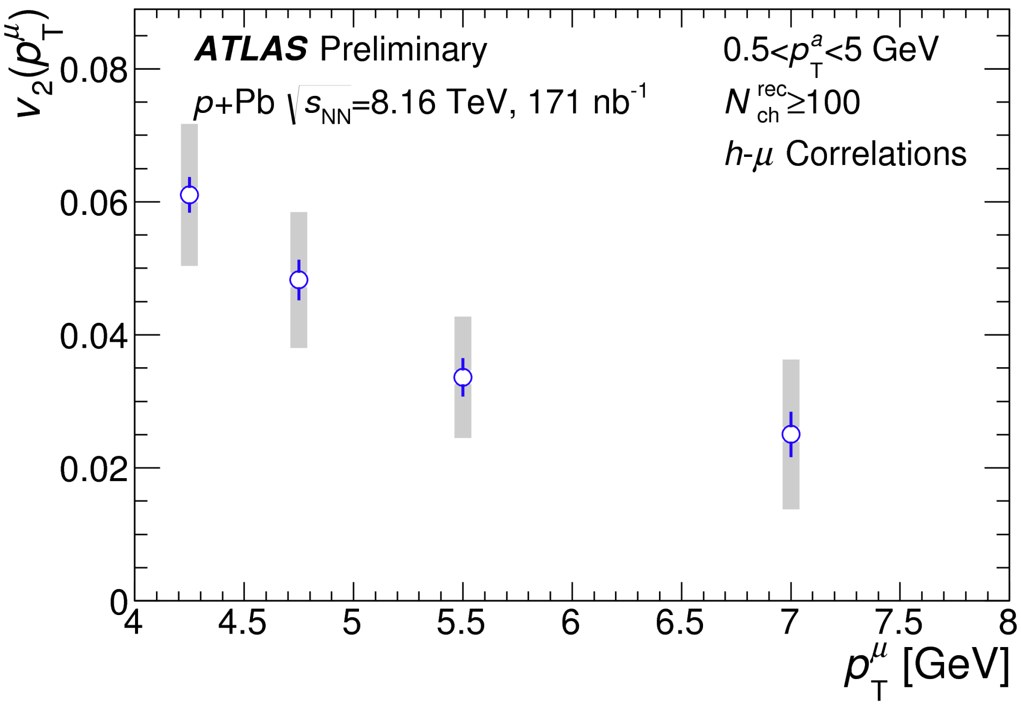
ATLAS : Phys Rev. C 98, 044905

Heavy quark transport calculations have a <u>tension</u> to simultaneously describe both R_{AA} & v_2

Many measurements in Pb+Pb – see recent review (https://arxiv.org/abs/1903.07709)

ATLAS Heavy-Flavor Muons in p+Pb

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-006/



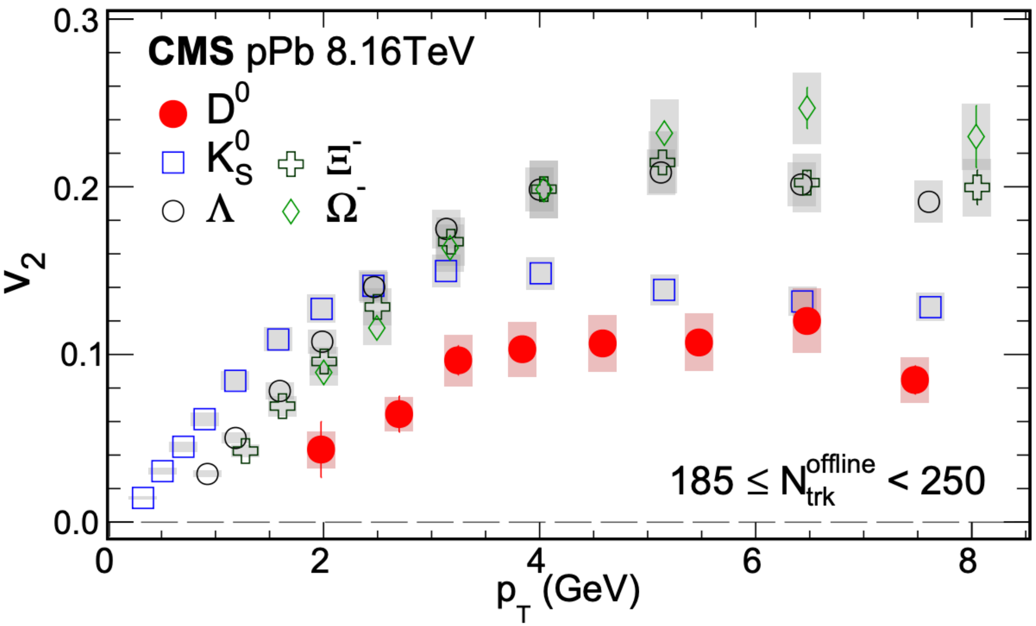
Non-zero heavy-flavor muon v_2

Not so different magnitude from Pb+Pb v_2 at $p_T \sim 4$ GeV, though maybe dropping more quickly

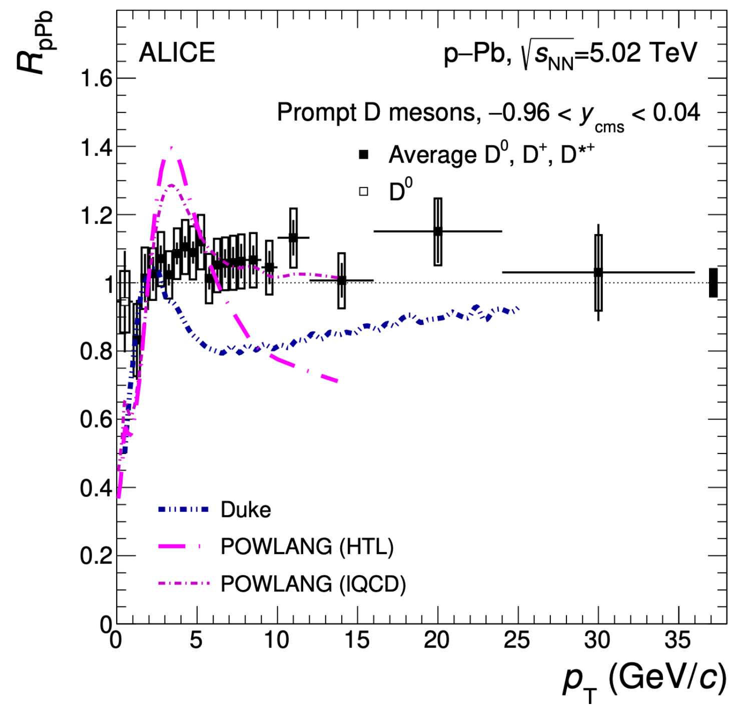
D mesons in *p*+Pb

CMS p+Pb D mesons show significant v_2, but the ALICE R_{pPb} is consistent with one – tension!

Phys. Rev. Lett. 121, 082301



arXiv:1906.03425



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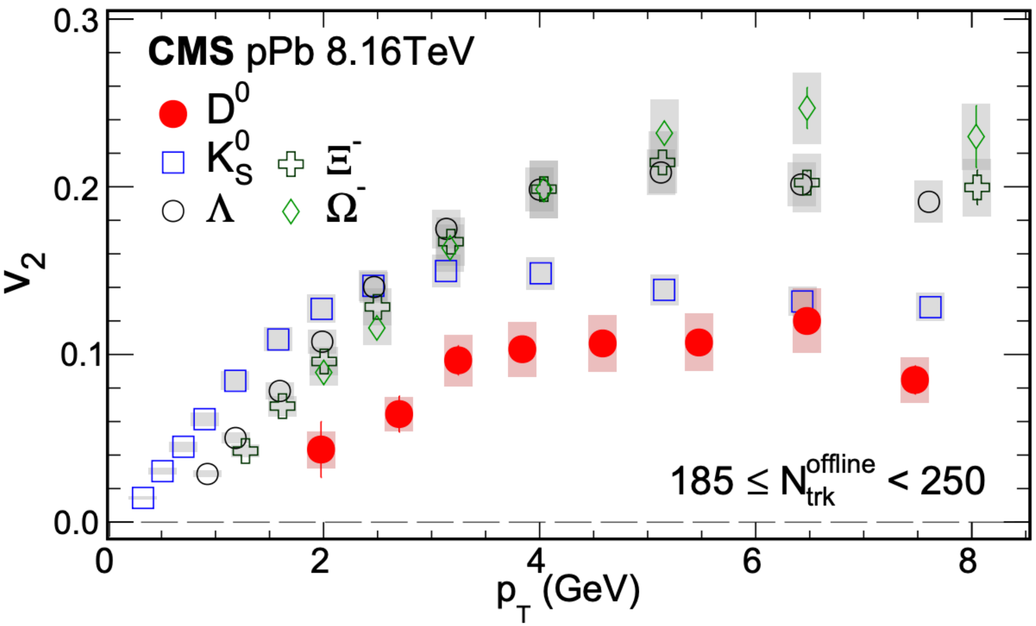

