Heavy flavour production and flow in large and small systems with ATLAS

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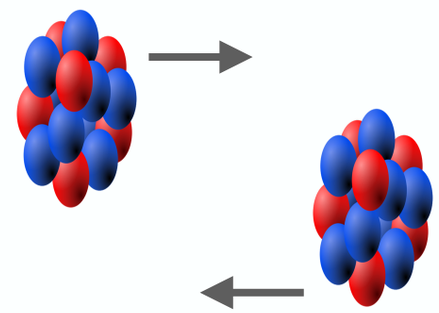
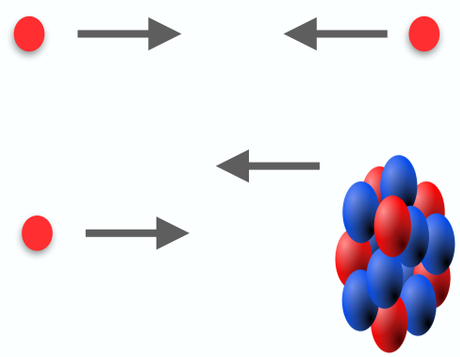
Hard Probes 2018

Physics motivation

- conserved from its production at an early stage of the collision
- charm and beauty production calculable from pQCD
- <u>A+A collisions</u>:
  - flavour dependent energy loss
  - transfer of the collective motion



- <u>*p*+A and *pp* collisions</u>:
  - baseline for A+A collisions
  - pQCD tests and CNM effects
  - probing collectivity in small systems
- measuring R_{AA}, v_2

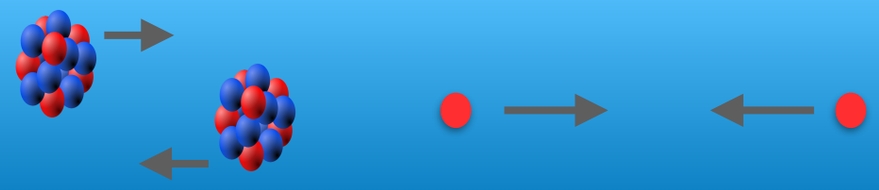


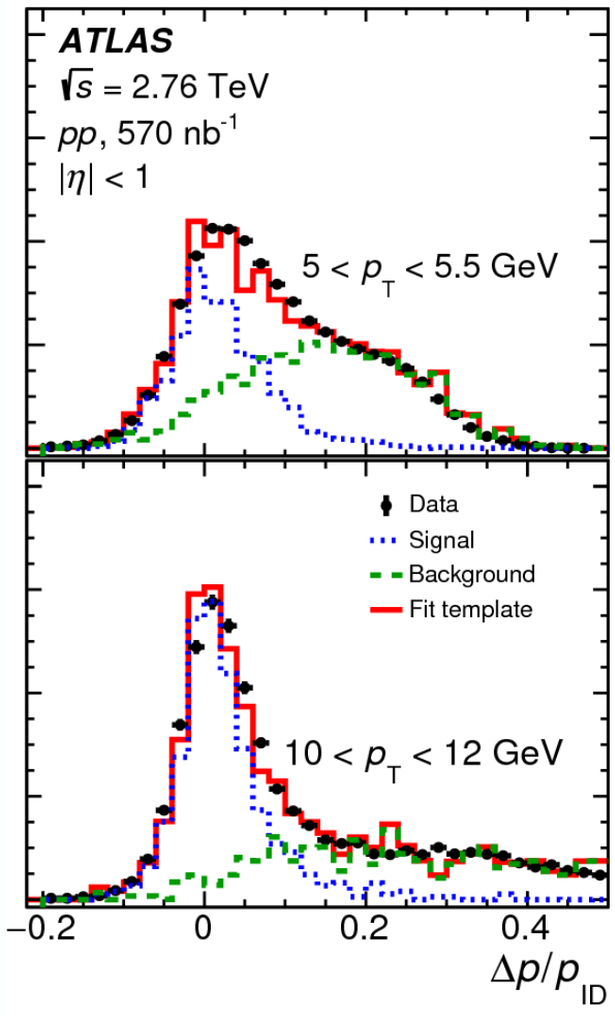
ATLAS measurements

- Heavy flavour muons (open charm and beauty)
  - HF muon yield and flow in 2.76 TeV Pb+Pb
  - HF muon flow in 8.16 TeV p+Pb
- D meson (open charm)
  - D meson yield and flow in 8.16 TeV p+Pb
- Non-prompt J/ψ (open beauty)
  - Non-prompt J/ψ yield in 5.02 TeV Pb+Pb
  - Non-prompt J/ψ flow in 5.02 TeV Pb+Pb **NEW**
  - Non-prompt J/ψ yield in 5.02 TeV p+Pb

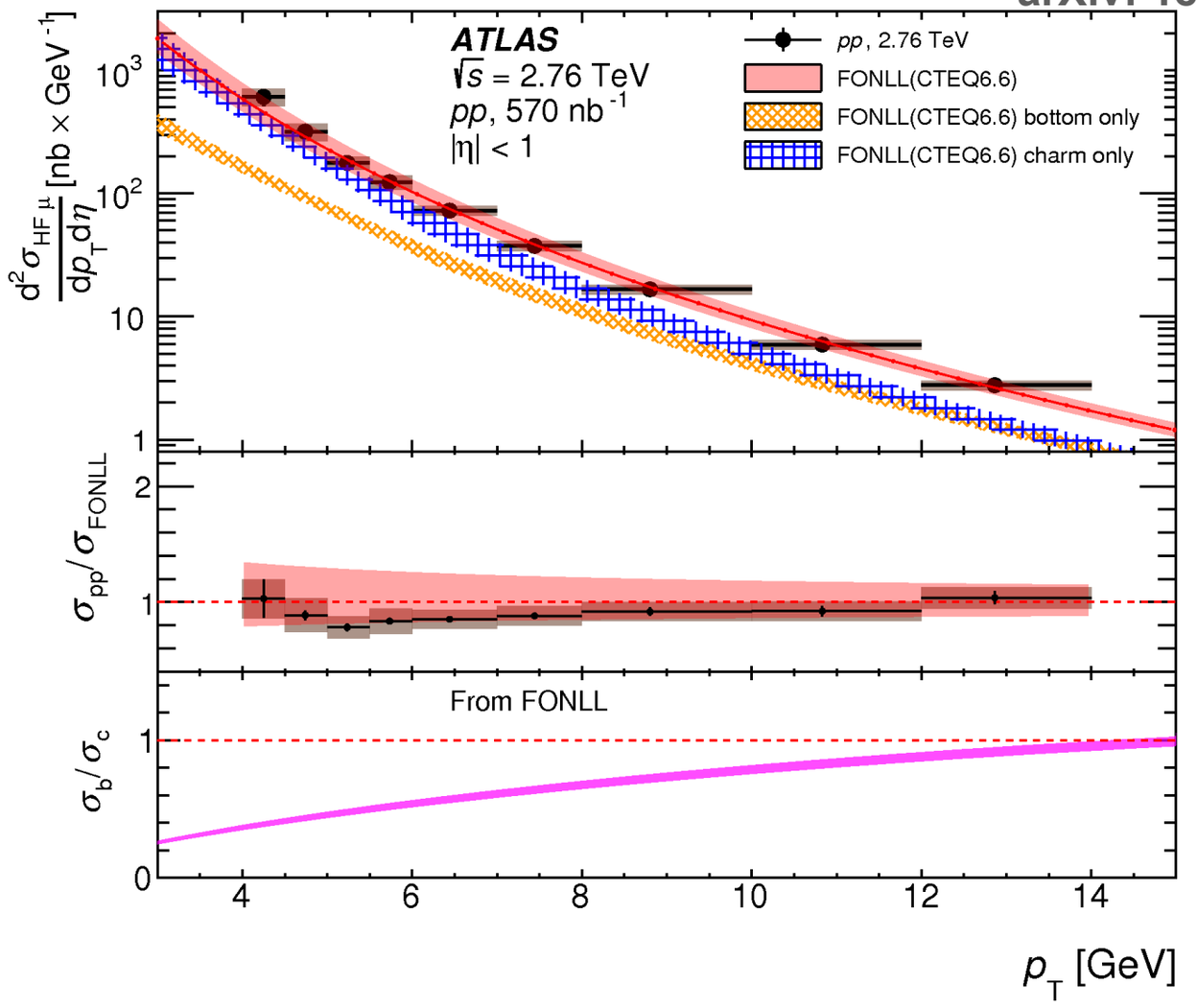
Sebastian Tapia Araya, this session

HF muon yields



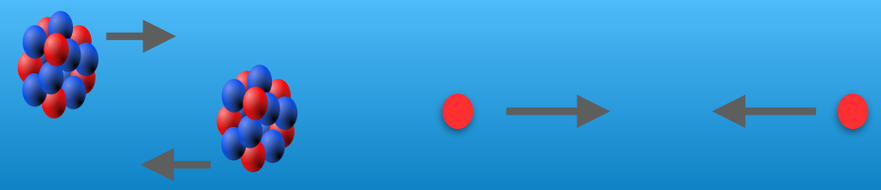


arXiv: 1805.05220

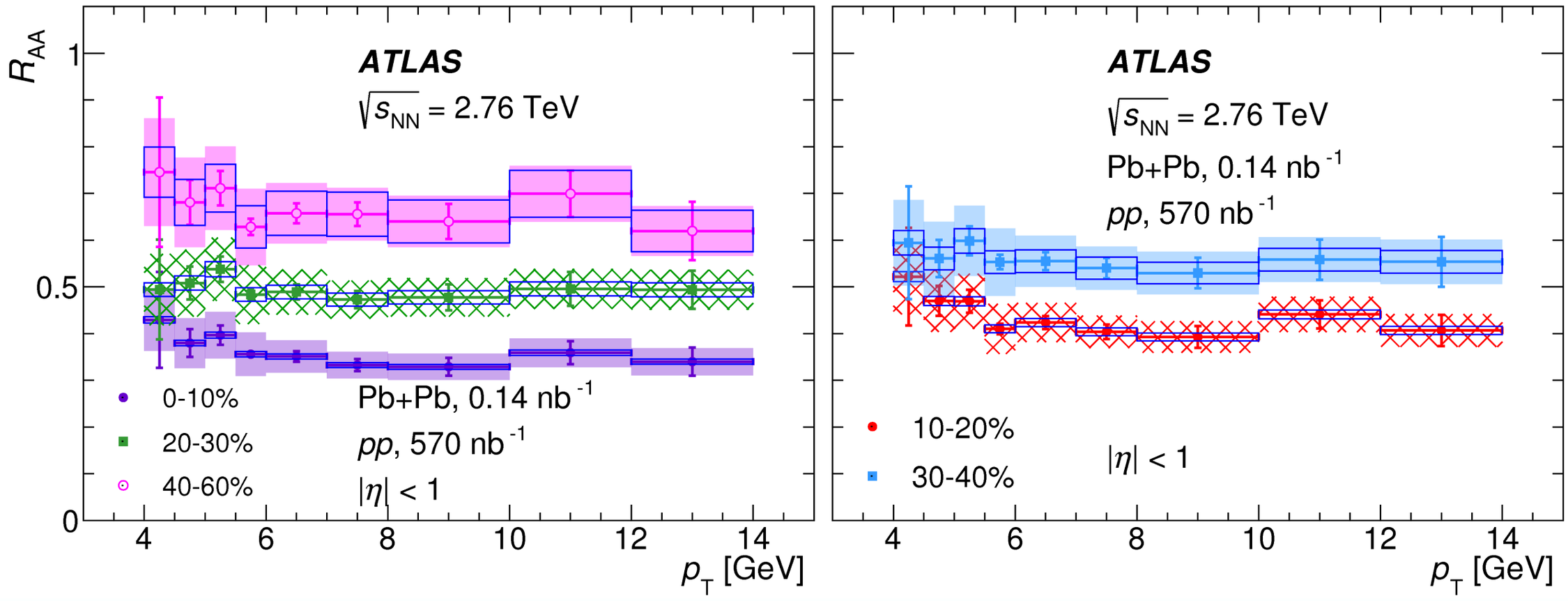


- separation of the signal and background by using the momentum imbalance cut: $\Delta p/p_{ID} = [p_{ID}-(p_{MS+}p_{Calo})]/p_{ID}$
- using template fits obtained from the MC
- pp reference in agreement with the FONLL calculation

HF muon R_{AA}



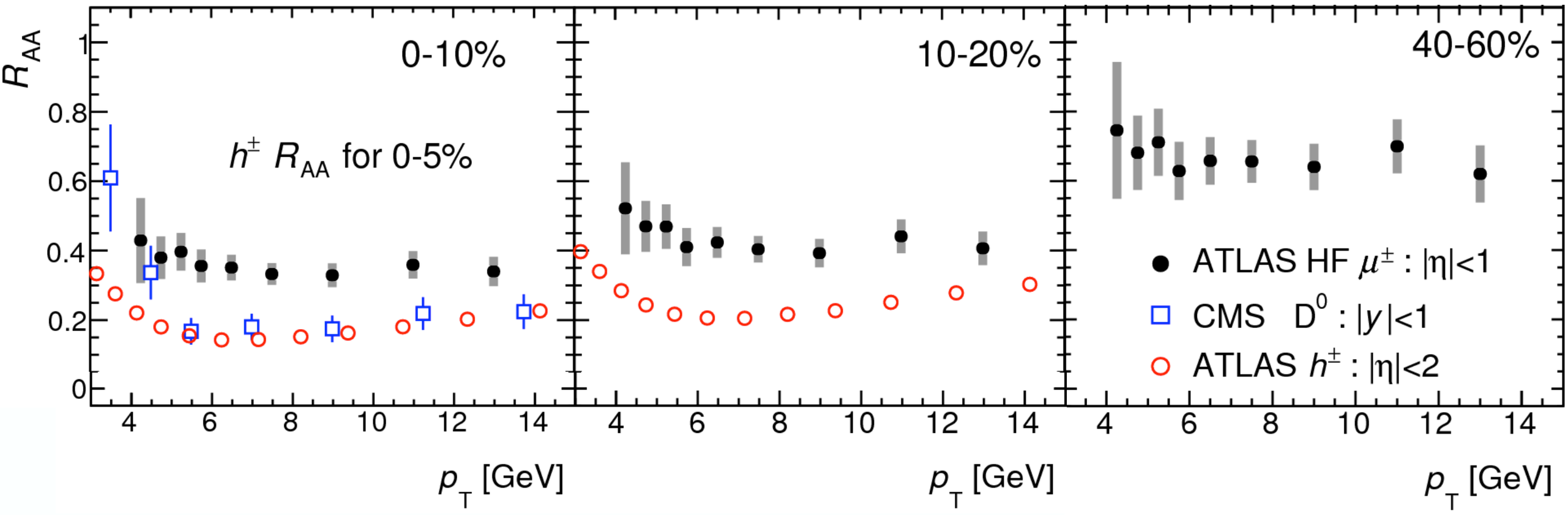
arXiv: 1805.05220



- measured in 5 centrality slices from 0-60%
- suppression scales with centrality from ~0.35 (most central) to ~0.65 (peripheral)
- no significant dependence on the p_T regime

HF muon R_{AA}: ATLAS vs CMS D^0

arXiv: 1805.05220

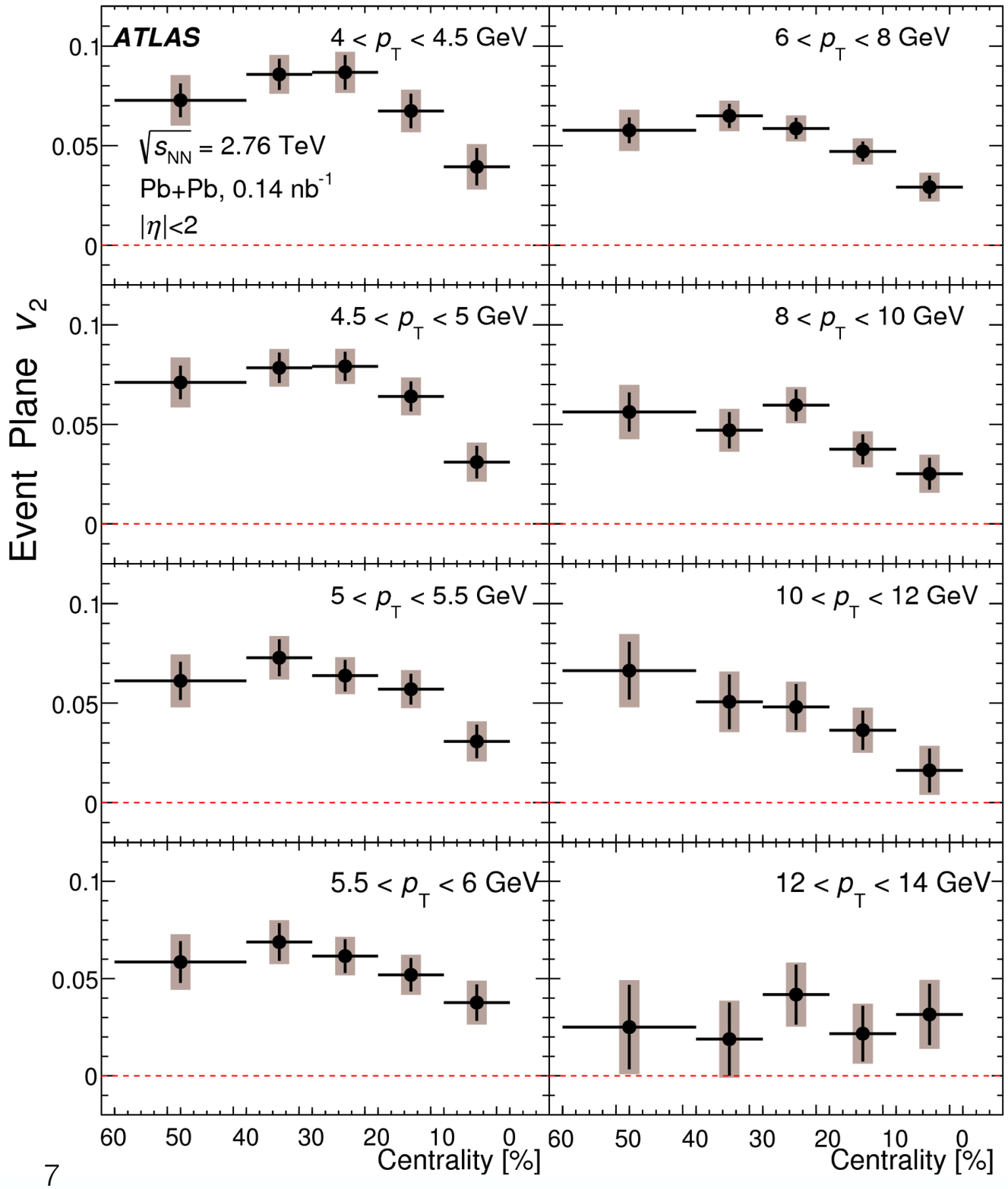


- similar in the low p_T regime
- HF muons less suppressed for the higher p_T regime