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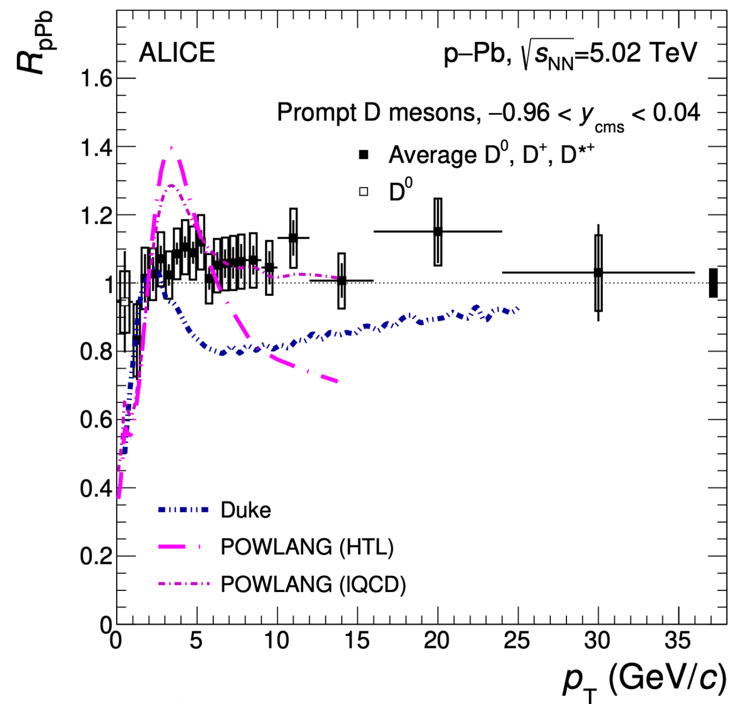
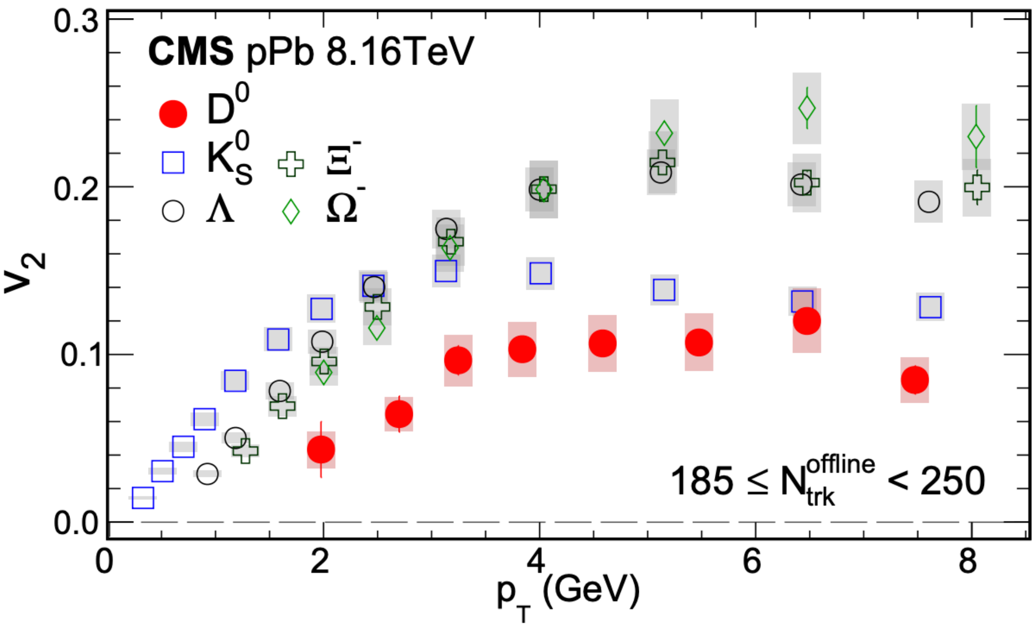


What about *pp*?

D mesons in p+Pb

CMS p+Pb D mesons show significant v_2, but the ALICE R_{pPb} is consistent with one – tension!

Phys. Rev. Lett. 121, 082301



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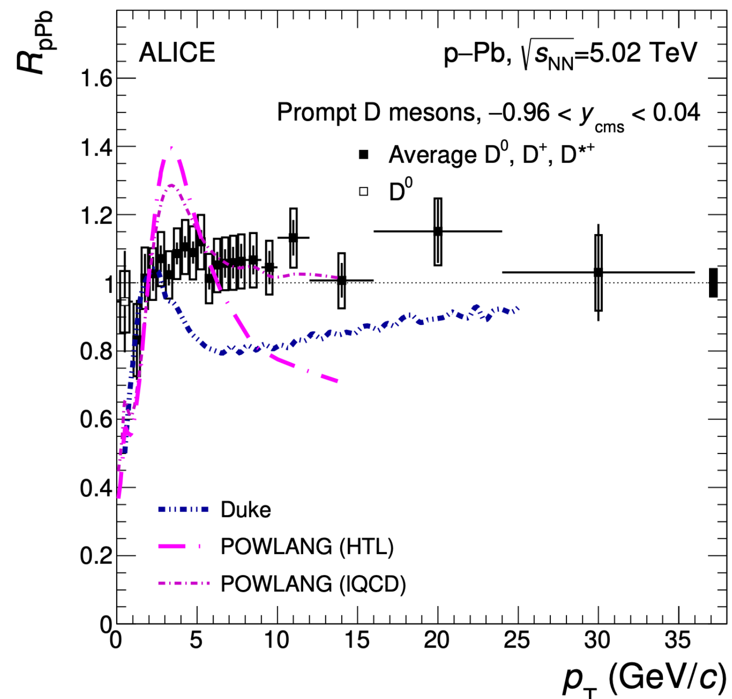
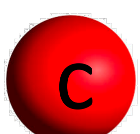
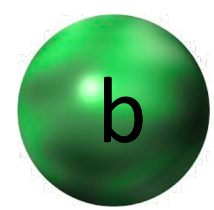


What about pp?



Do the experiment!


Analysis Details

- Use single muons from heavy-flavor decays and measure elliptic flow

1. *pp* collisions at sqrt(s) = 13 TeV from 2017
    - low luminosity μ ~ 2 sample
    - integrated luminosity of 150 pb^{-1}
    - muon triggers (p_T > 4 GeV) + high multiplicity triggers

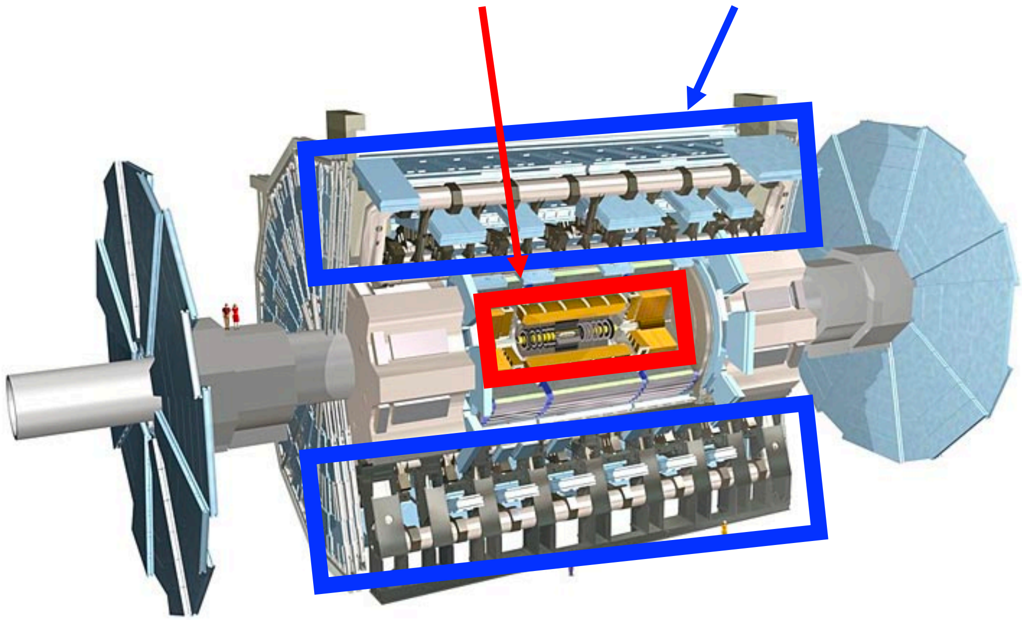
2. First separate heavy-flavor muons (signal) decays, etc. (background).

3. Then separate charm and bottom within signal.

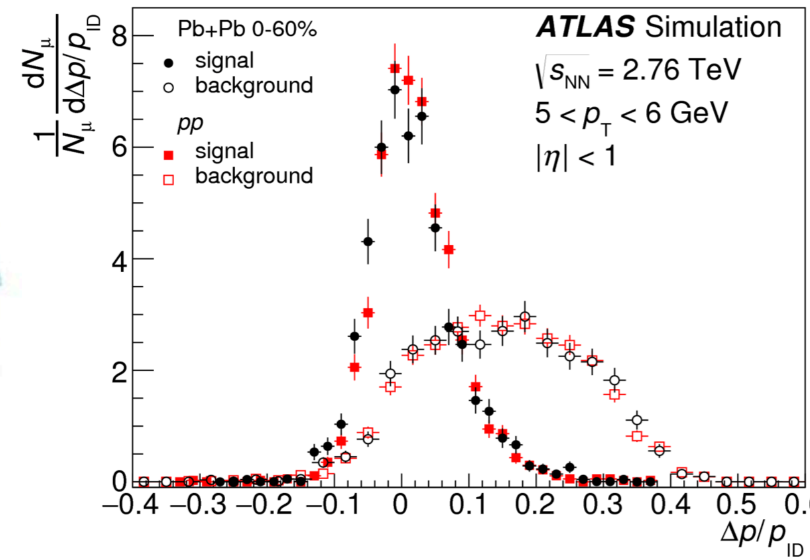
- ATLAS-CONF-2019-023

Muon Signal and Background Separation

$\Delta p = p_{\mathrm{ID}} - p_{\mathrm{muon}}$



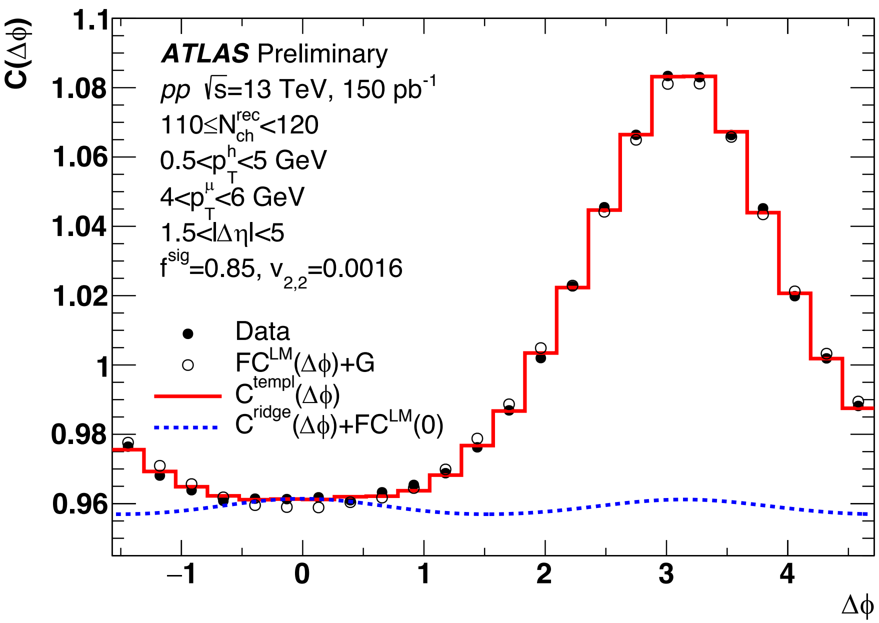
Phys. Rev. C 98, 044905



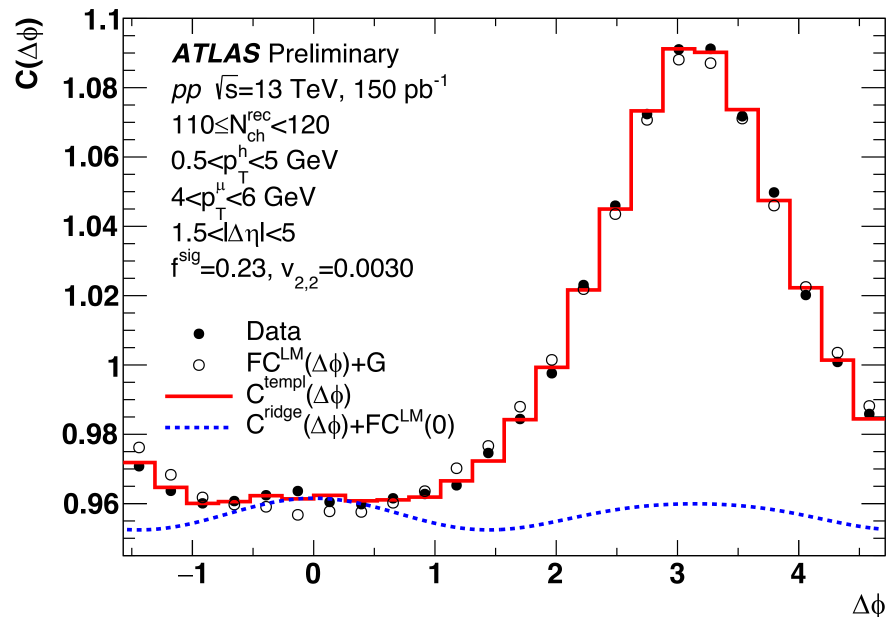
* Note that in pp 13 TeV, the non-background contains ~ 2.5% from quarkonia, low mass resonances, and tau leptons (based on PYTHIA8 simulation)

Muon-Hadron Correlation Functions

Two-particle correlations and standard ATLAS template non-flow subtraction
[Phys. Rev. Lett. 116, 172301]