HF muon v_2 in Pb+Pb

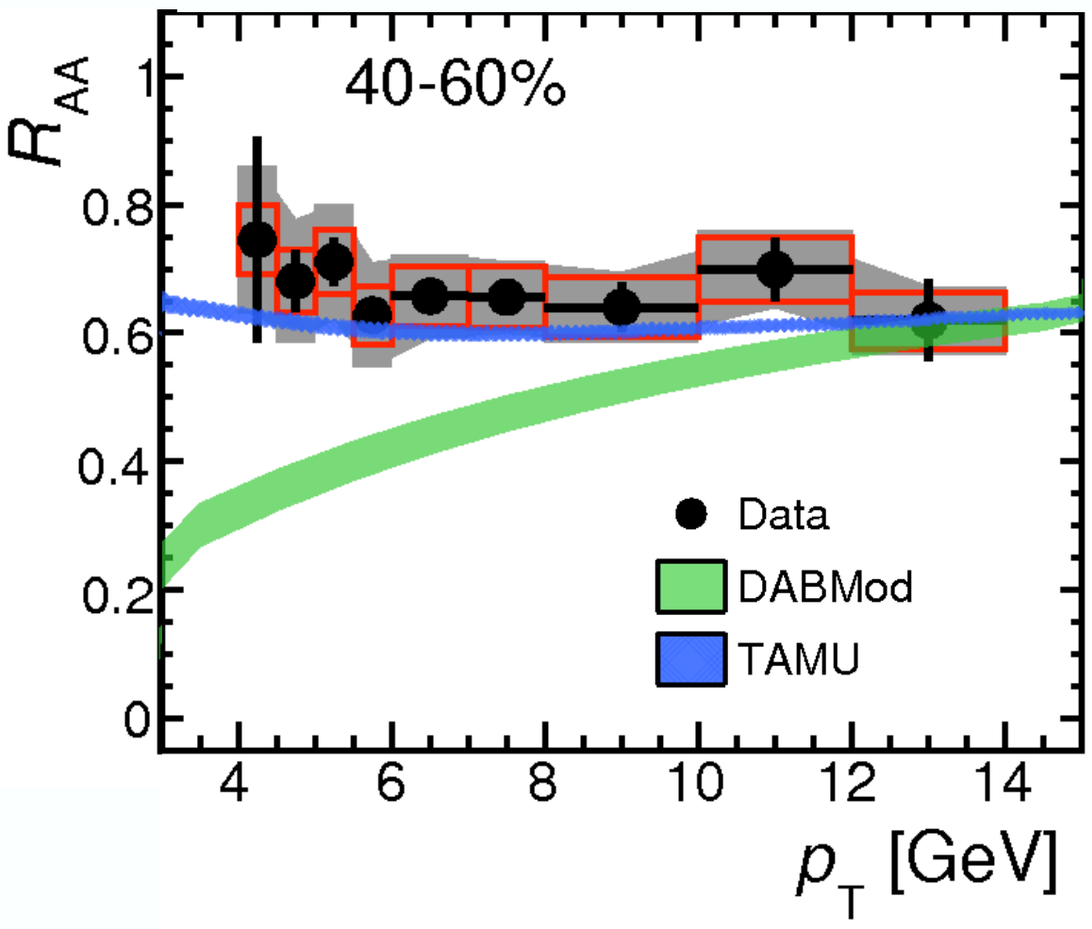
arXiv: 1805.05220

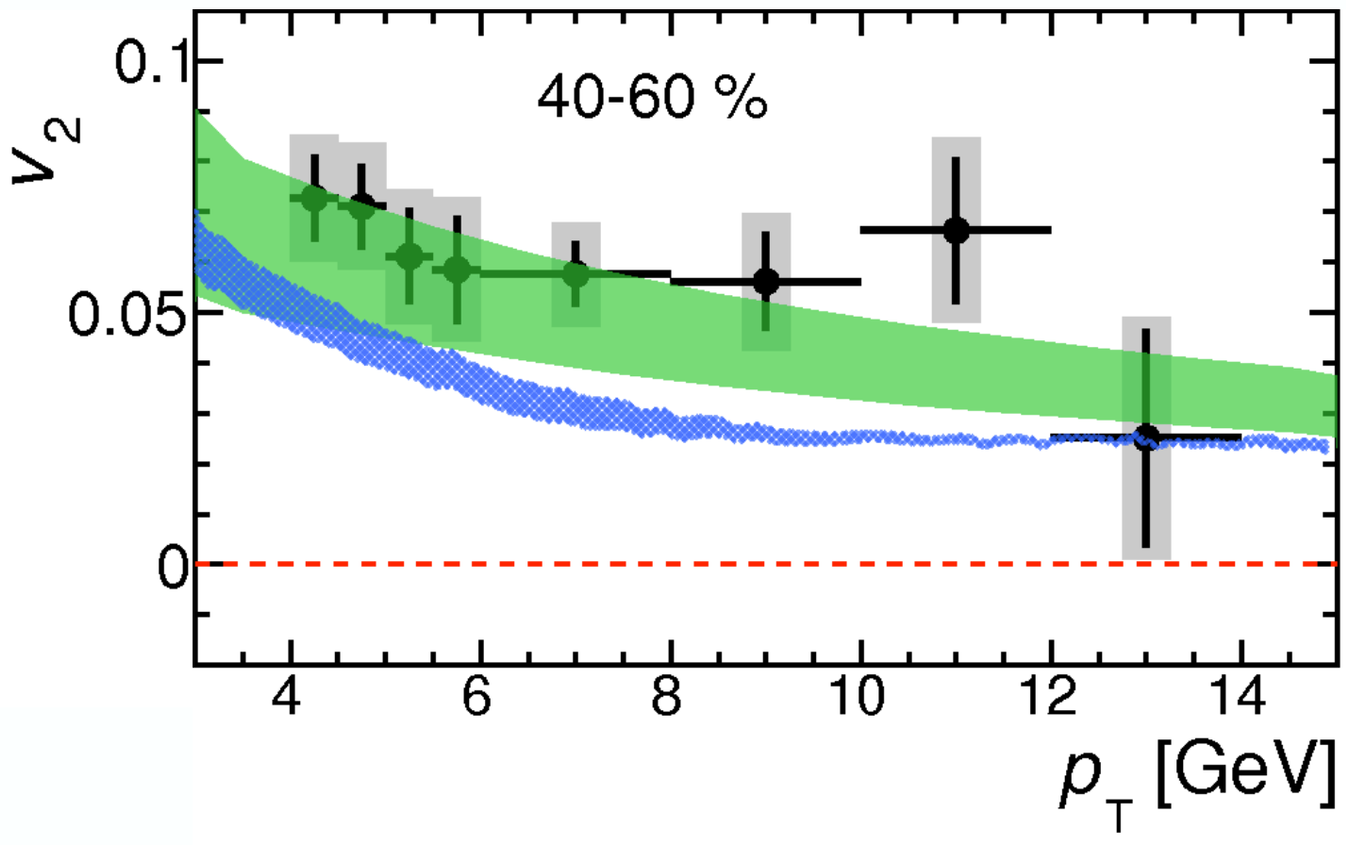
- v_2 extracted by using the event plane method
- consistent with the scalar product method
- momentum imbalance template fits used for the combinatorial background subtraction
- significant v_2 measured in 8 p_T slices and in all centrality classes



HF muon R_{AA} and v_2 vs calculations

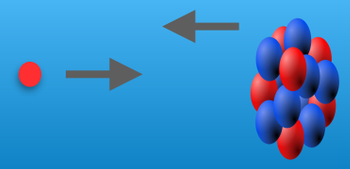
arXiv: 1805.05220
TAMU: PLB 735 (2014) 445
DABMod: PRC 96 (2017) 064903





- **TAMU** describes well the suppression magnitude but underestimates the flow (no even-by-event fluctuation)
- **DABMod** accounts correctly for the flow but overestimates the suppression in the low p_T regime (incomplete modelling of suppression at $p_T \lesssim m_b$)

HF muon flow in *p*+Pb



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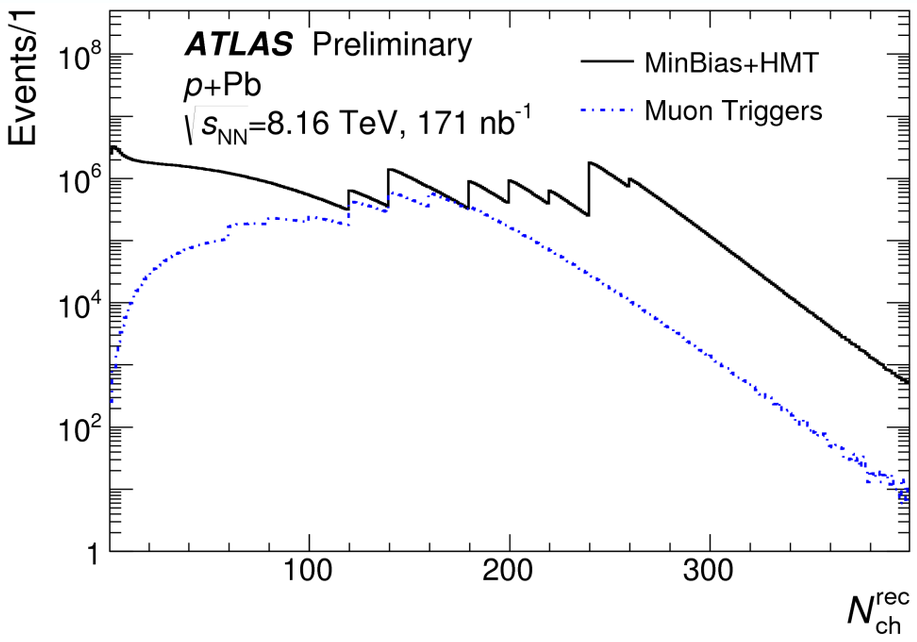
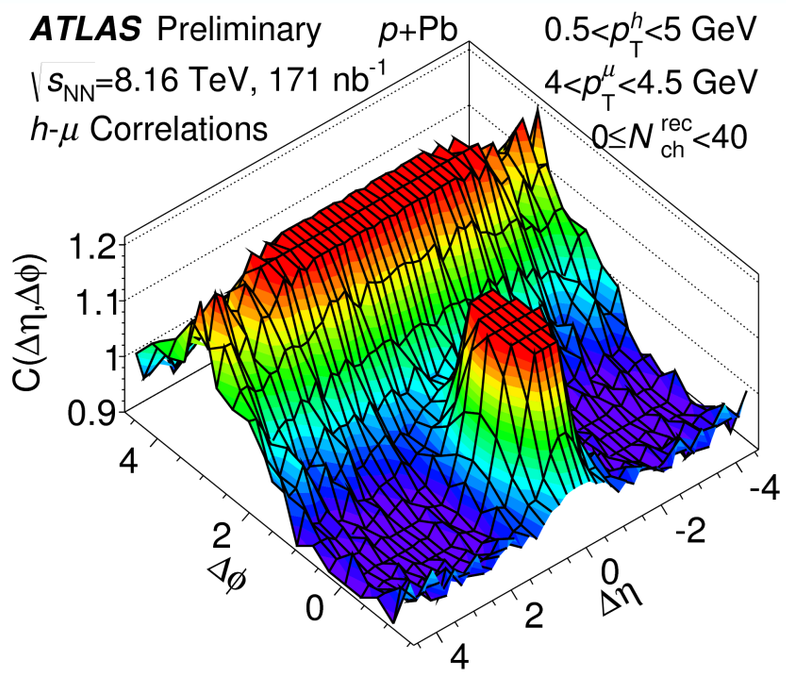
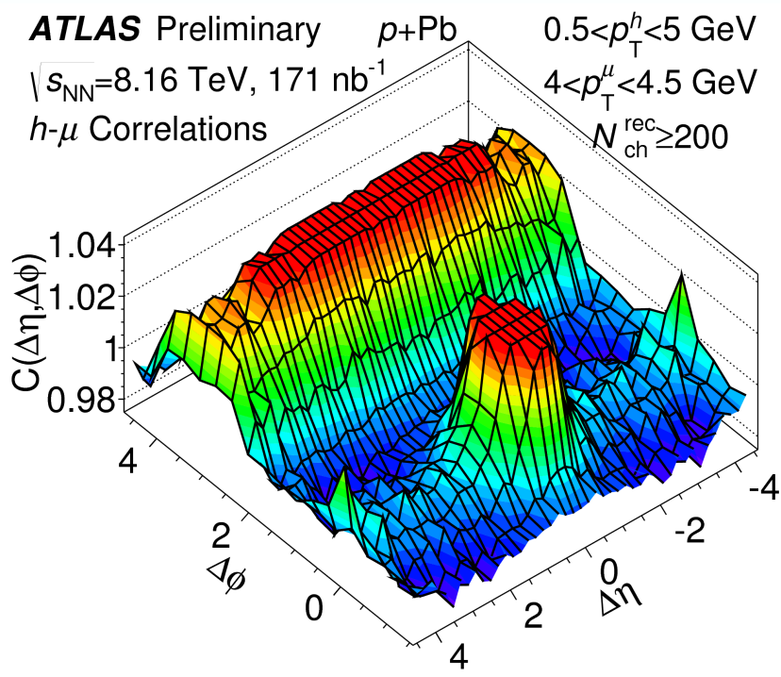


N_{ch}<40



N_{ch}>200

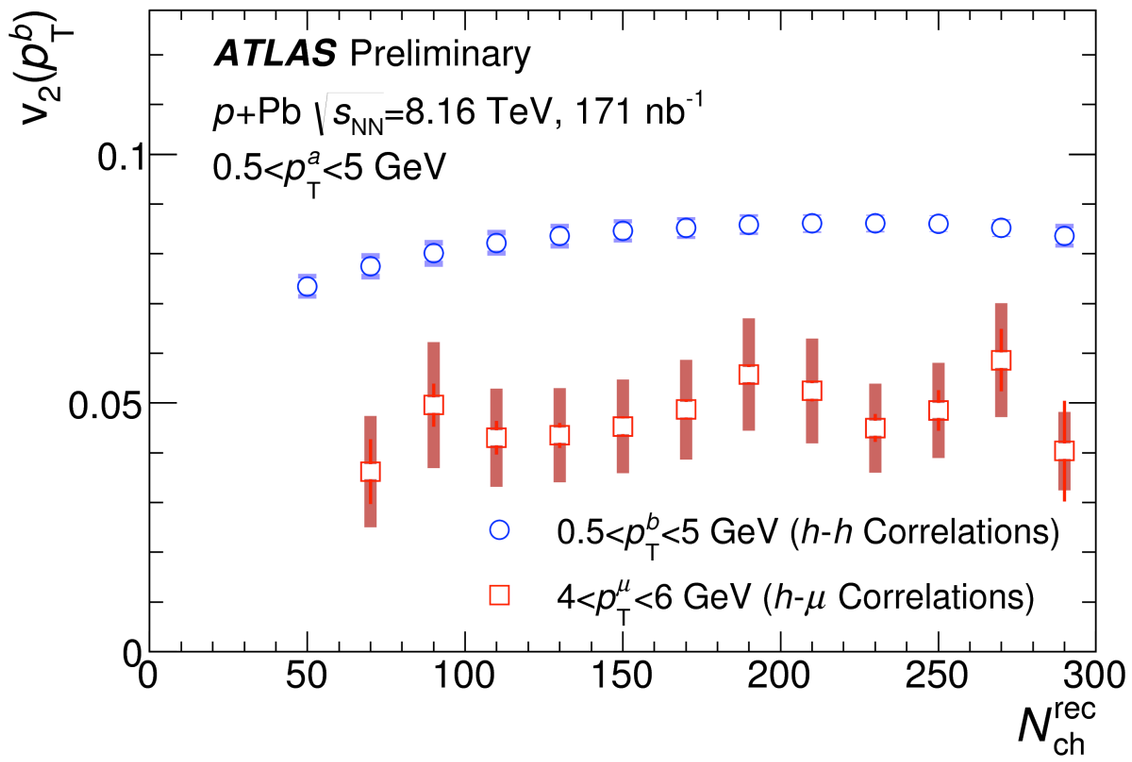


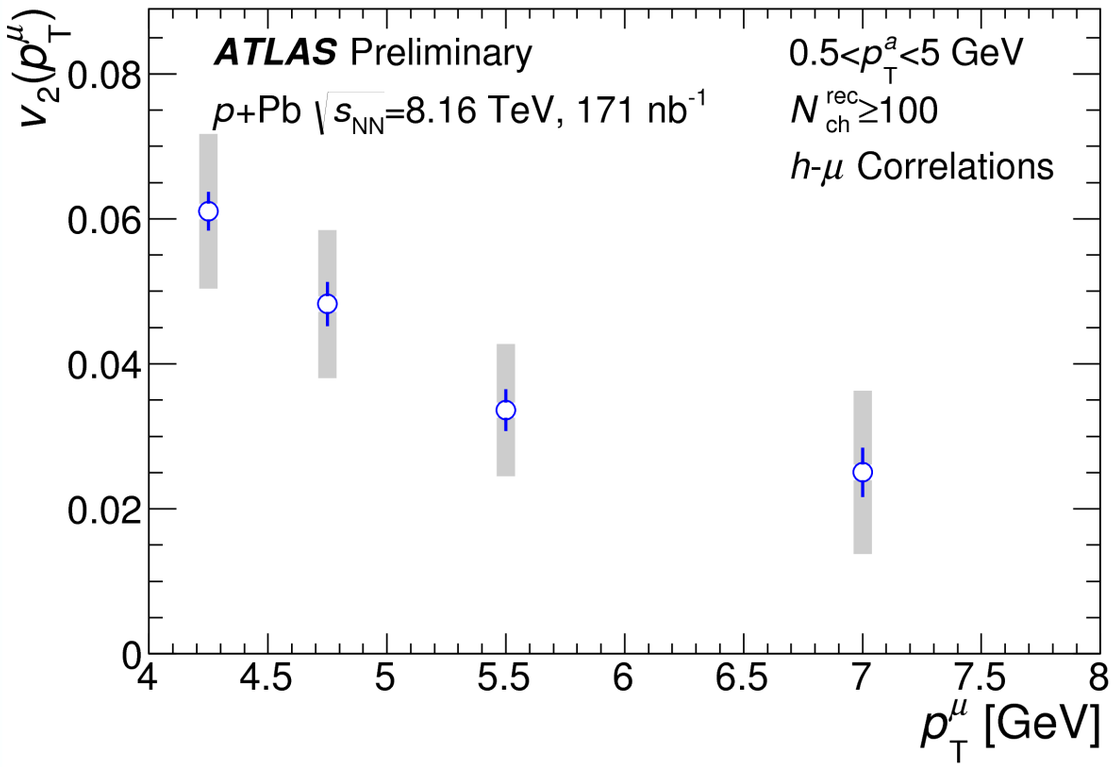
- events collected by requiring a muon and high track multiplicity
- measuring the correlation function for the HF muon and charged hadrons

$$v_n(p_T^{\mu}) = \frac{v_{n,n}(p_T^{h}, p_T^{\mu})}{\sqrt{v_{n,n}(p_T^{h}, p_T^{h})}}$$