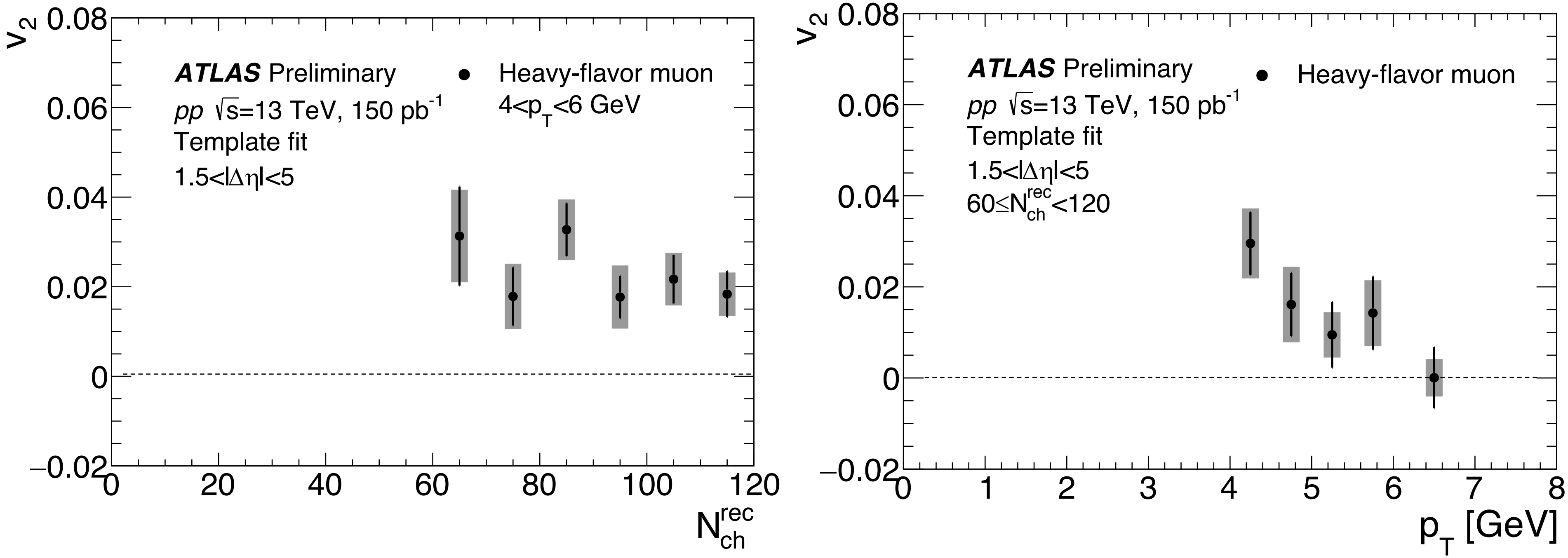
Signal = 0.85, Background = 0.15



Signal = 0.23, Background = 0.77

$$v_{2,2}(p_T^{\mu}, p_T^{h}) = f^{sig} v_{2,2}^{sig}(p_T^{\mu}, p_T^{h}) + \left(1 - f^{sig}\right) v_{2,2}^{bkg}(p_T^{\mu}, p_T^{h})$$

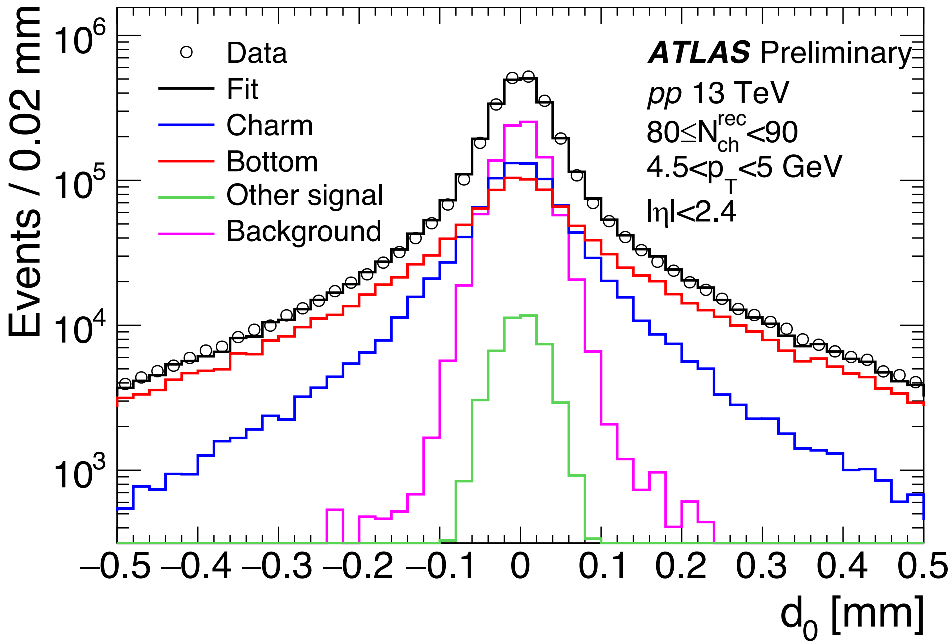
Heavy-flavor Muon Elliptic Flow in pp 13 TeV

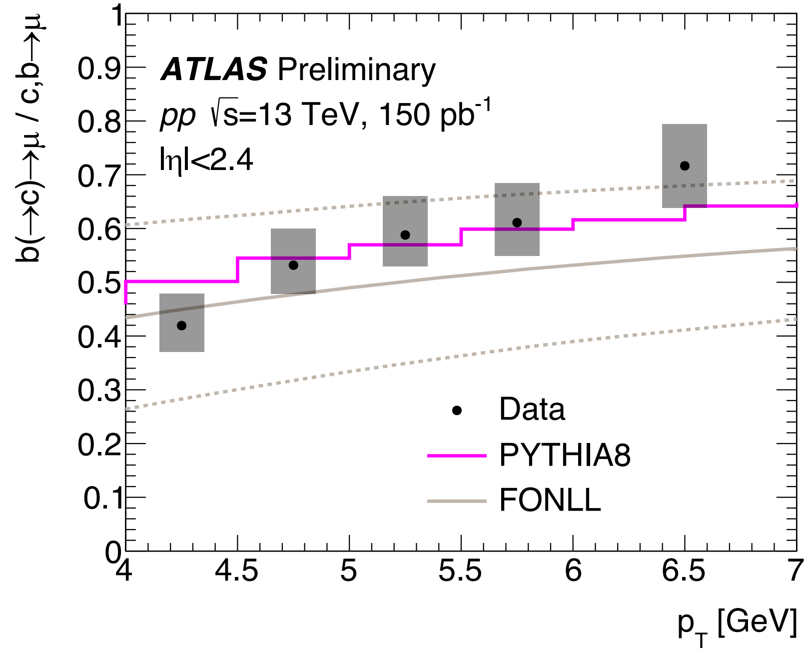


$N_{\mathrm{ch}}^{\mathrm{rec}}$: p_T > 0.4 GeV, $|\eta|$ < 2.5, no eff. correction

- First observation of heavy-flavor elliptic flow in *pp* collisions
- Non-zero v_2 independent of multiplicity for $N_{\mathrm{ch}}^{\mathrm{rec}} > 60$ (corresponding to ~ 1% highest *pp*)
- Decreasing v_2 as a function of p_T

Charm and Bottom Separation



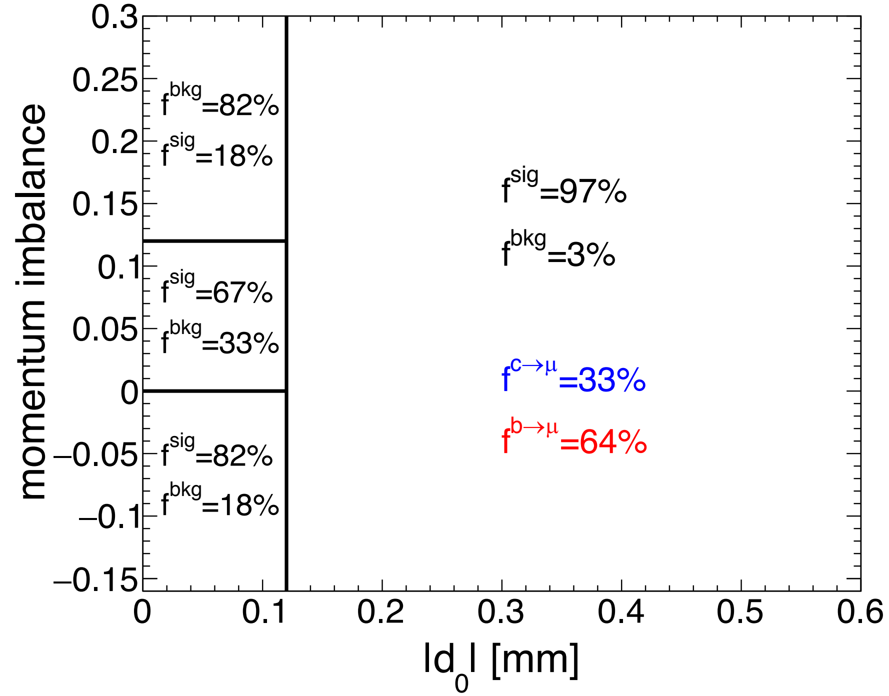


d_0 = impact parameter of muon relative to the associated vertex

Redo correlation analysis selecting regions in d_0 and momentum mismatch.

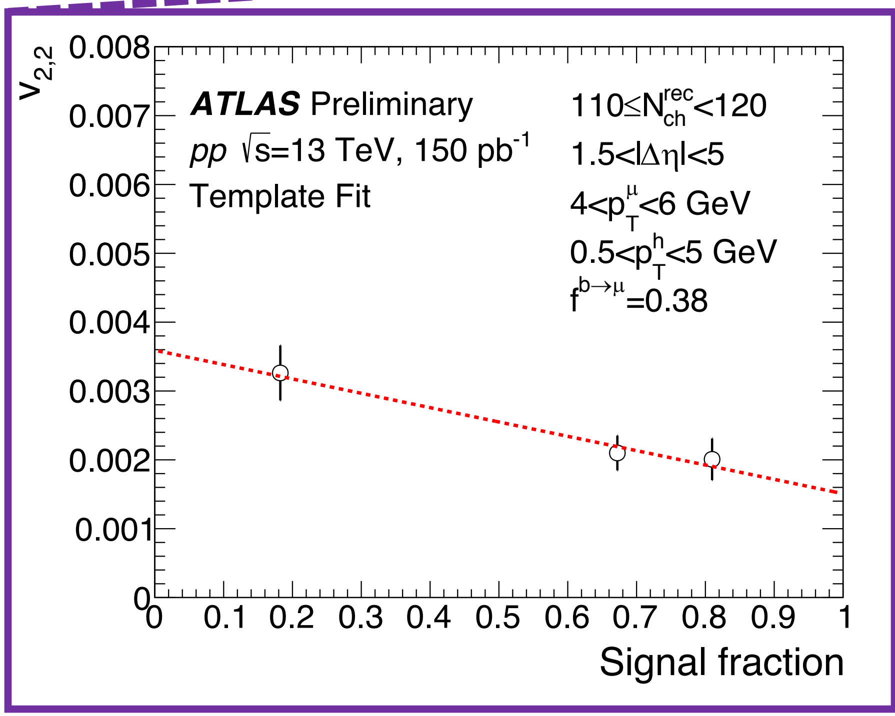
Extracted bottom fraction consistent with FONLL/PYTHIA8, which are used for additional systematic uncertainties.