HF muon flow in *p*+Pb

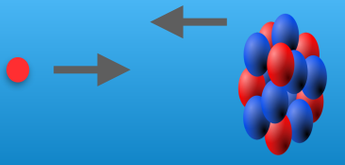
ATLAS-CONF-2017-006



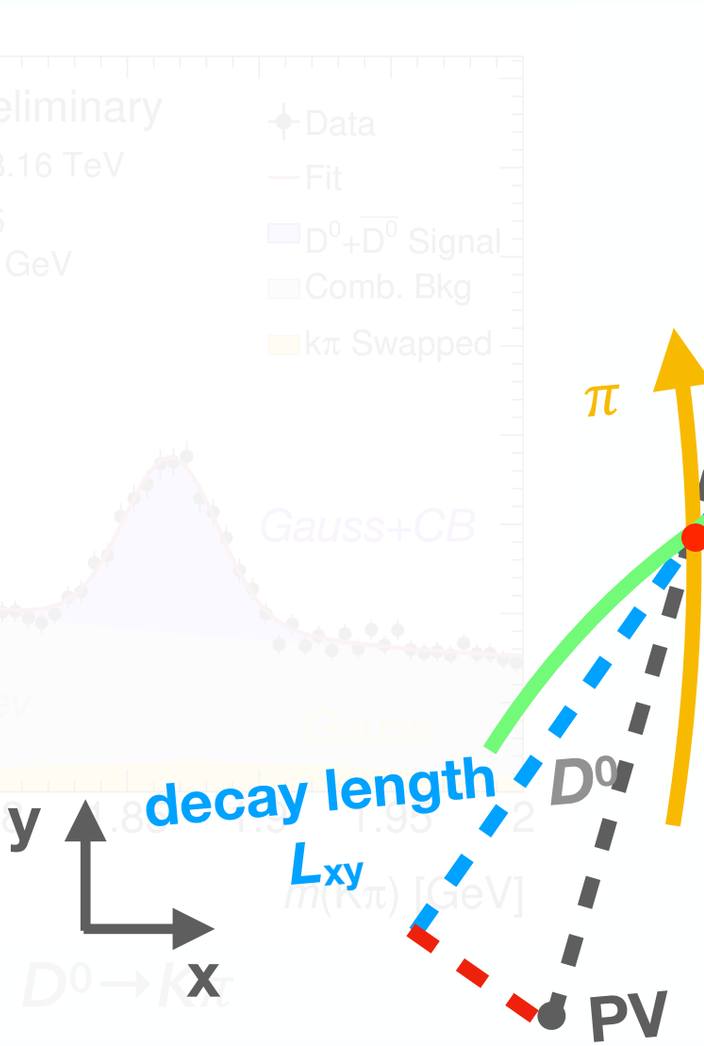


- HF muon v_2 constant over large range of multiplicities
- lower compared to the charged hadron flow (factor of ~0.6)

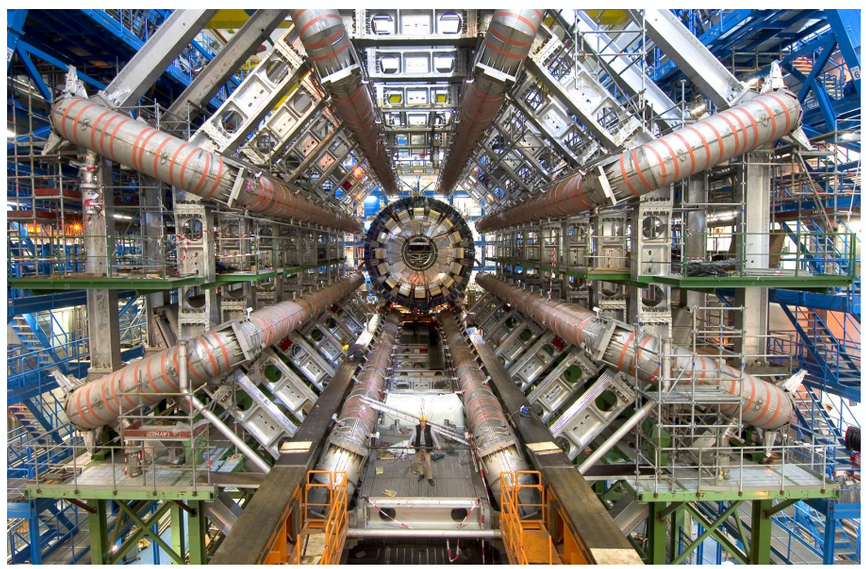
Prompt D^0 and D^* yield in p+Pb



ATLAS-CONF-2017-073



- events collected by the MinBias trigger
- $D^0 \rightarrow K\pi$ decay vertex selection:
  - vertex probability,
  - pointing angle,
  - decay length significance $L_{xy} / \sigma(L_{xy})$



Prompt D^0 and D^* yield in p+Pb

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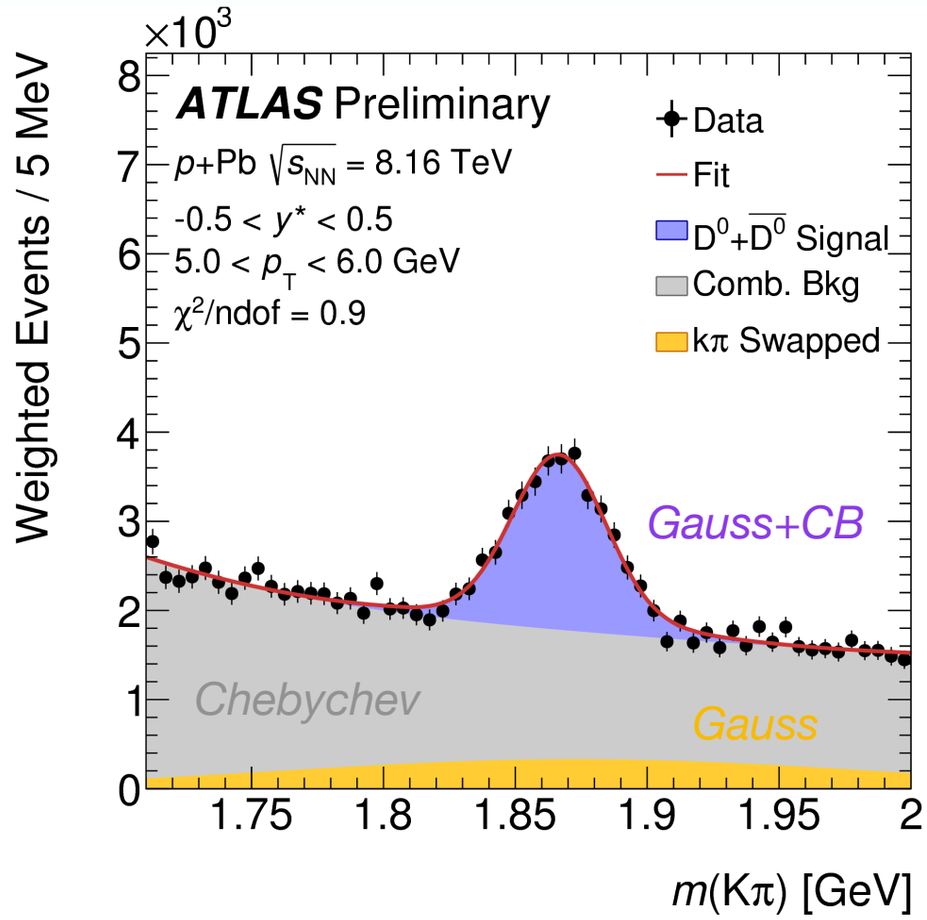
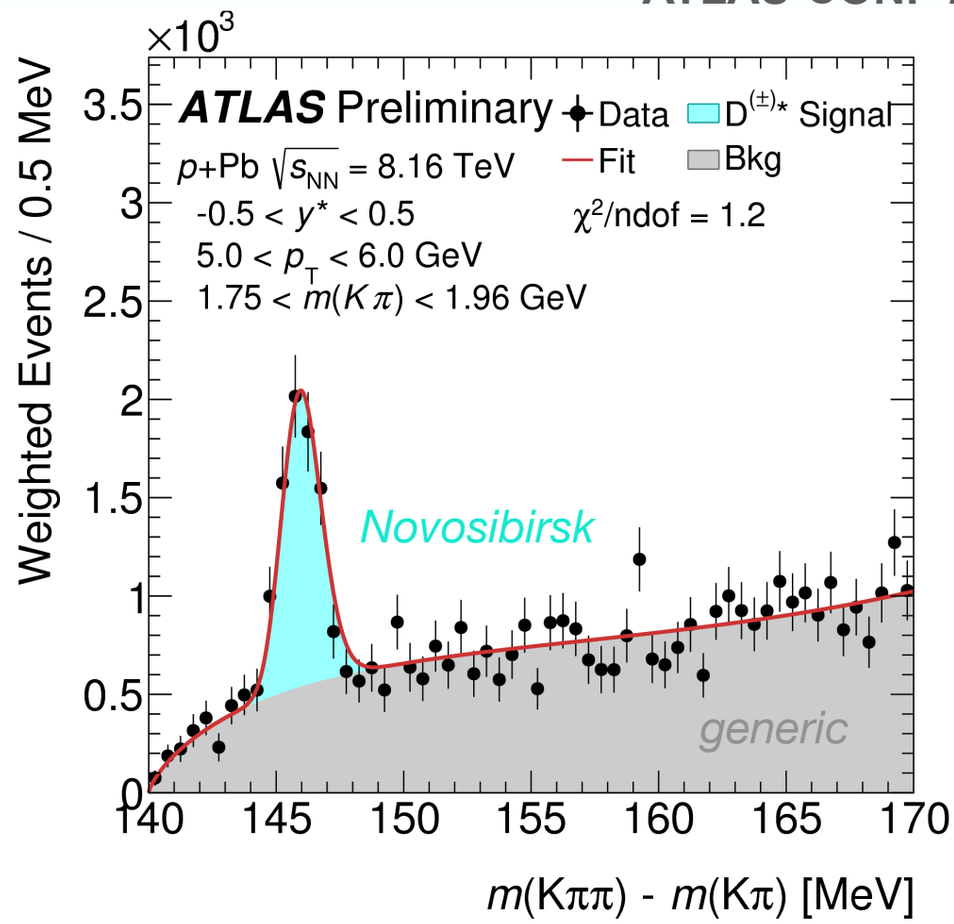


$D^0 \to K\pi$



$D^* \to D^0\pi_s \to K\pi\pi_s$

- open charm contribution dominates after the selection cuts

Prompt D⁰ and D* yield in *p*+Pb

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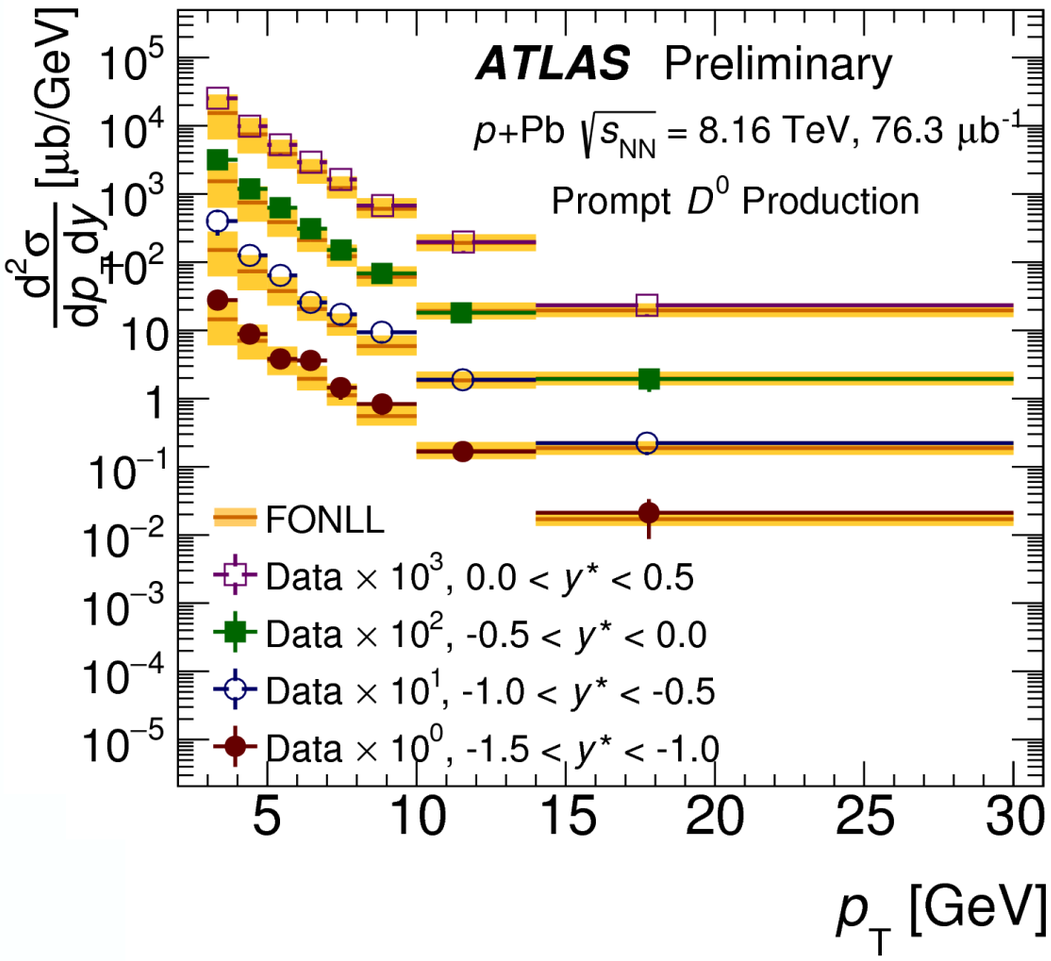
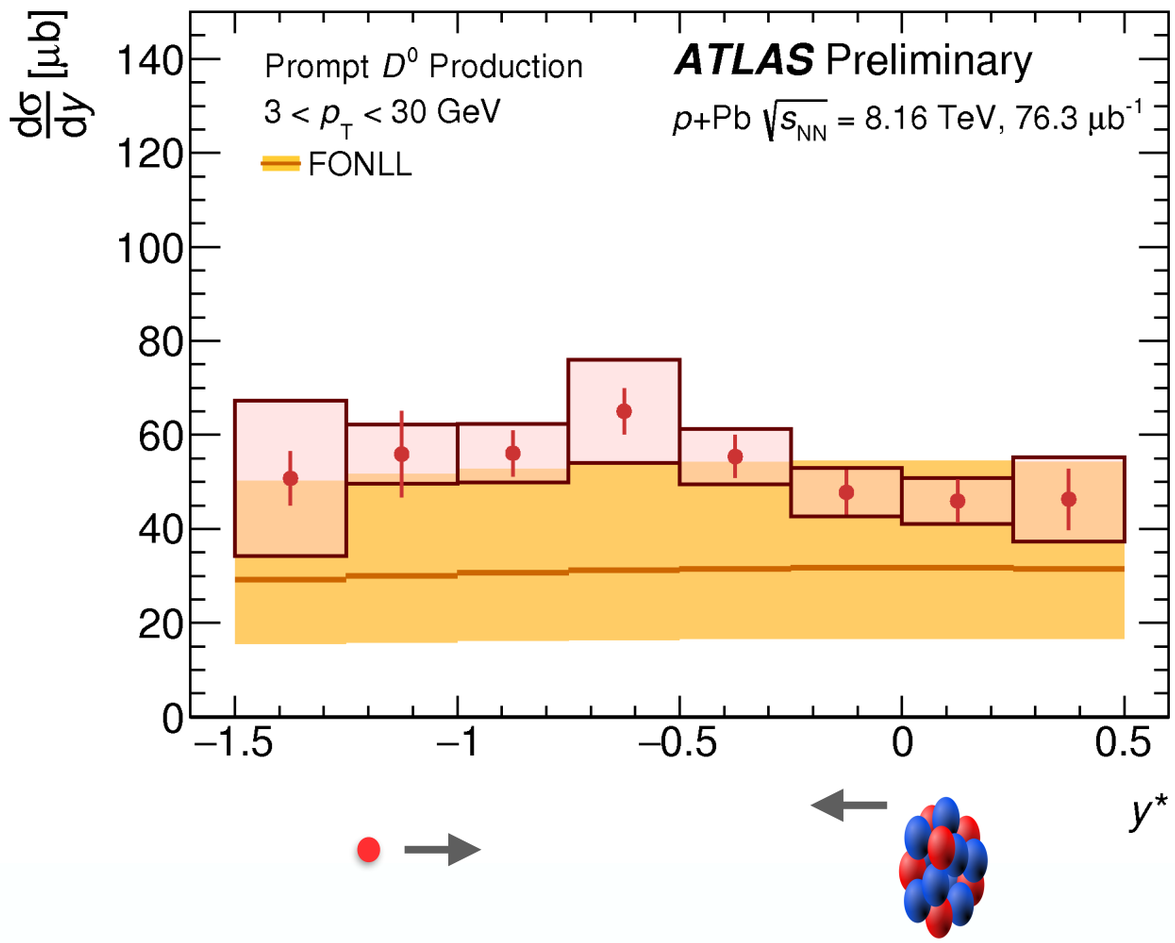