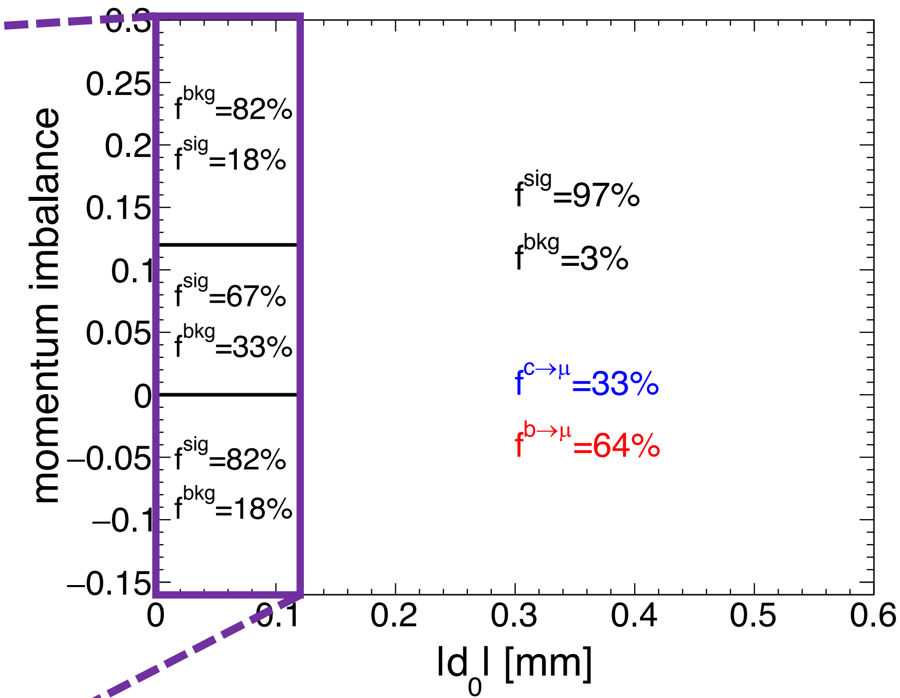
Charm and Bottom Separation



Measure $v_{2,2}$ in each of the four regions

Charm and Bottom Separation



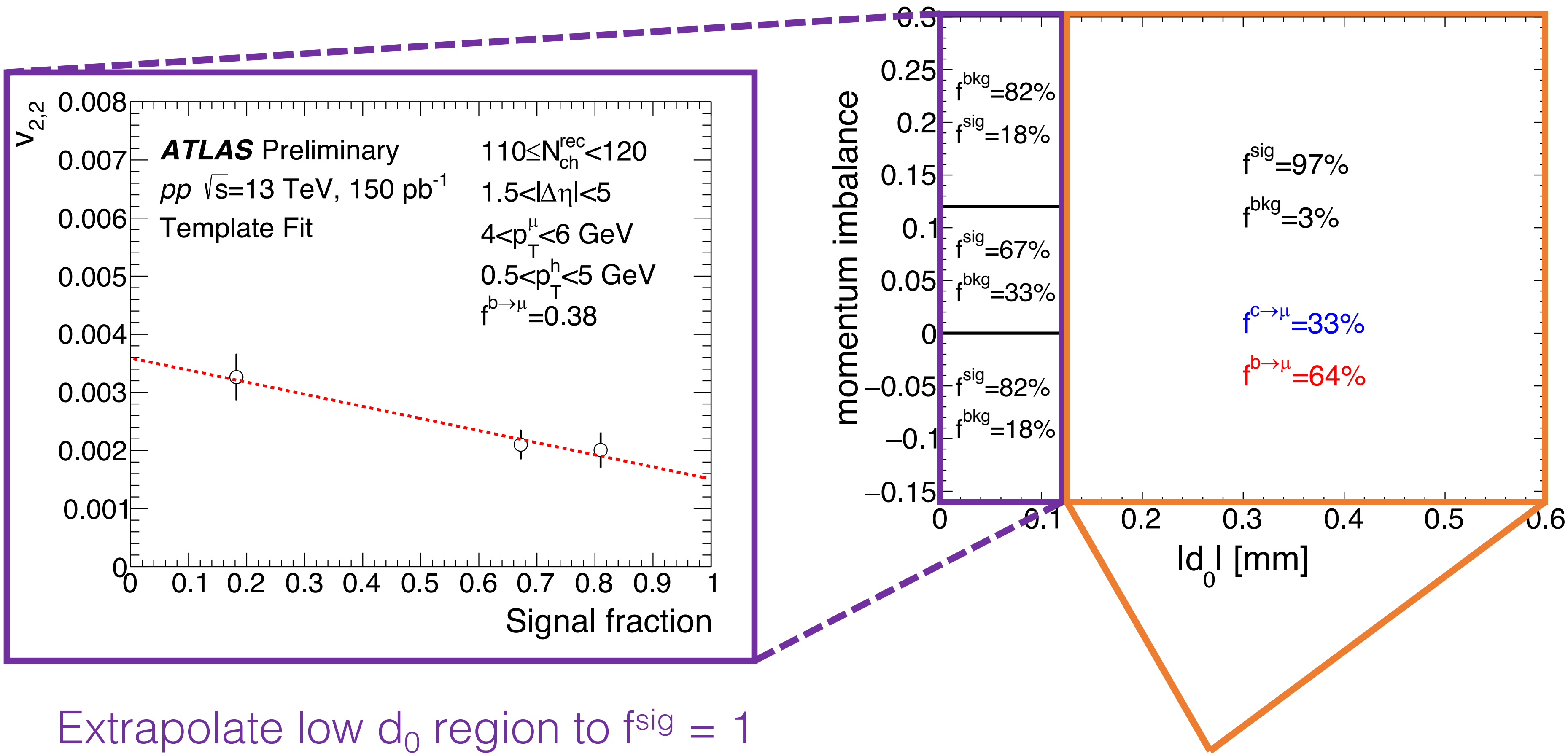


Extrapolate low d_0 region to $f^{sig} = 1$

$$v_{2,2} = f^{sig} v_{2,2}^{sig} + (1 - f^{sig}) v_{2,2}^{bkg}$$

Measure $v_{2,2}$ in each of the four regions

Charm and Bottom Separation



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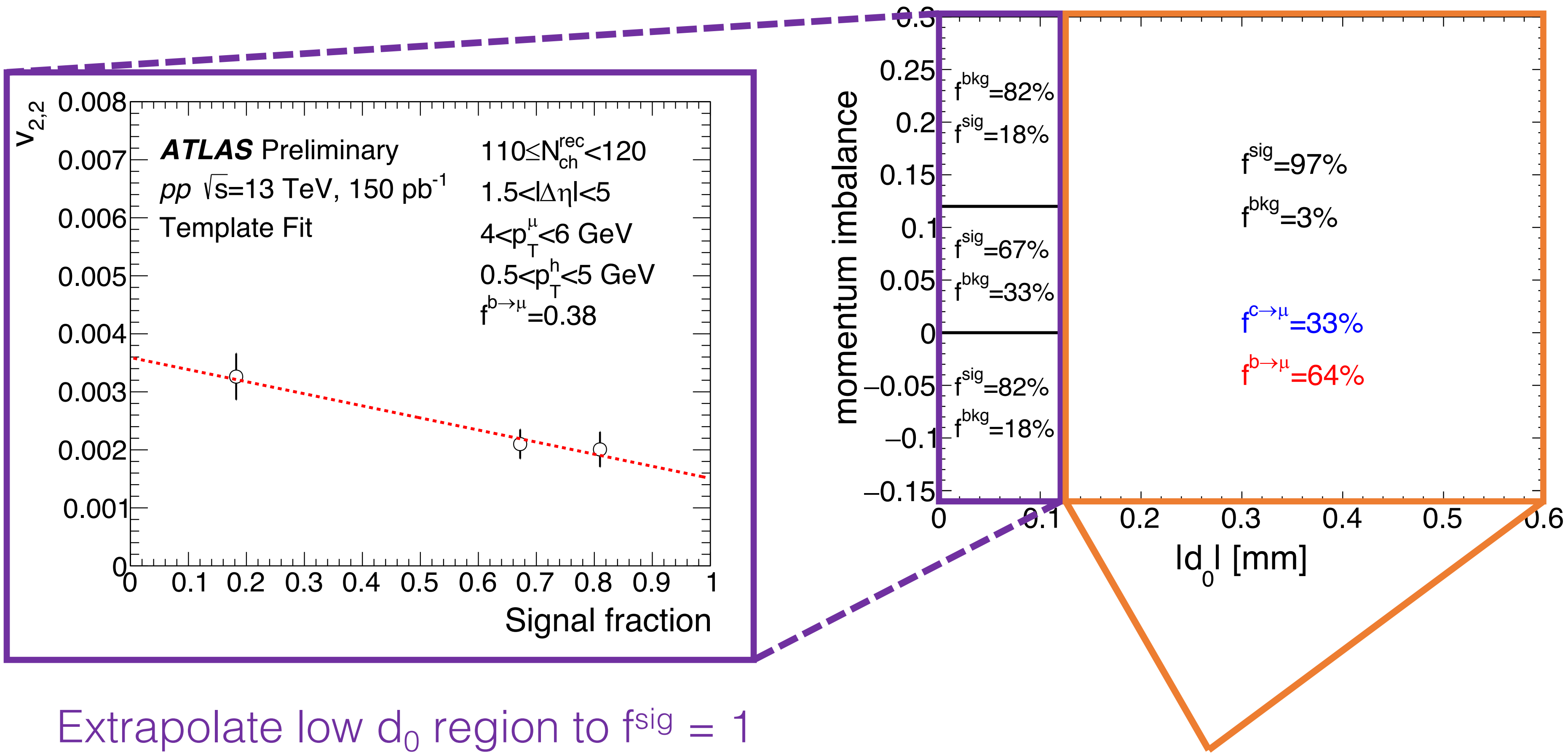
High d_0 region $v_{2,2}$ determined directly

Measure $v_{2,2}$ in each of the four regions

Charm and Bottom Separation



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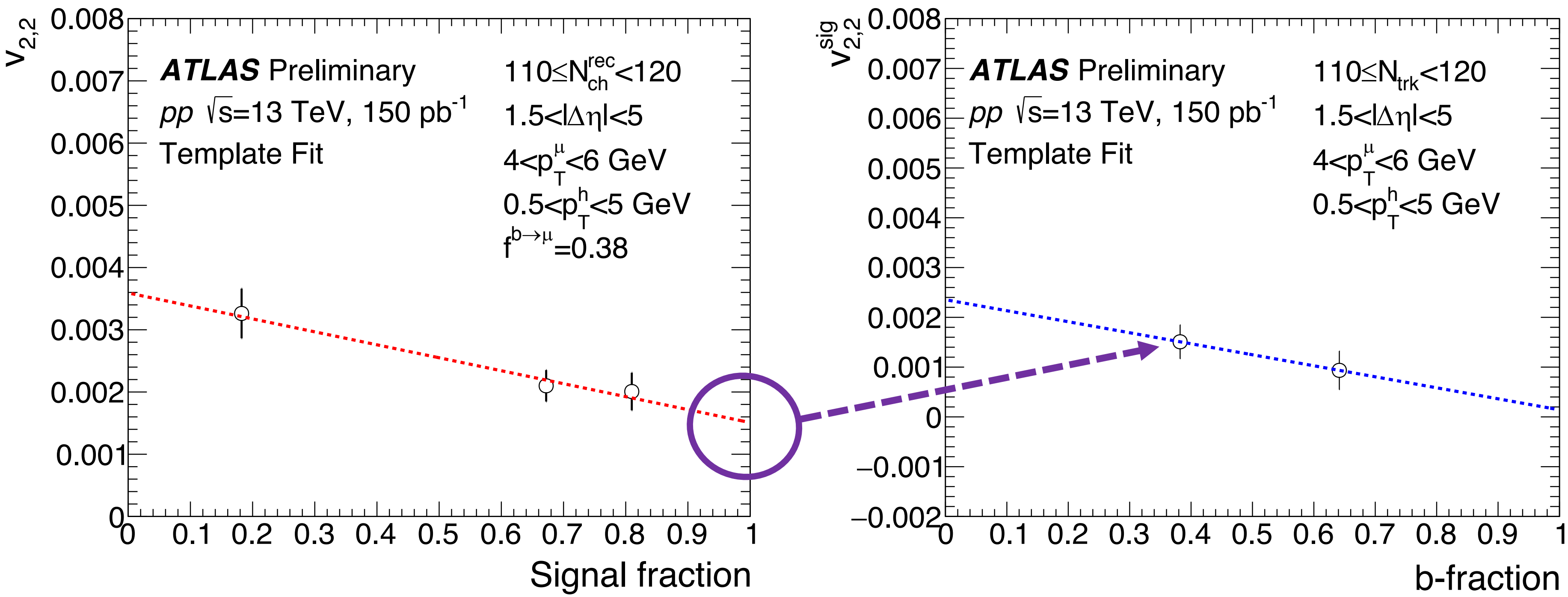
High d_0 region $v_{2,2}$ determined directly