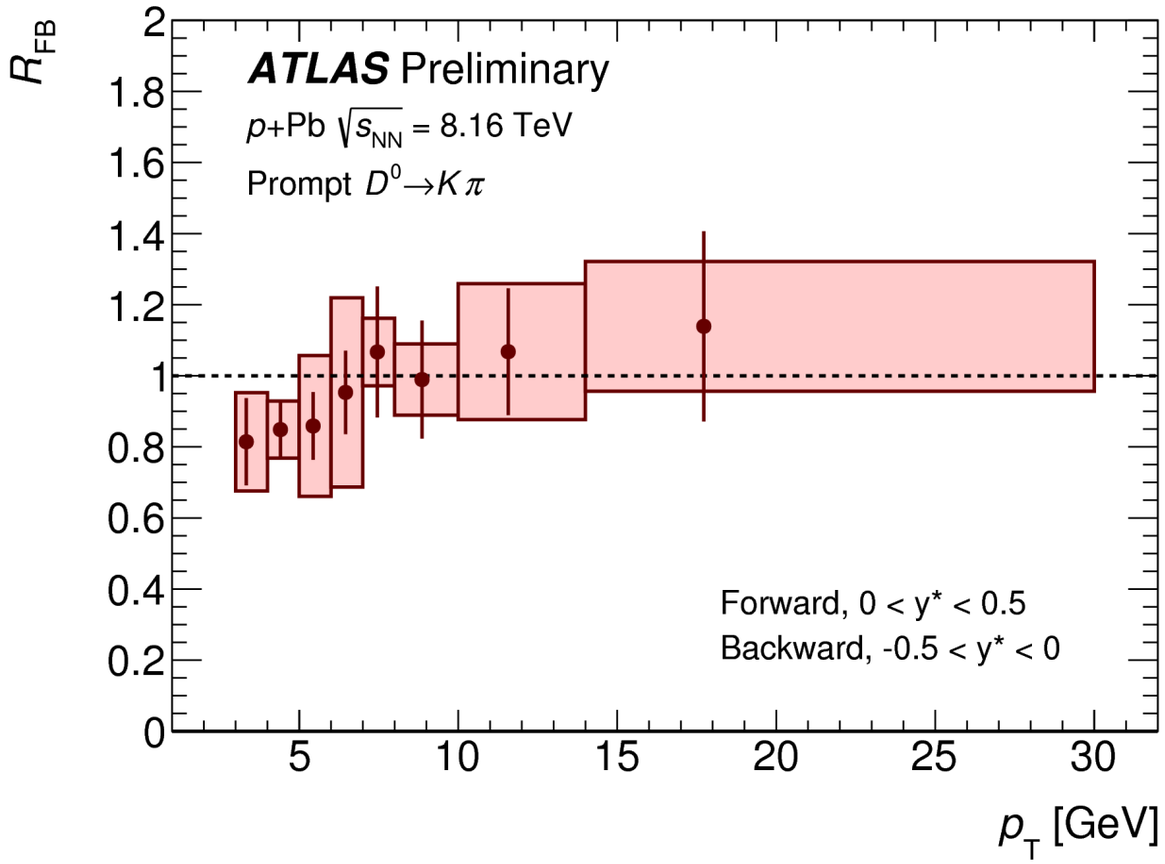


- prompt D⁰ measured in the range $3<p_T<30$ GeV
- compared to FONLL calculation at 8 TeV scaled by A(Pb)
- good agreement between data and theory

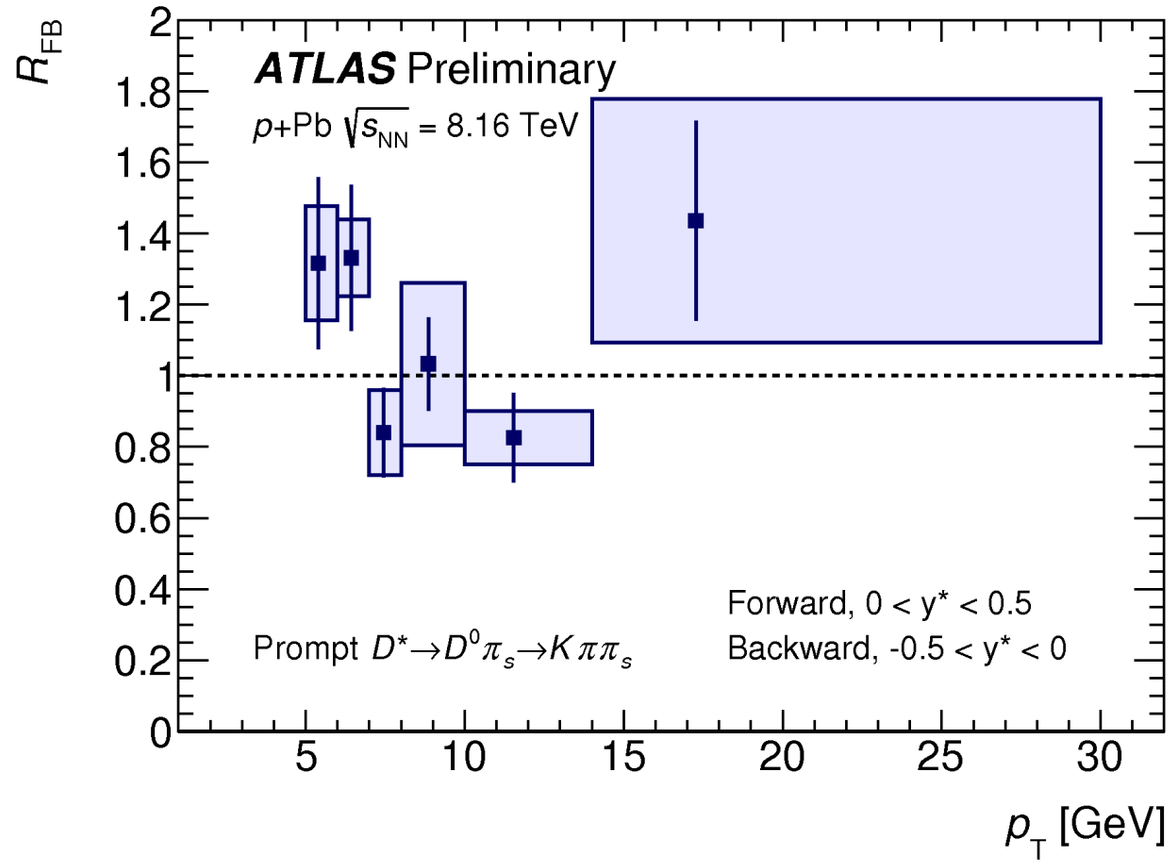
Prompt D^0 and D^* yield in p+Pb

ATLAS-CONF-2017-073

prompt D^0



prompt D^*



- forward defined as 0<y*<0.5 and backward as -0.5<y*<0
- no obvious modification for the prompt D meson
- LHCb result indicates p_T and rapidity dependence of the CNM effects

D* meson flow in *p*+Pb

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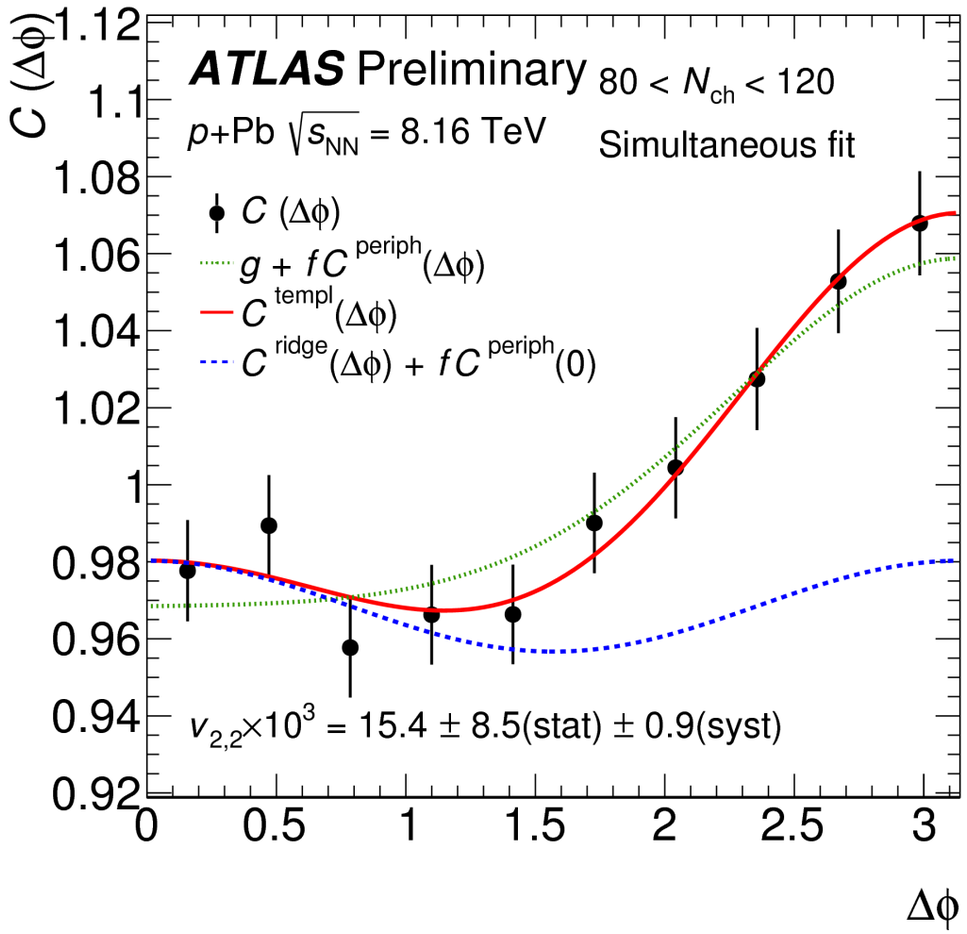
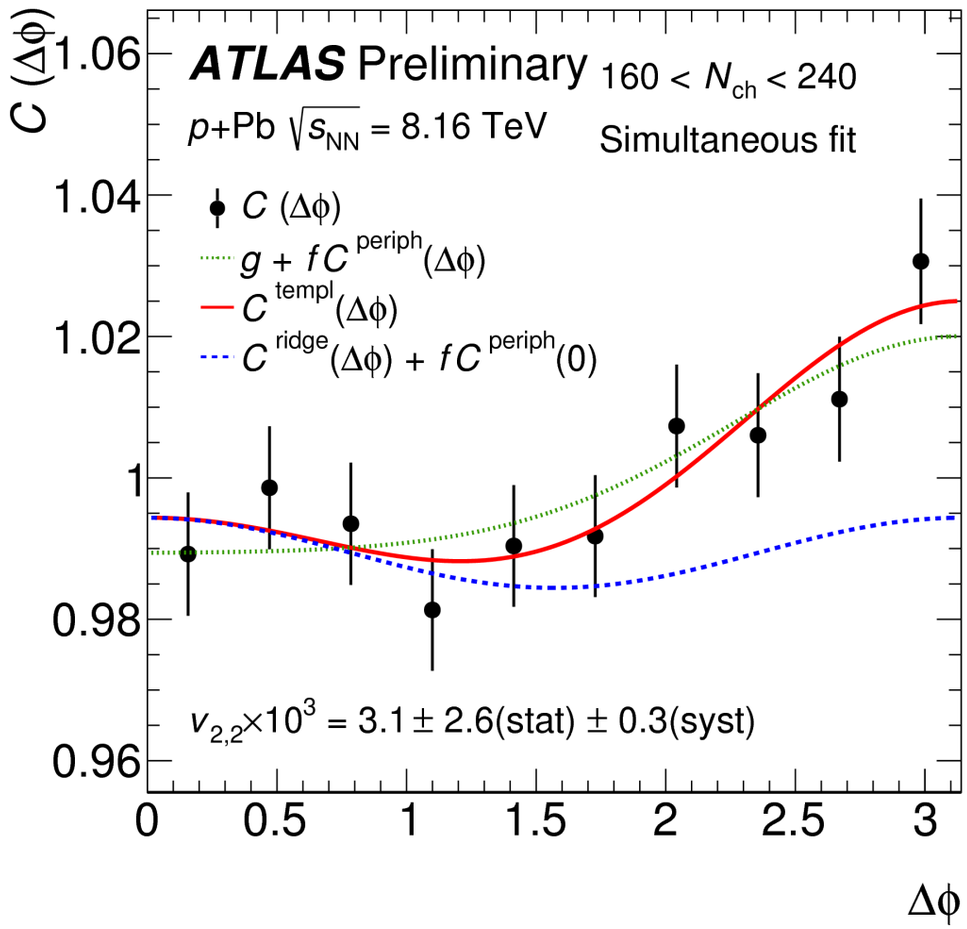
80<N_{ch}<120

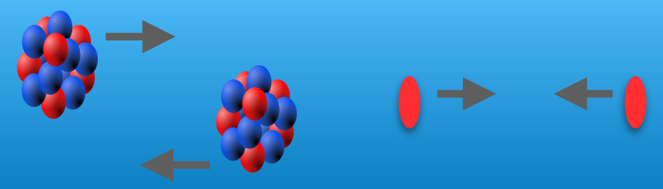


160<N_{ch}<240



- result favours non-zero coefficient for cos(2Δϕ)
  - statistical indication of the D* azimuthal modulation
- improved measurement of the D meson v_n coming soon

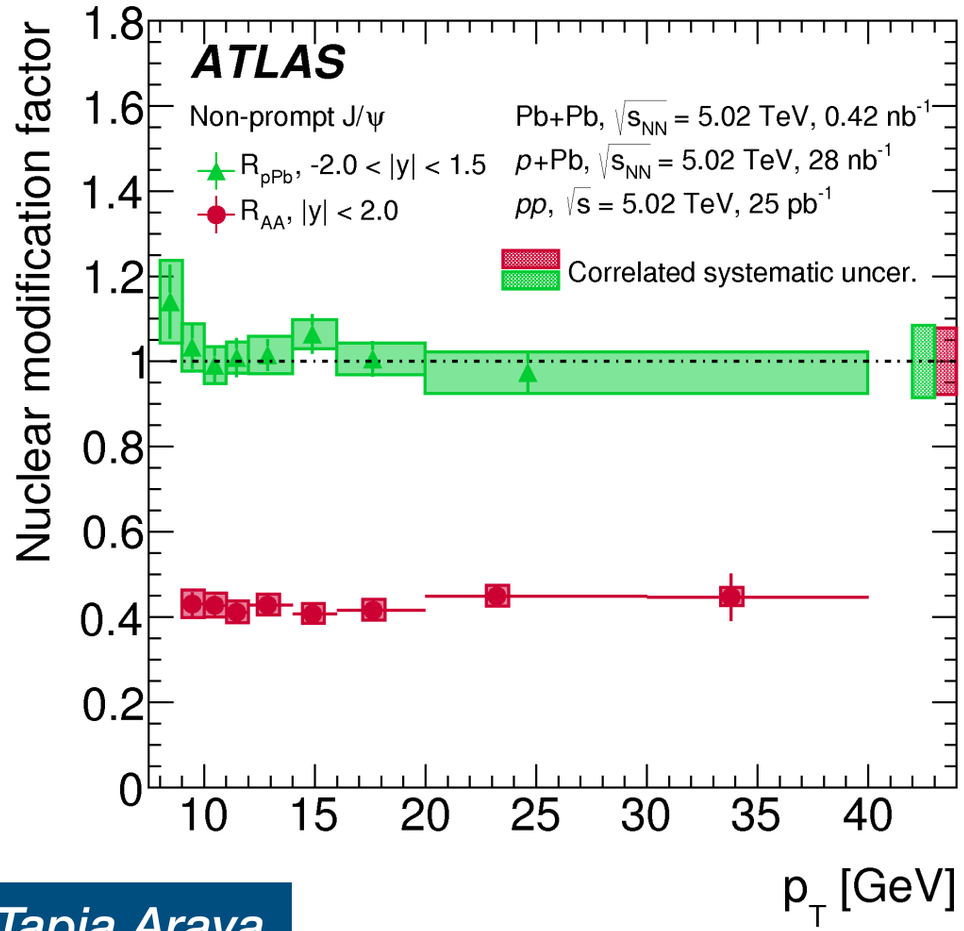
Non-prompt J/ψ R_{AA}

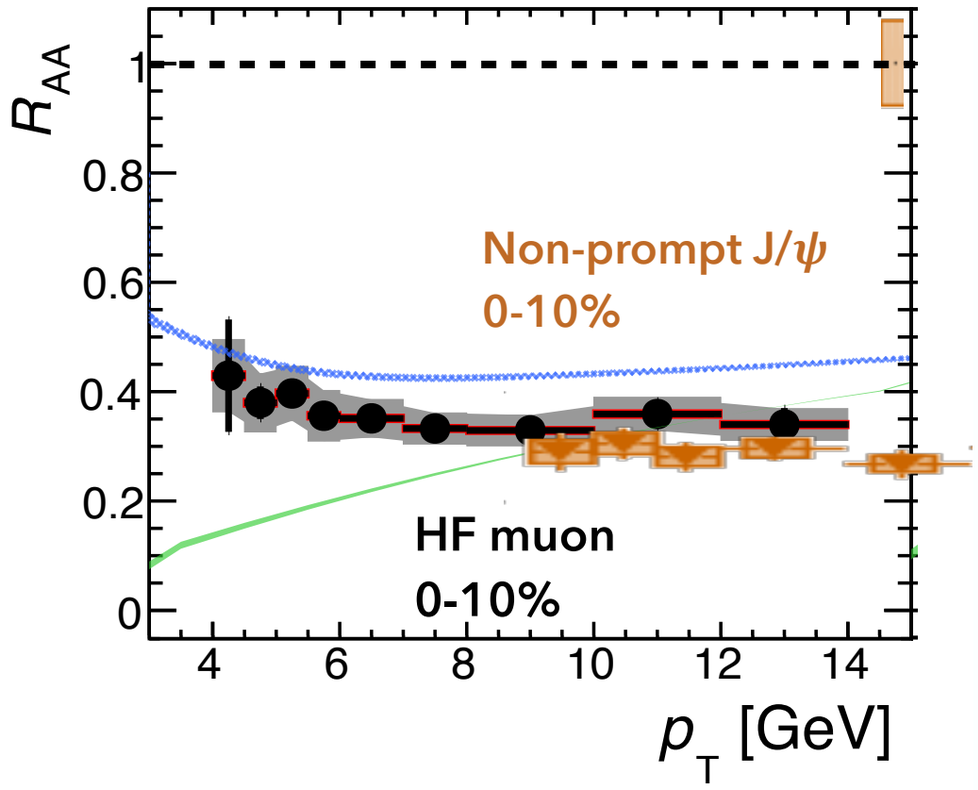


arXiv: 1805.05220
arXiv: 1805.04077

R_{pPb}

R_{AA}





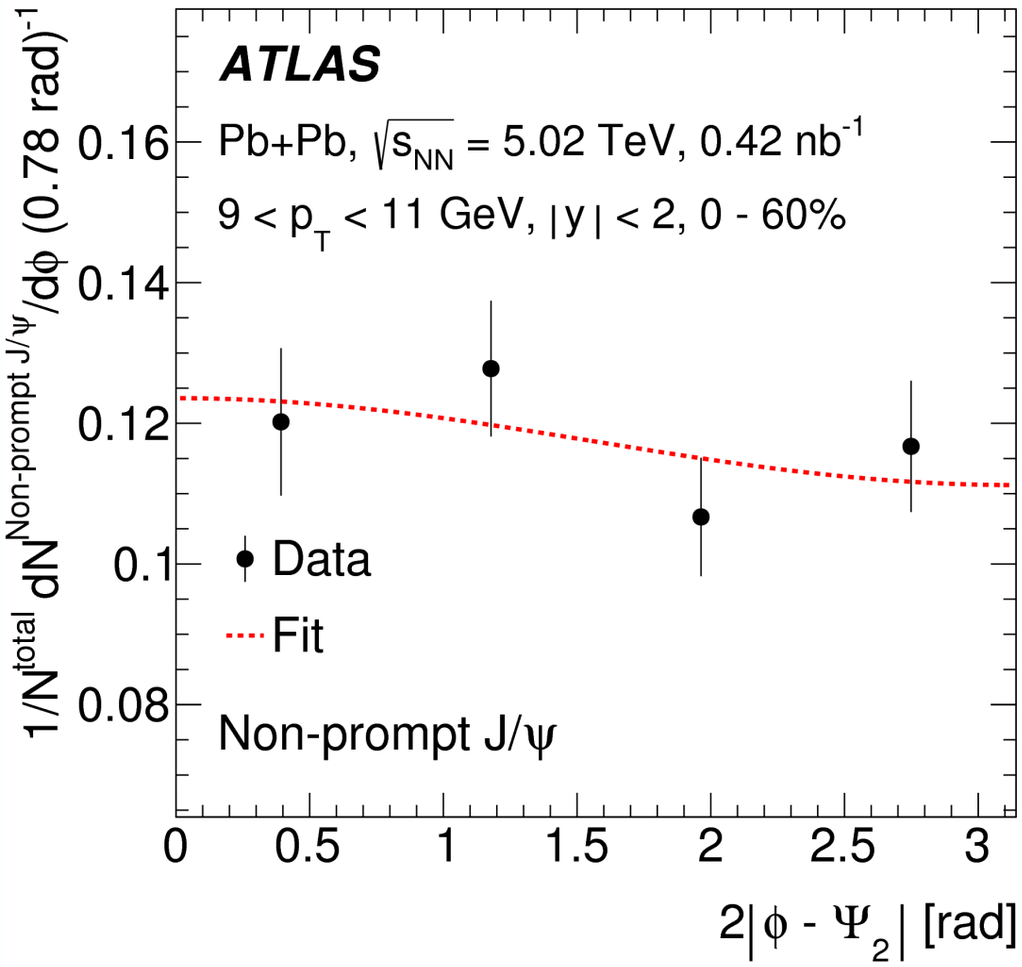
Sebastian Tapia Araya, this session

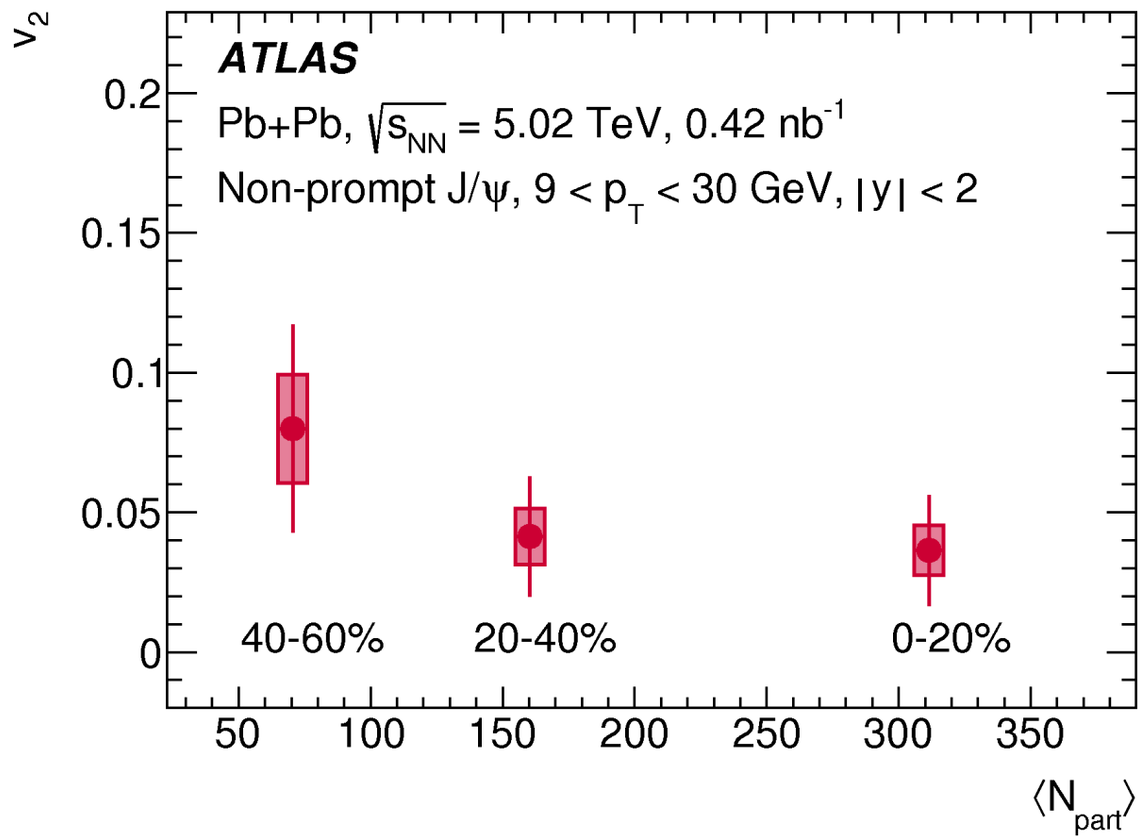
- consistent with no modification due to CNM effects in *p*+Pb
- strong suppression in Pb+Pb collisions
- suppression comparable to HF muon measurement

Non-prompt J/ψ v_2

NEW

arXiv: 1807.05198

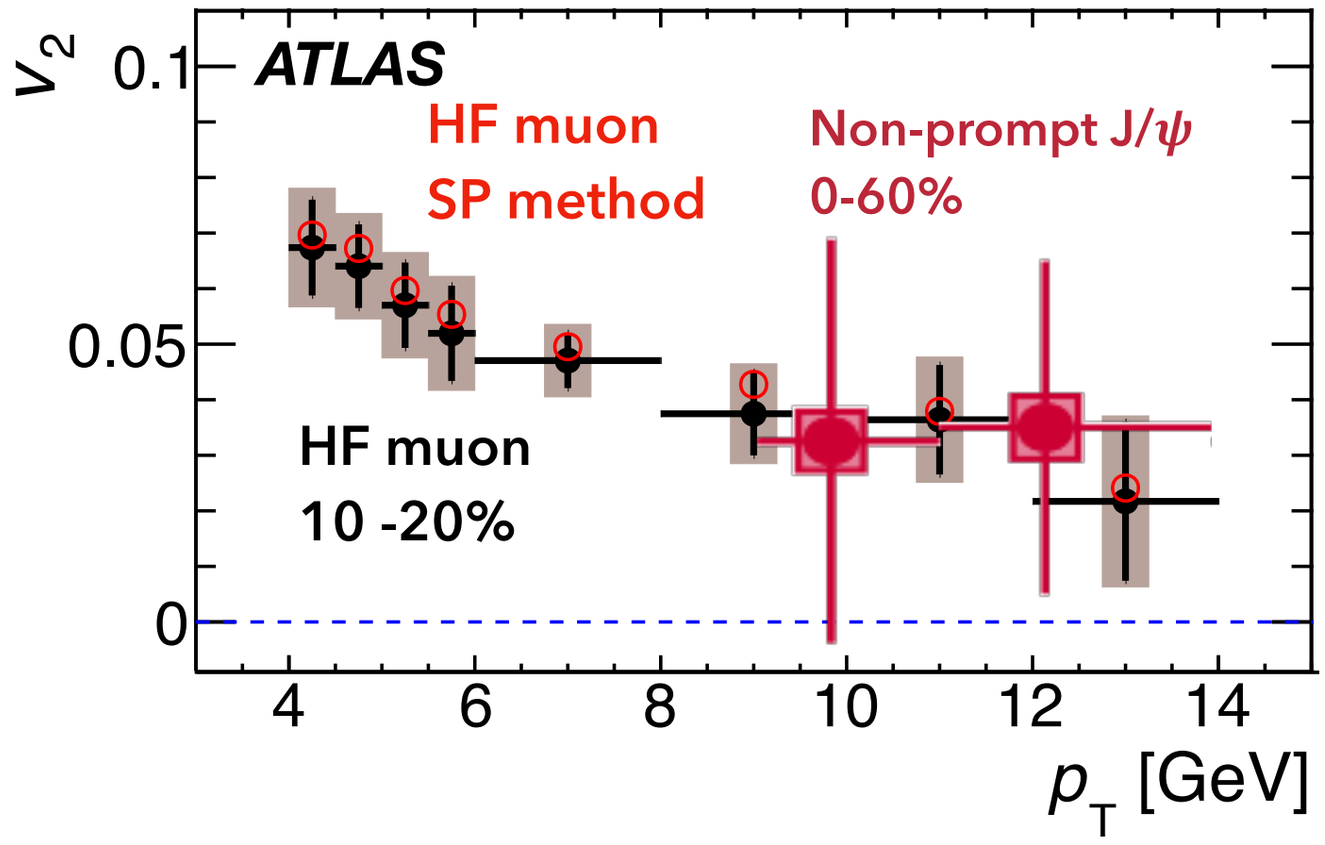




- v_2 extracted by using the event plane method
- non-zero flow measured for the non-prompt J/ψ
- no centrality dependence observed

Non-prompt J/ψ v_2 vs HF muon

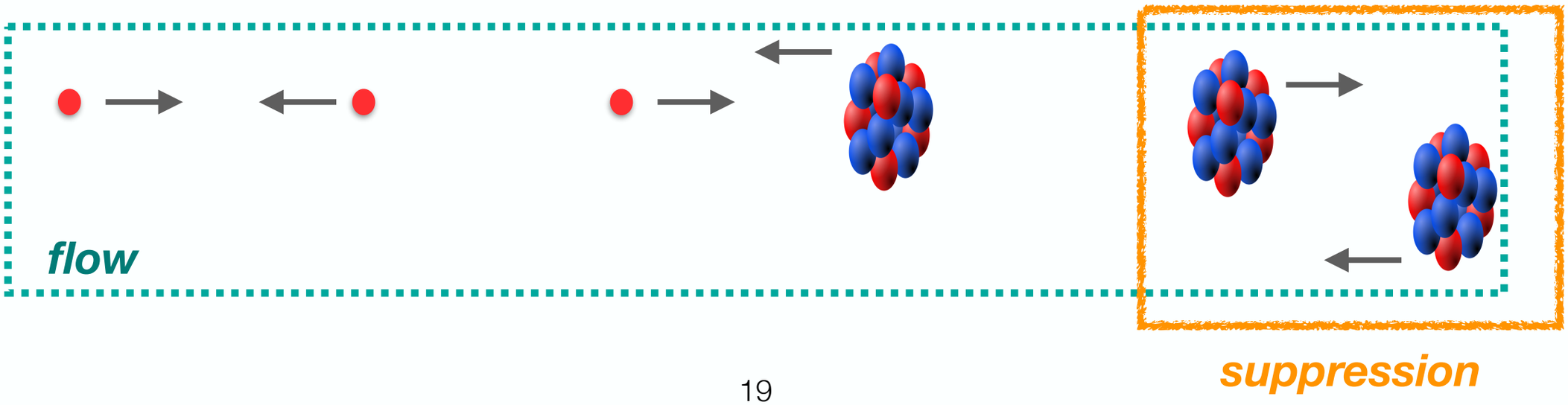
arXiv: 1805.05220
arXiv: 1807.05198



- J/ψ v_2 consistent with a constant in two p_T ranges measured
- in agreement with the HF muon measurement for p_T>9 GeV

Summary

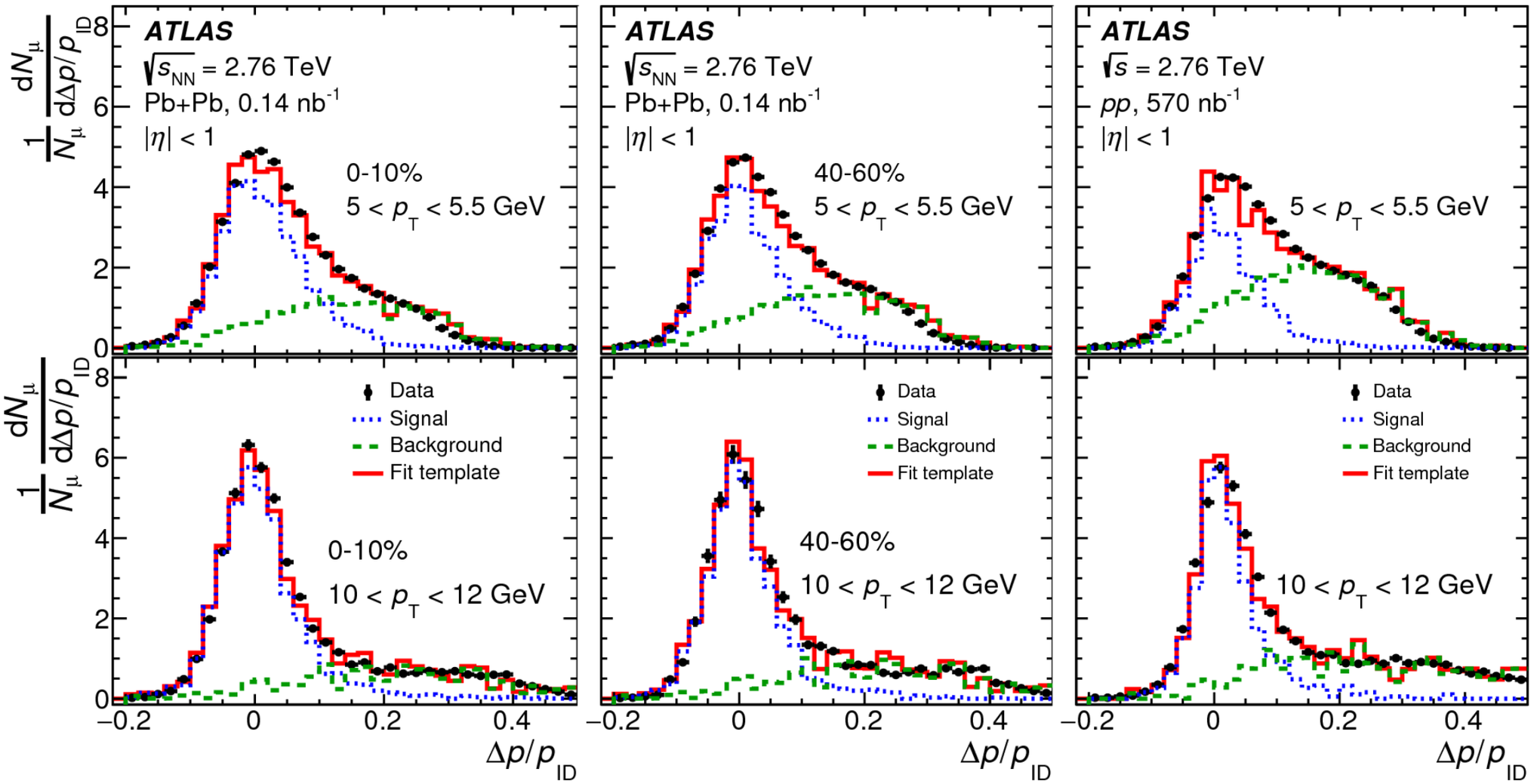
- wide scope of HF results in large and small systems presented
- <u>large system</u>:
  - all HF probes show large **suppression** and significant **flow**
- <u>small system</u>:
  - no modification in the yield production
  - significant HF muon **flow** observed
- challenge for theoretical models to simultaneously describe HF suppression and flow both in large and small systems