Two measurements of $v_{2,2}^{sig}$ with two different b fractions

Charm and Bottom Separation

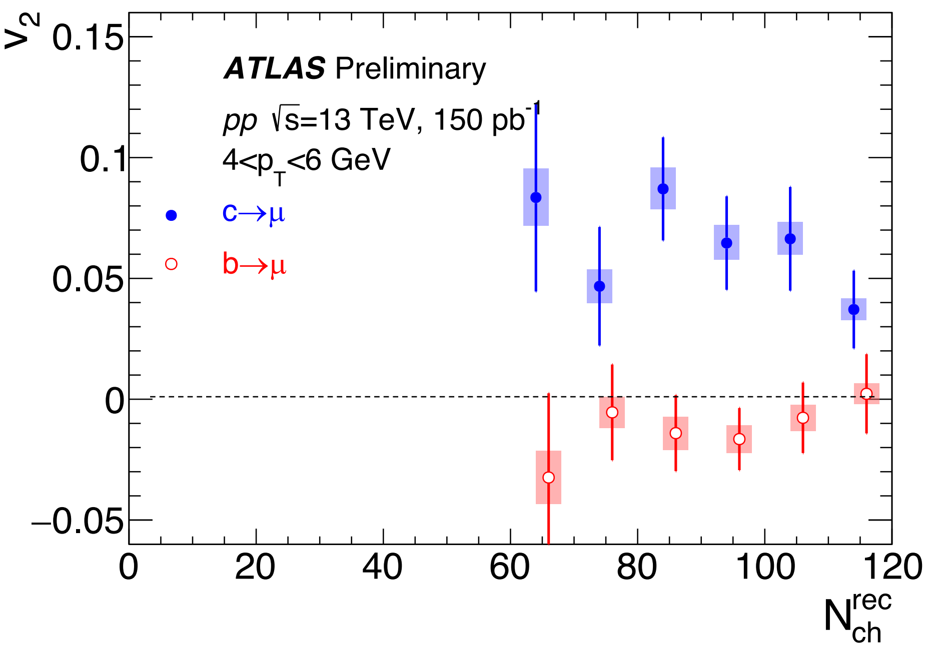


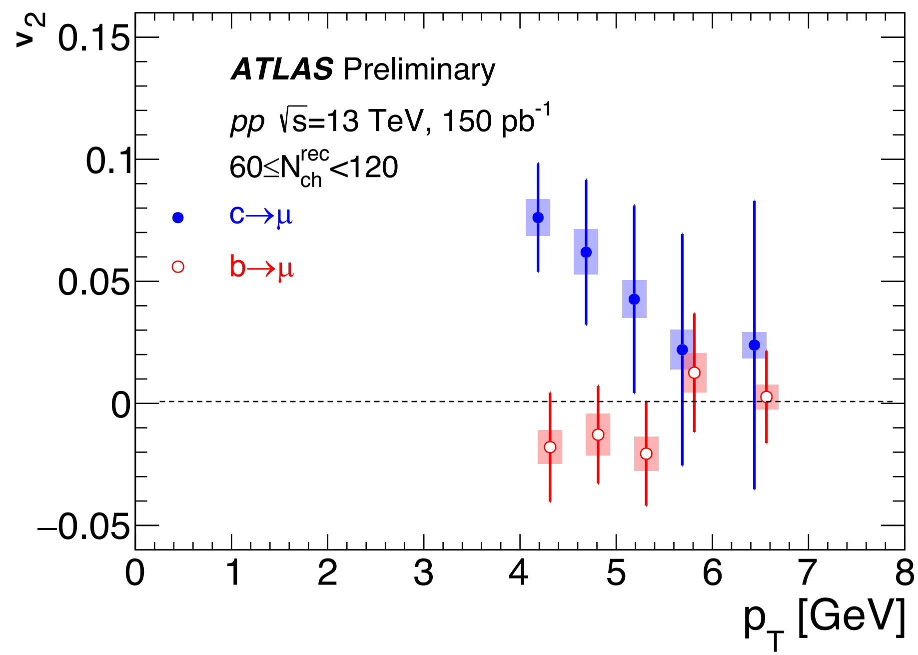
Extrapolate low d_0 region to $f^{sig} = 1$

$$v_{2,2}^{sig} = f^{b\to\mu} v_{2,2}^{b\to\mu} + (1 - f^{b\to\mu}) v_{2,2}^{c\to\mu}$$

Now can solve for v_2 charm and v_2 bottom

Charm and Bottom Elliptic Flow in *pp* 13 TeV



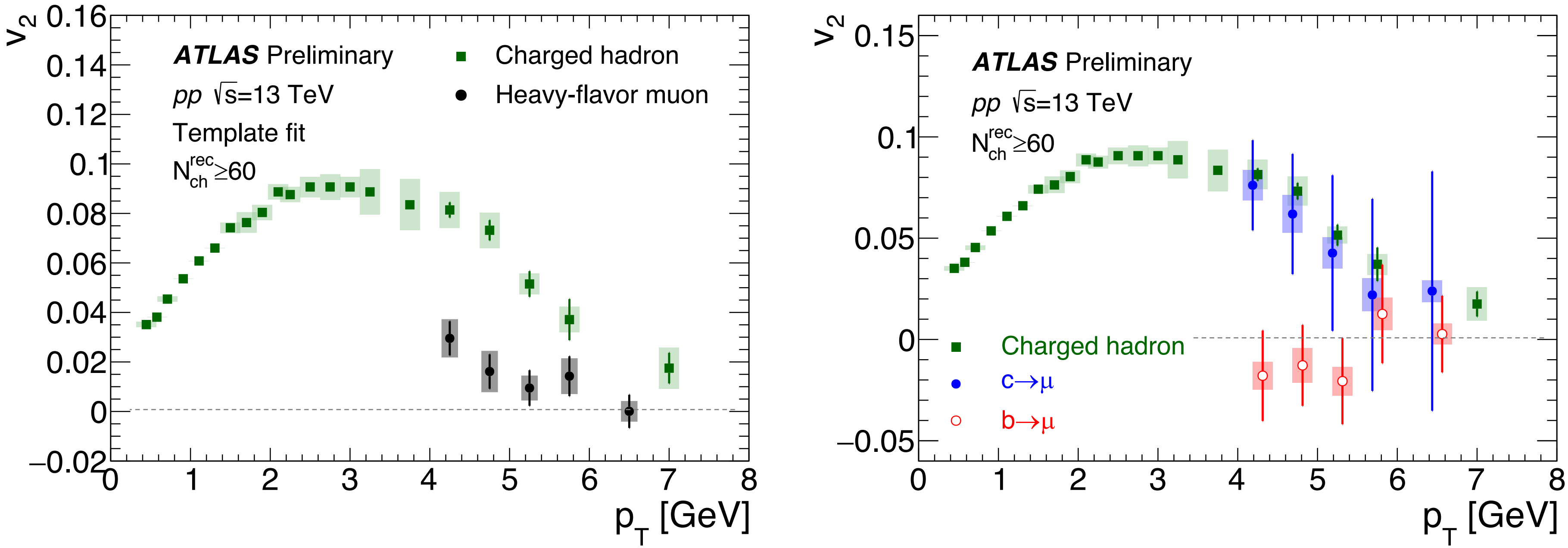


Charm decay muons show significant non-zero v_2!
Consistent with independent of N_{ch}^{rec} and decreasing with p_T

Bottom decay muons have v_2 consistent with zero within uncertainties

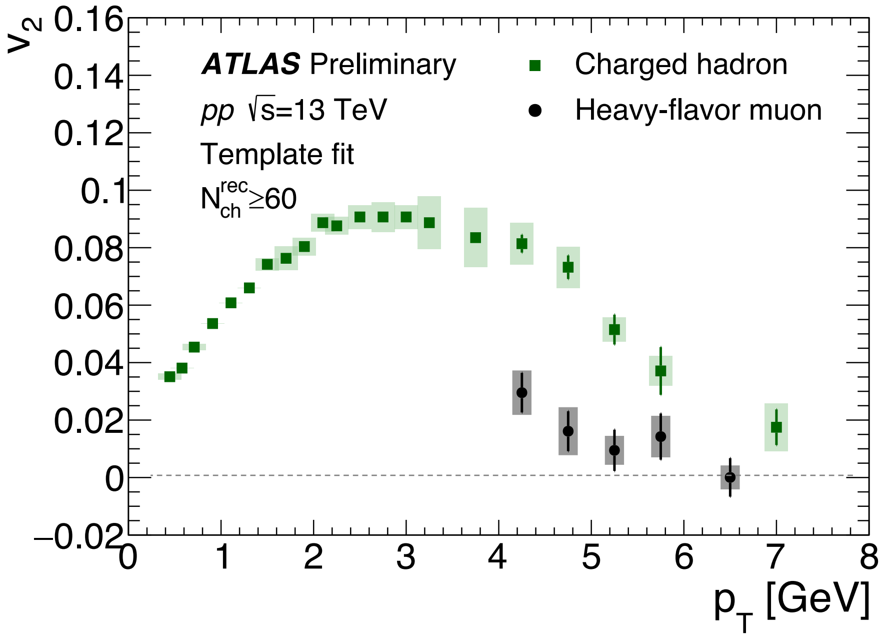
No theory calculations available yet. Excited to see possible physics explanations.