Backup

Physics probes: HF muons

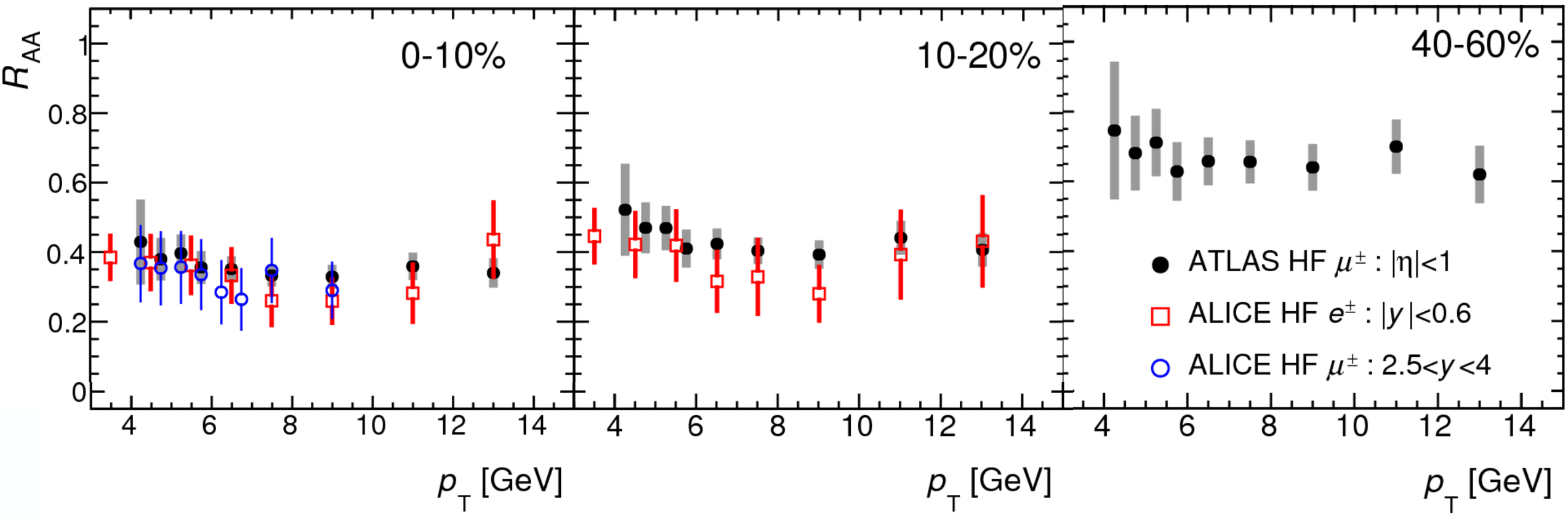
0-10% Pb+Pb **40-60% Pb+Pb** ***pp*** **arXiv: 1805.05220**



- measuring momentum imbalance:
  $\Delta p/p_{ID} = [p_{ID}-(p_{MS}+p_{Calo})]/p_{ID}$
- using template fits obtained from the MC

HF muon R_{AA}: ATLAS vs ALICE

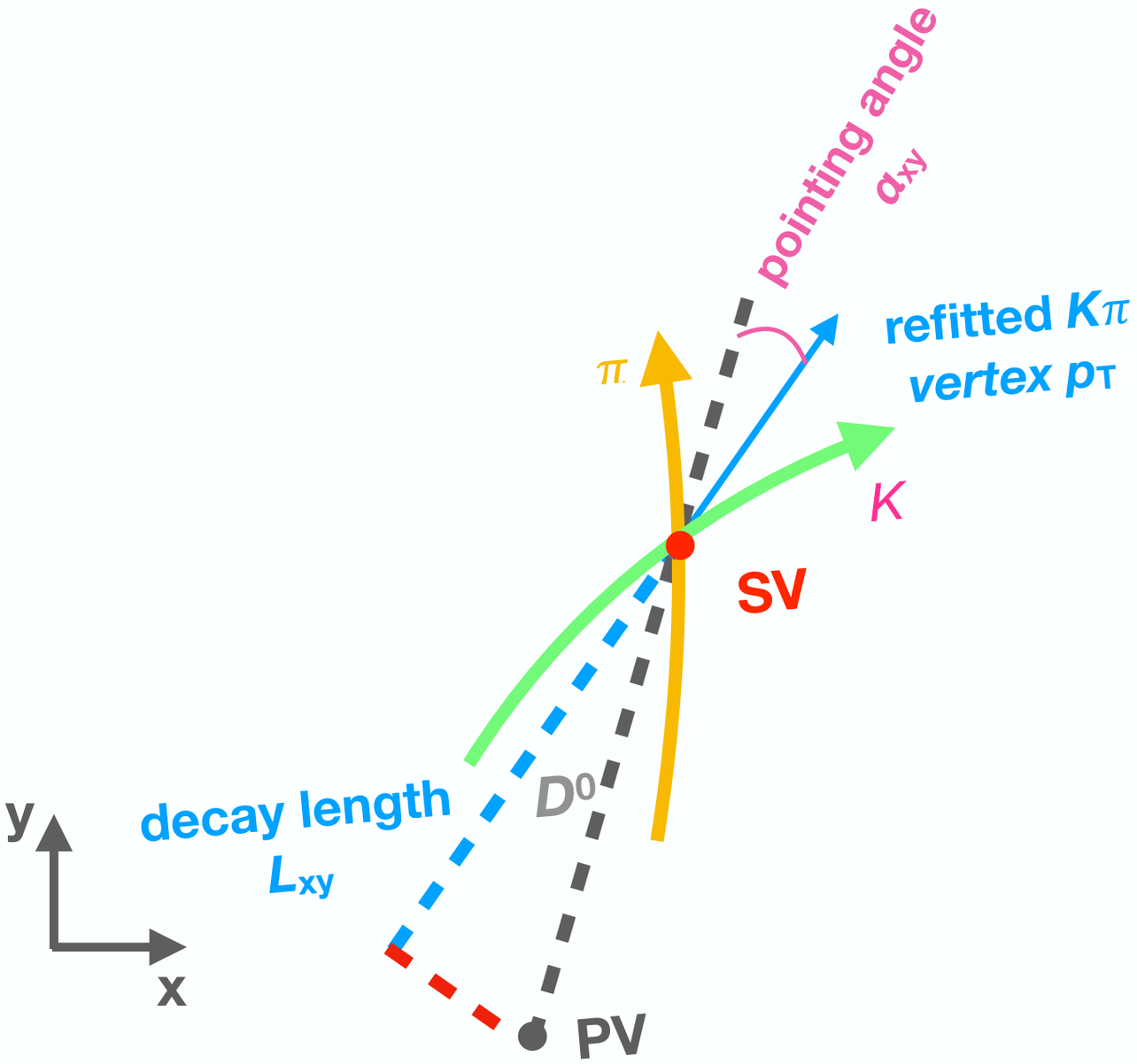
arXiv: 1805.05220

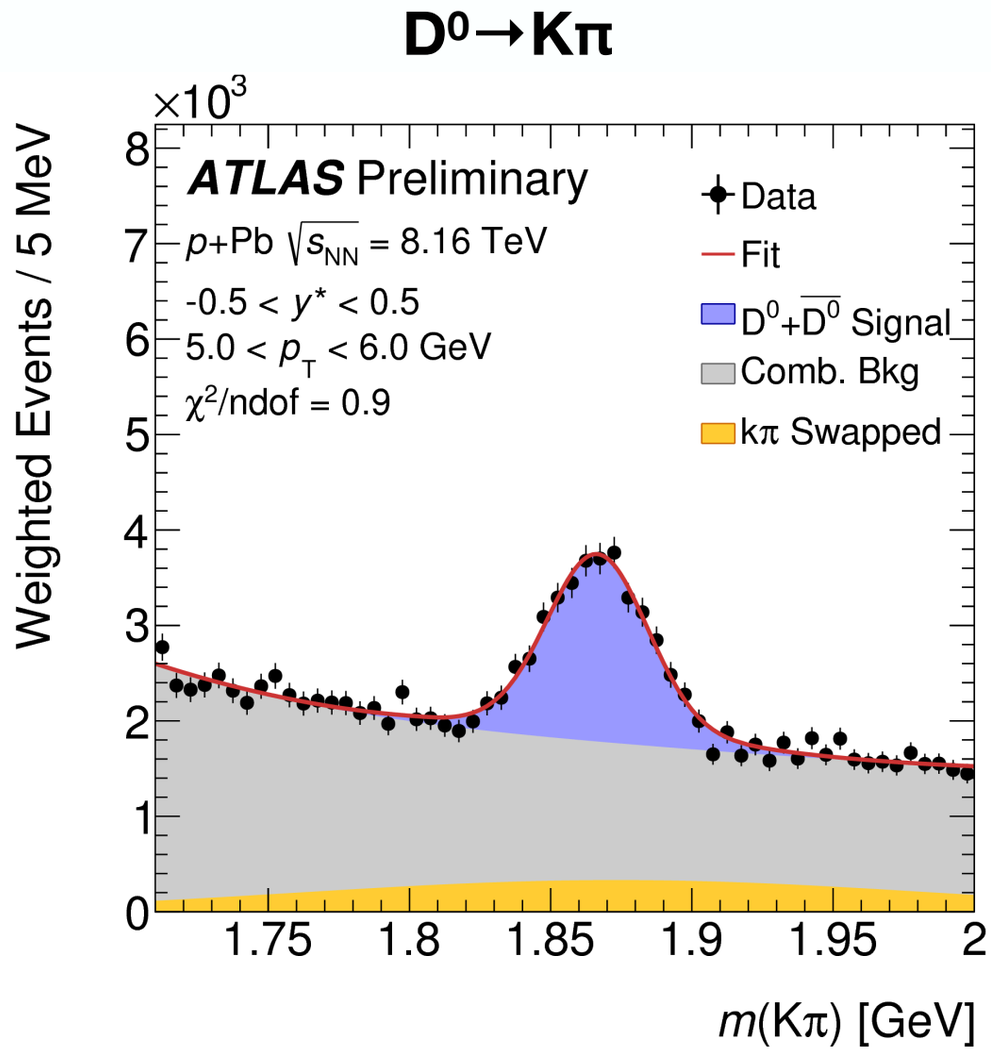


- good agreement between ATLAS and ALICE HF for electrons (mid-rapidity) and muons (forward rapidity)

Physics probes: D mesons

ATLAS-CONF-2017-073

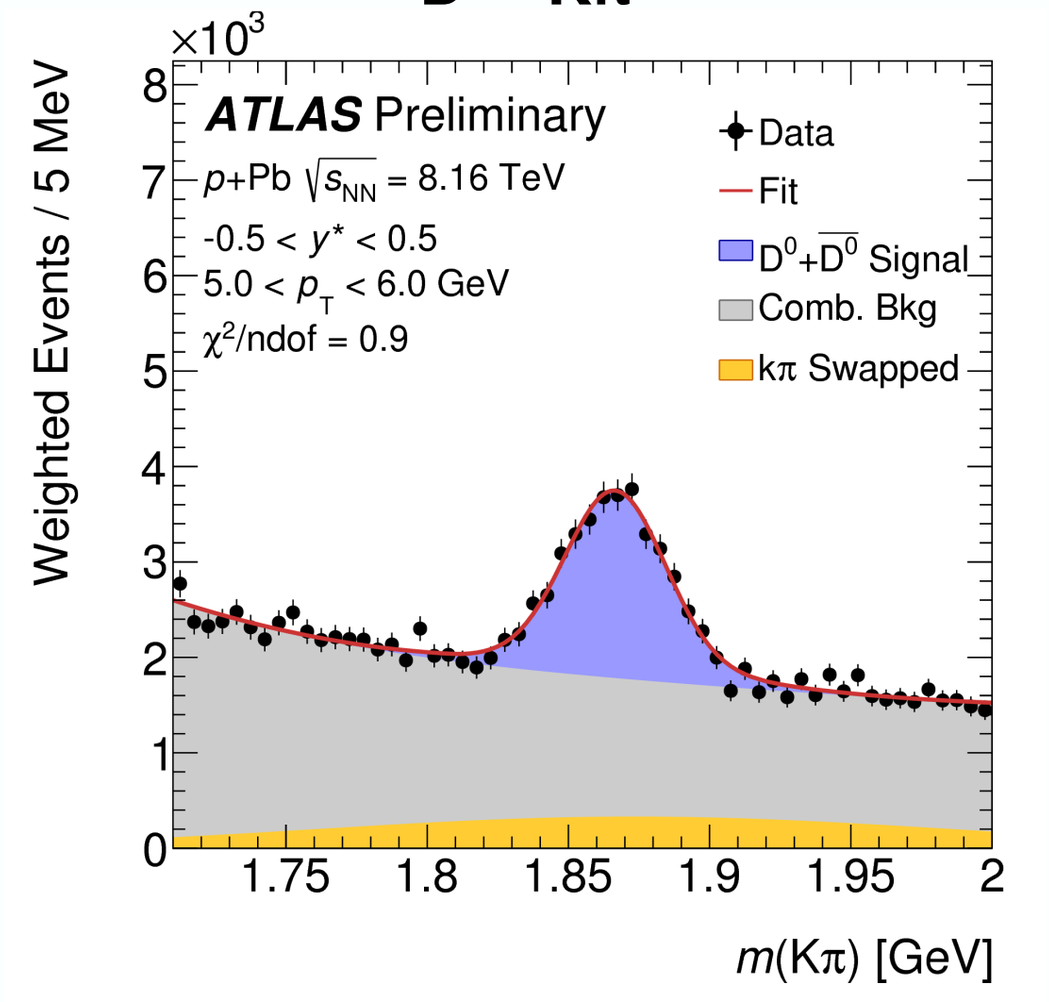


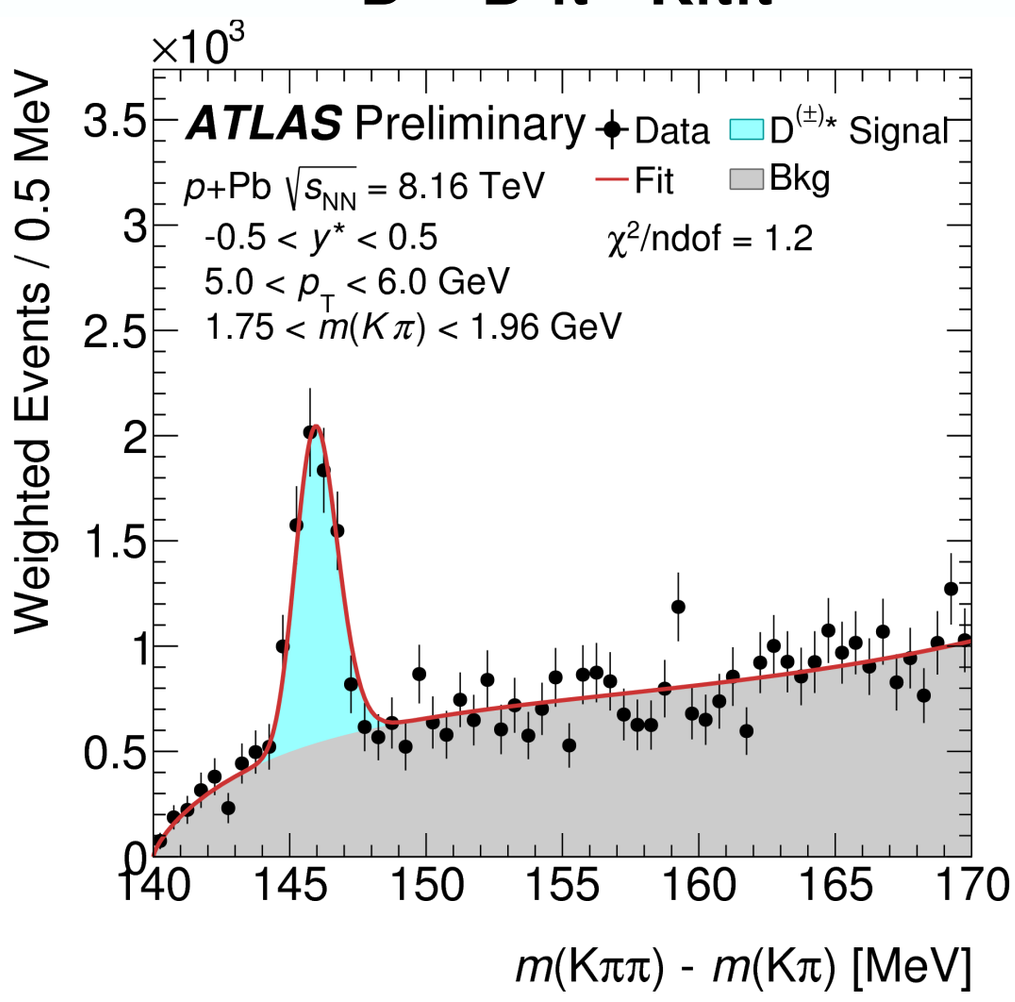


- reconstruct the D^0 decay using vertex probability, pointing angle and decay length significance
- open charm contribution dominates

Physics probes: D mesons

ATLAS-CONF-2017-073



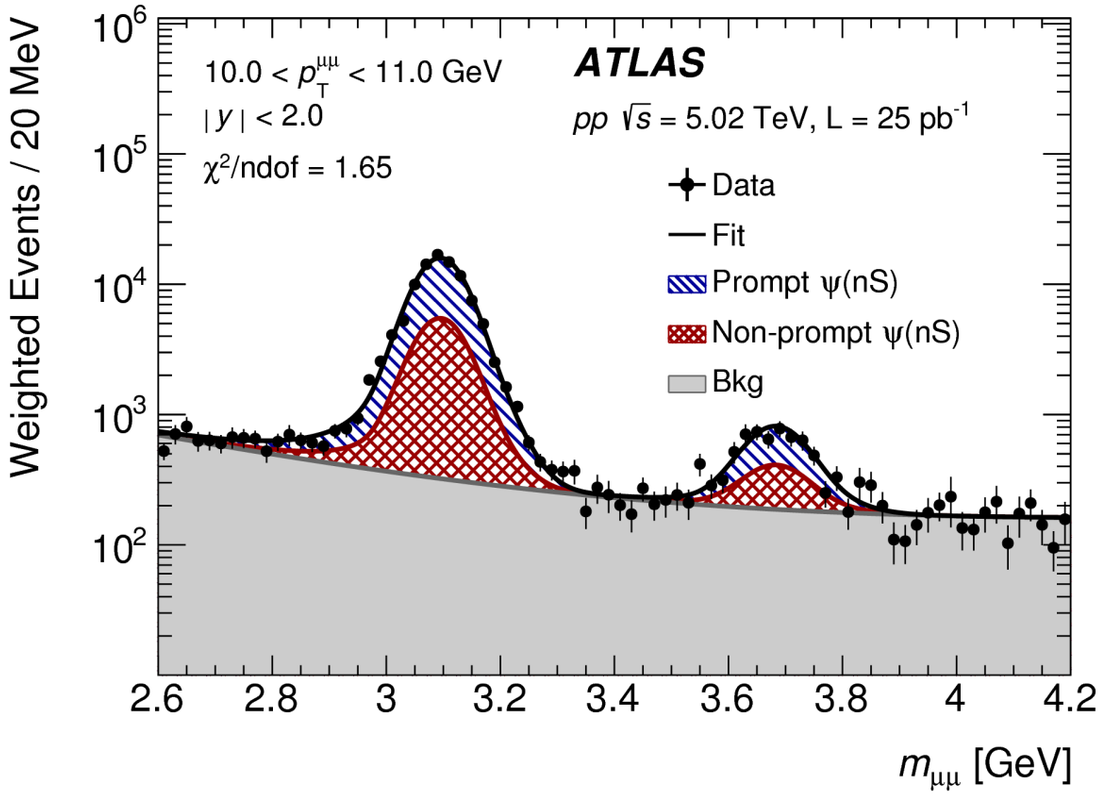


- reconstruct the D^0 decay using vertex probability, pointing angle and decay length significance
- open charm contribution dominates

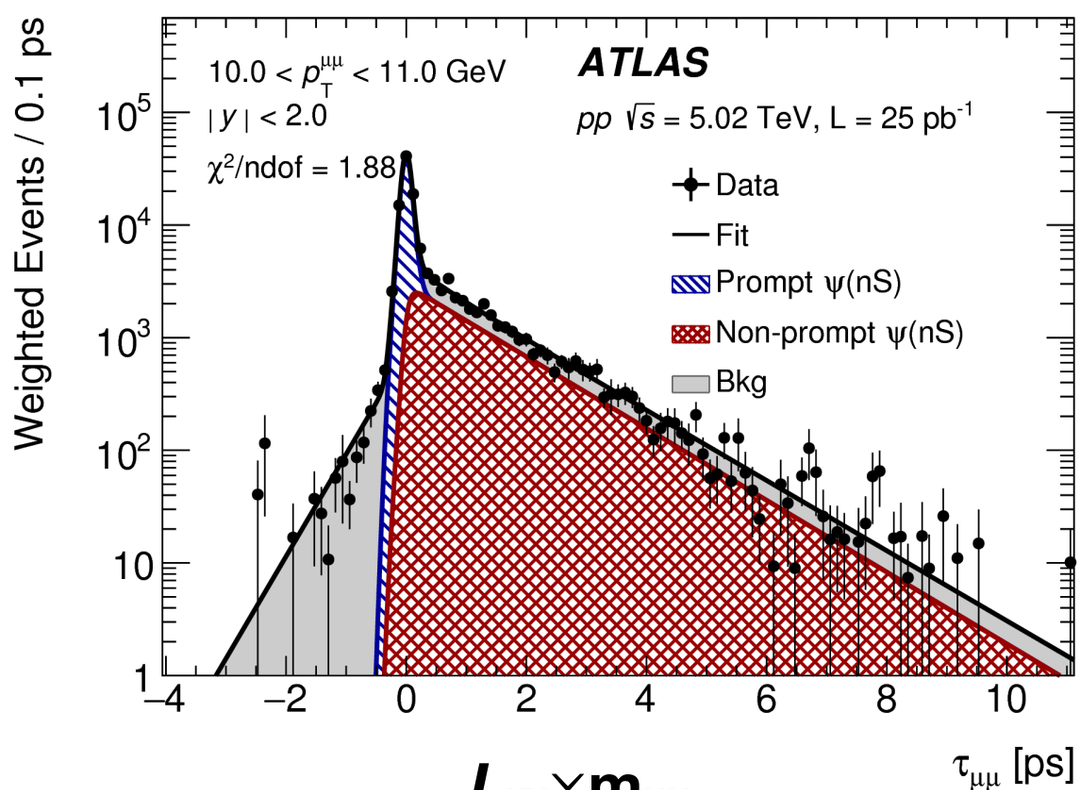
Physics probes: non-prompt J/ψ

Eur. Phys. J. C 78 (2018) 171

fit projection on the $m_{\mu\mu}$



fit projection on the $\tau_{\mu\mu}$



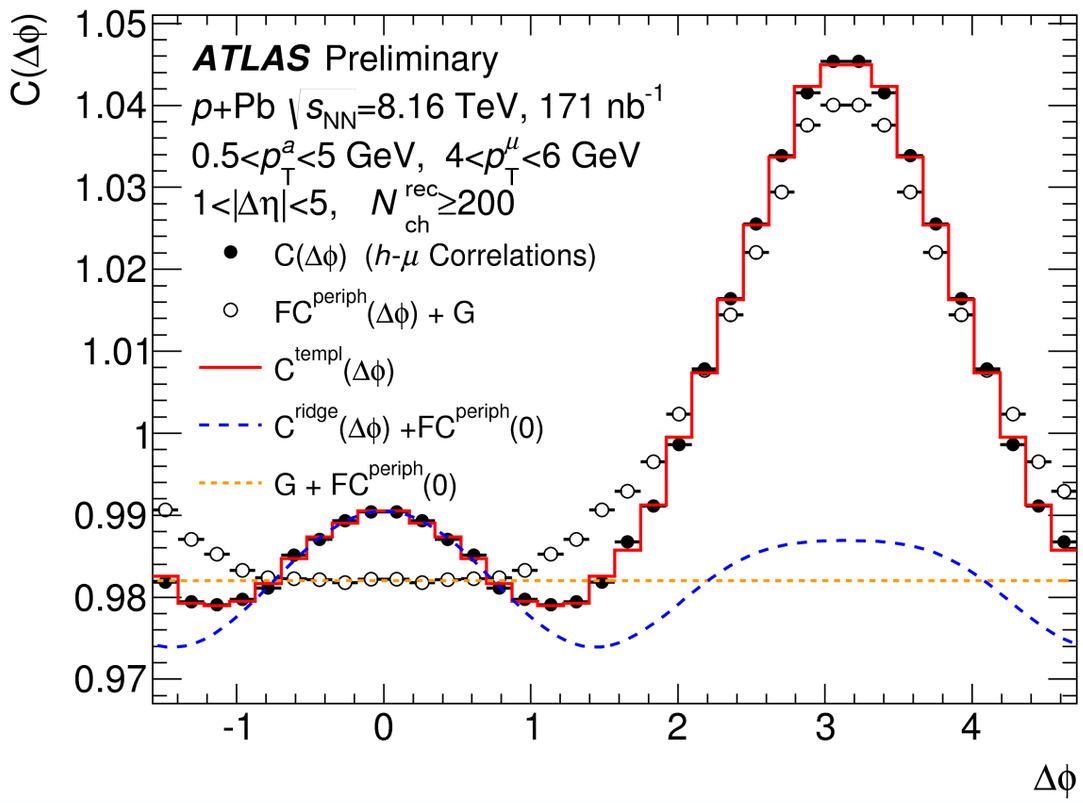
$$\tau_{\mu\mu} = \frac{L_{xy} \times m_{\mu\mu}}{p_T^{\mu\mu}}$$

- J/ψ from B hadron decays
- dimuon decay channel
- 2D fit in invariant mass and pseudo-proper lifetime

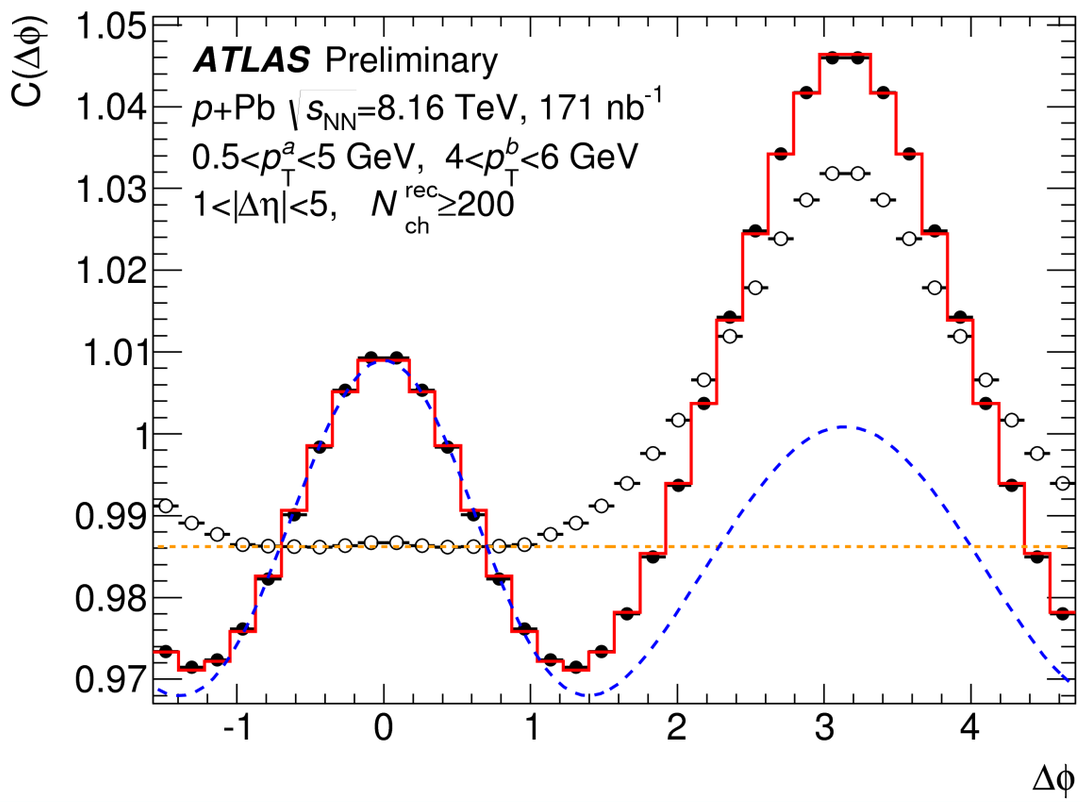
HF muon flow in *p*+Pb

ATLAS-CONF-2017-006

muon-hadron



hadron-hadron



- non-flow background subtracted with template fits
- fake HF muons suppressed with the momentum imbalance cut

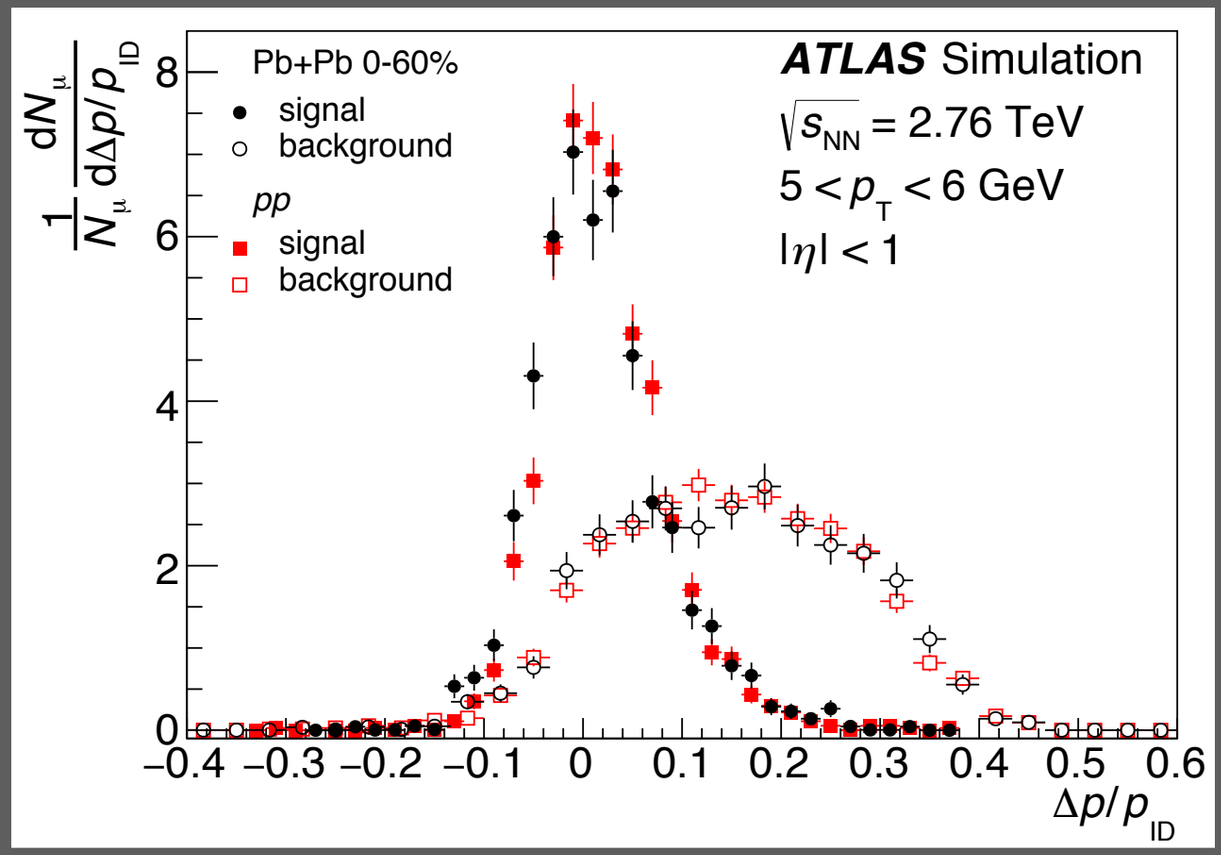
Heavy flavor probes in ATLAS

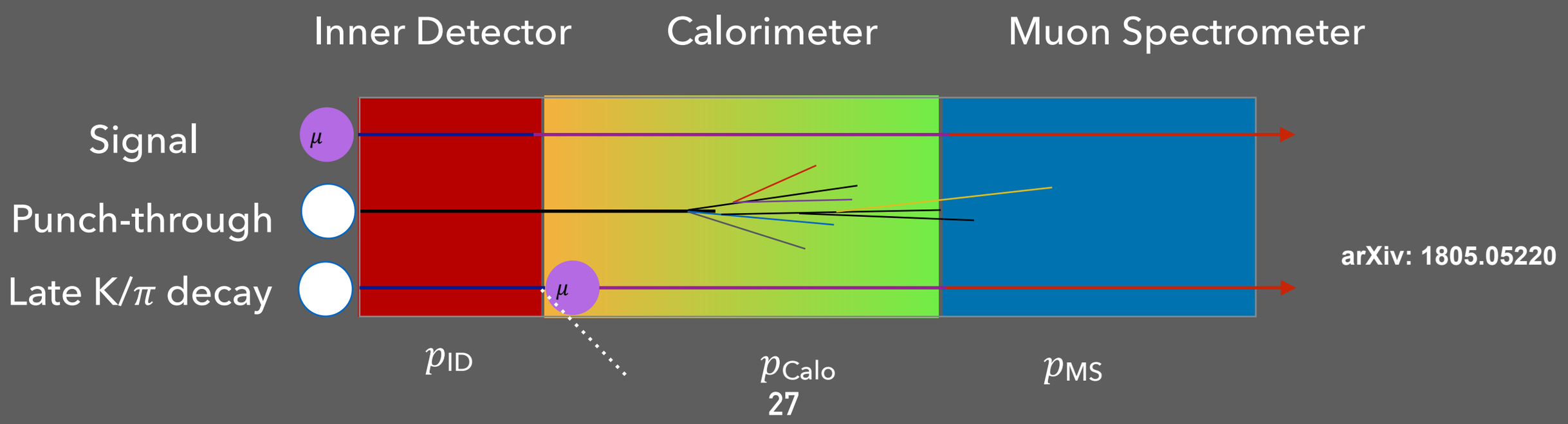
HF muons

Momentum imbalance

$\Delta p = p_{\mathrm{ID}}$ - (p_{MS} + p_{Calo})