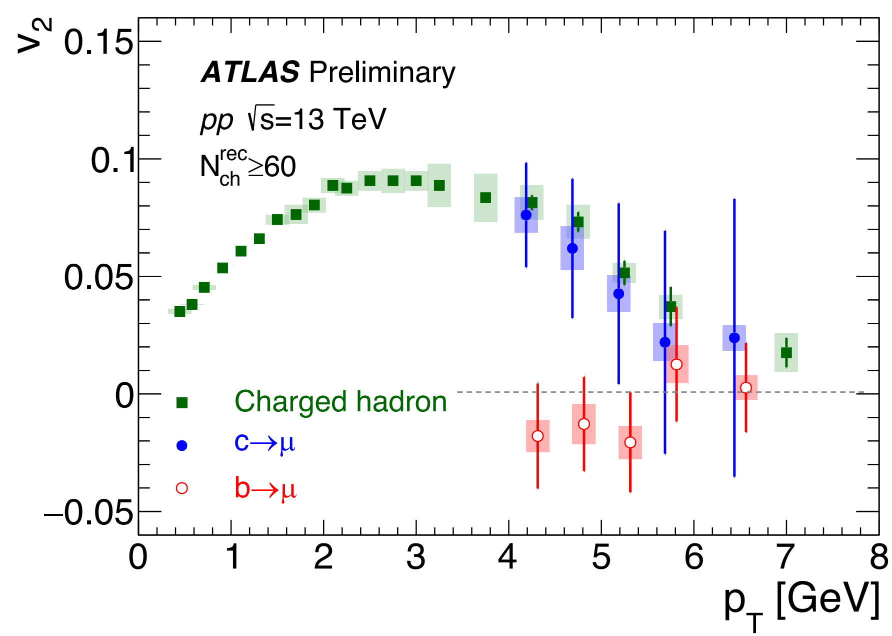
Comparison with Charged Hadrons



Muons from charm have v_2 similar to charged hadrons.

Comparison with Charged Hadrons



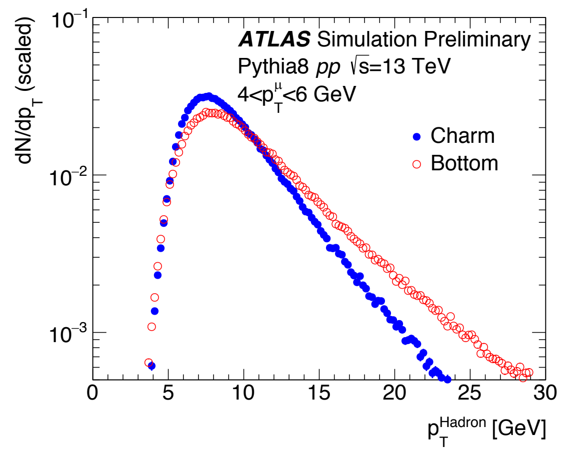


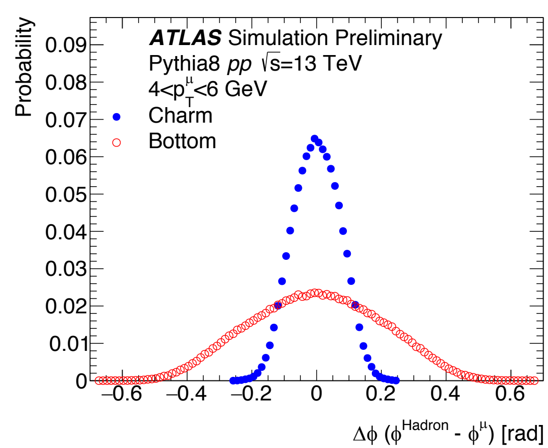
Muons from charm have v_2 similar to charged hadrons.

Caveat: kinematics really matter

Charm muons p_T =4-6 GeV come from charm hadrons with most probable p_T ~ 7 GeV

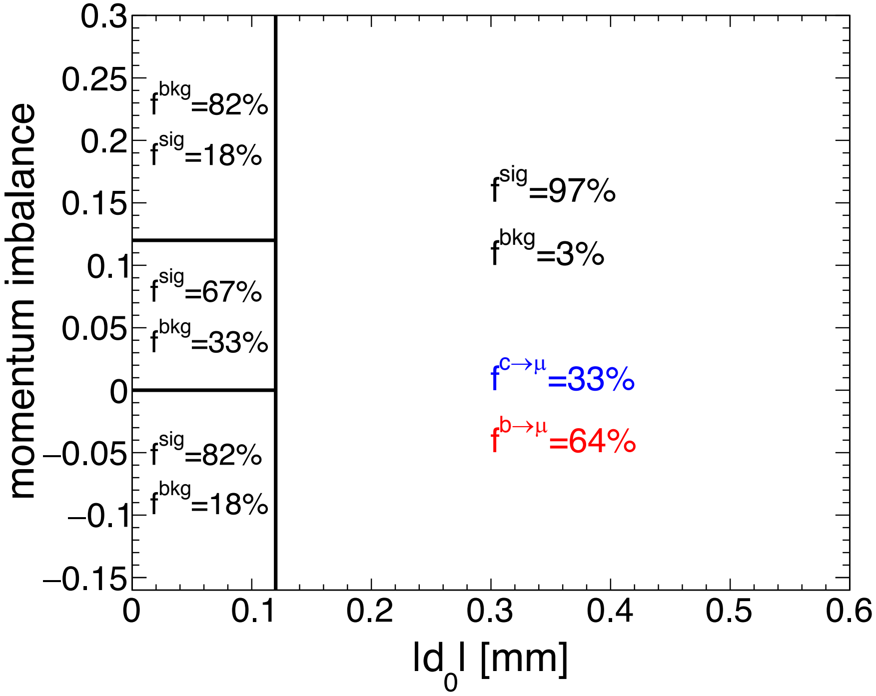
Also, there is an $\Delta\phi$ (hadron-muon) effect. This is modest.

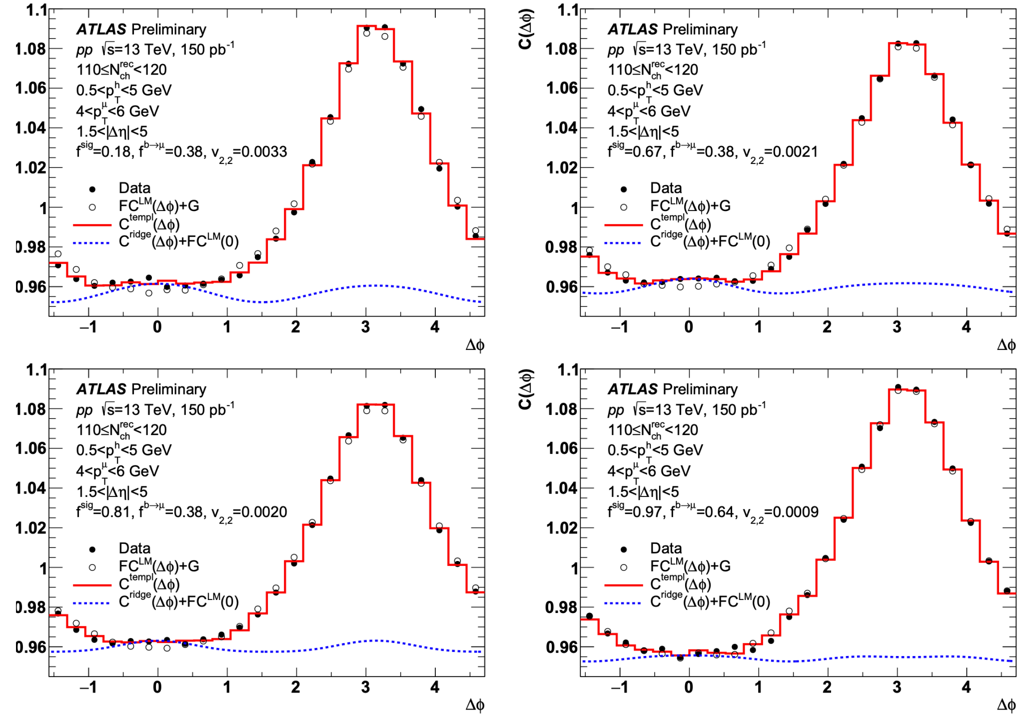




Thank you!

Charm and Bottom Separation





$V_{2,2}$ Correlations