template fit

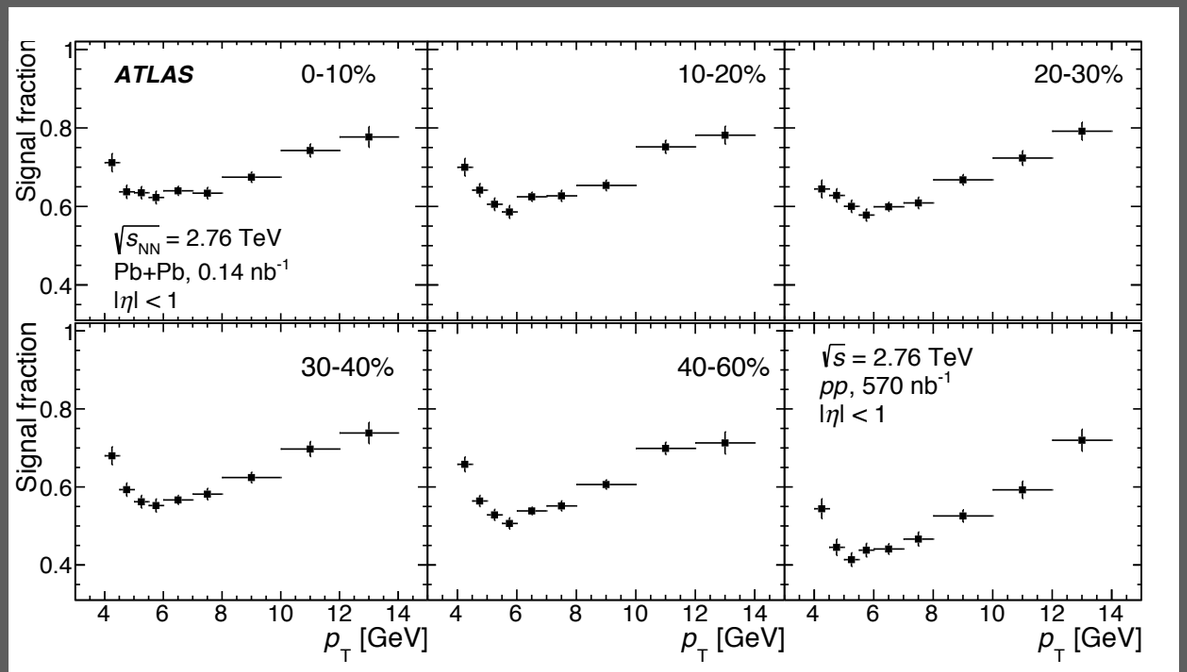




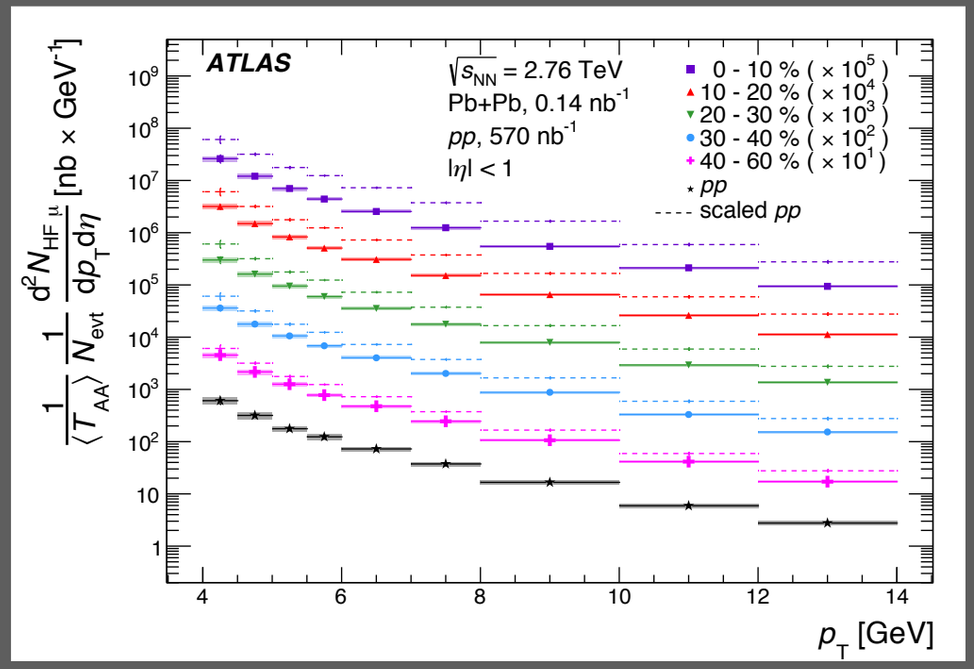
arXiv: 1805.05220

HF muon yields in Pb+Pb

Signal fraction



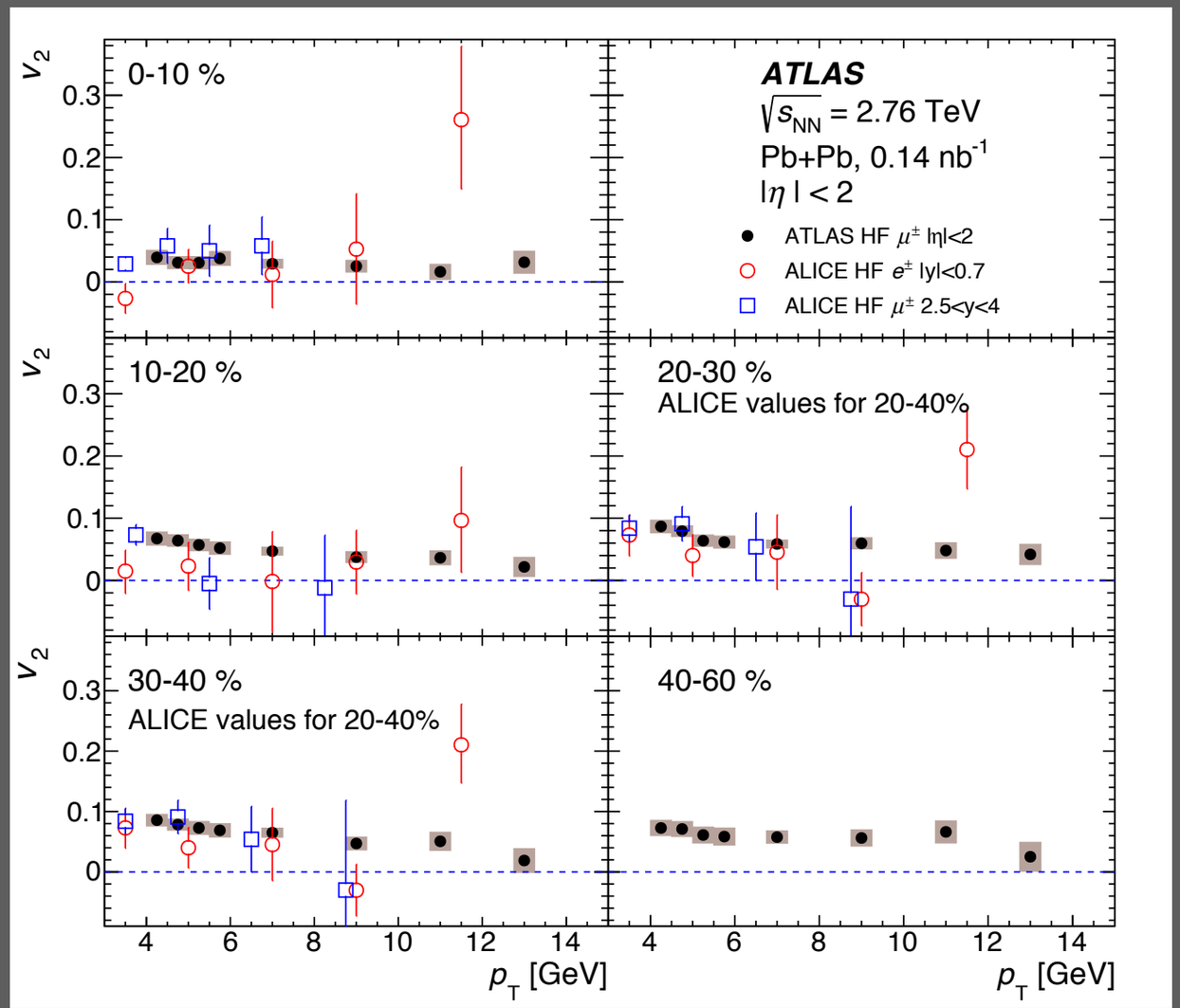
Yields



arXiv: 1805.05220

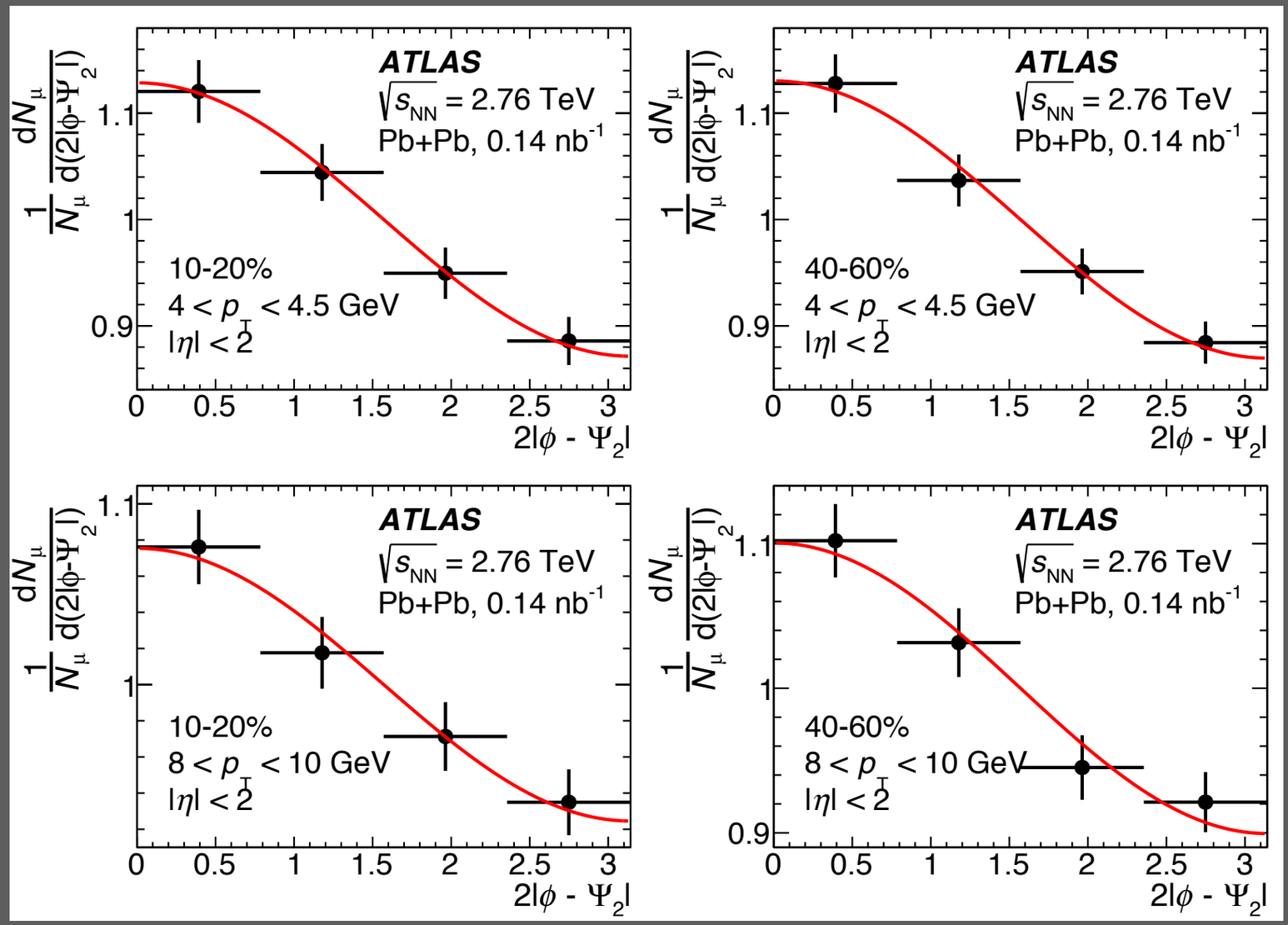
HF muon v_2 in Pb+Pb

- Good agreement between ATLAS and ALICE
- Smaller uncertainties of ATLAS results would provide tight constraints on models



arXiv: 1805.05220

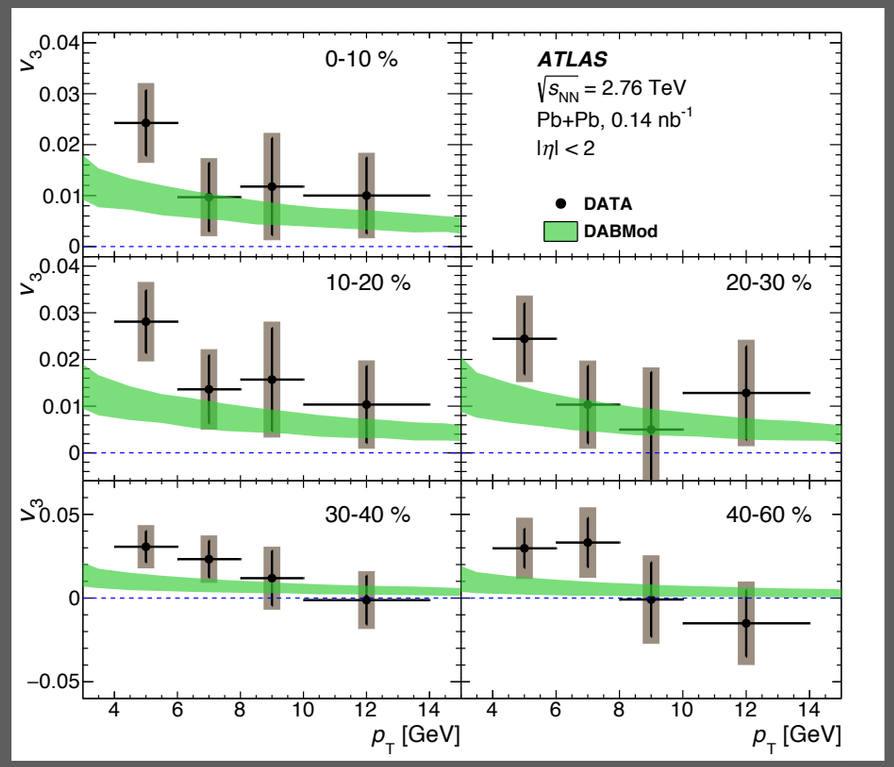
HF muon yields wrt. event plane



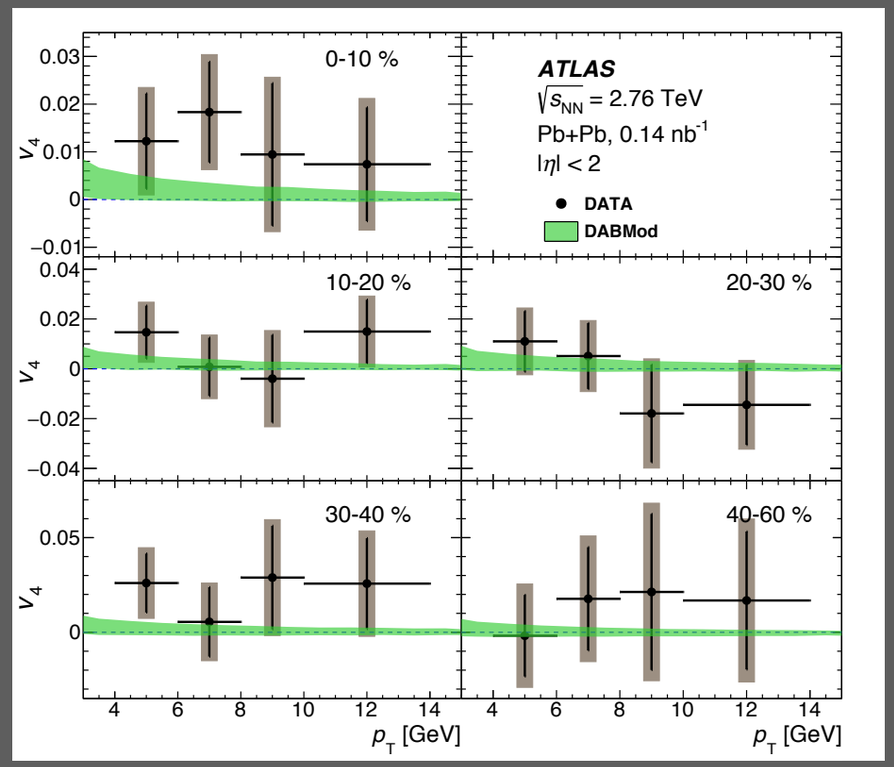
arXiv: 1805.05220

HF muon flow in Pb+Pb

v_3



v_4



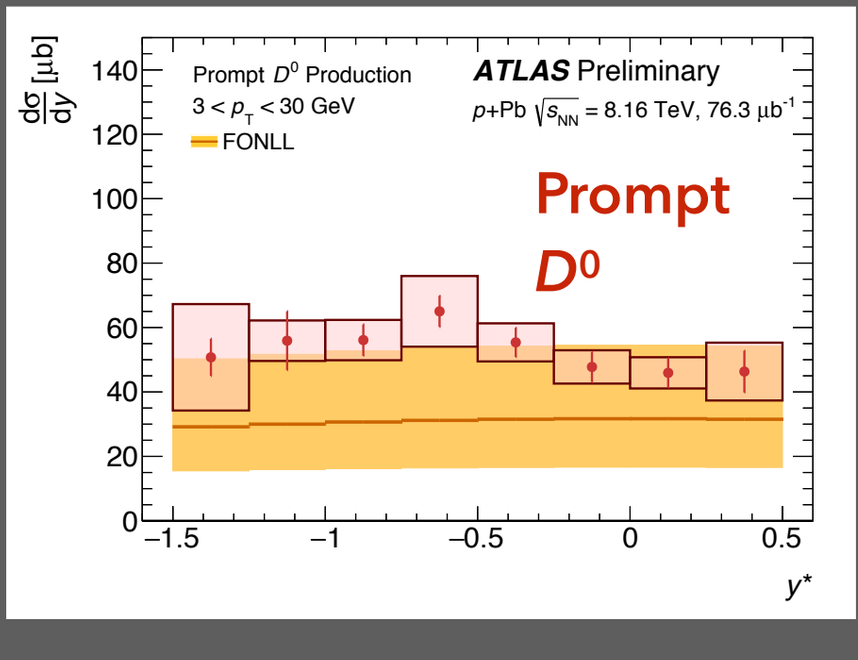
- Measured HF muon v_3 and v_4 agrees DABMod calculations

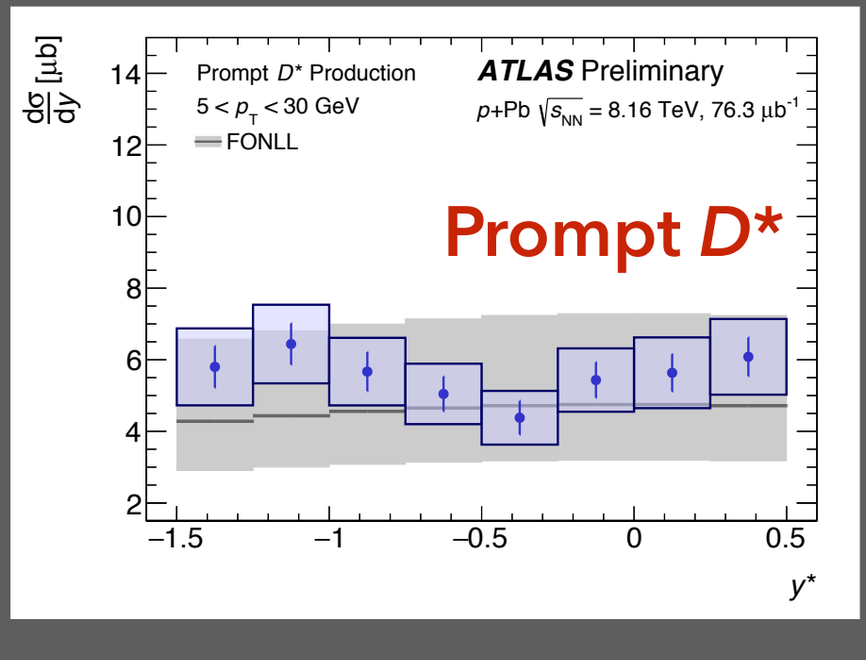
arXiv: 1805.05220

D reconstruction

Trigger selection	MinBias (+HMT for correlation)
D^0 selection	**Two tracks, p_T > 1GeV** **π and K masses assigned in turn, 1.7 < m(Kπ) < 2.0 GeV** **Vertex probability** **Pointing angle cosα_{xy}** **L_{xy} / σ(L_{xy})**
D* selection	**A selected D^0 vertex** **An additional track (π mass), same charge with the π in D^0 with soft pion p_T > 400 MeV (for yield) or 250 MeV (for correlation)**

Cross sections





FONLL uncertainties

- renormalisation scale
- factorization scale
- charm quark mass
- pdf

- Prompt D^0 ($3 < p_T < 30$ GeV) and prompt D^* ($5 < p_T < 30$ GeV)
- $|y_{lab}(D)| < 1.0$ for better mass resolution $\longrightarrow$ $-1.5 < y^* < 0.5$
- FONLL (fixed-order next-leading-logarithm) prediction extrapolated from 7 and 8 TeV calculates, and scaled by 208
- Relatively small modification in p+Pb

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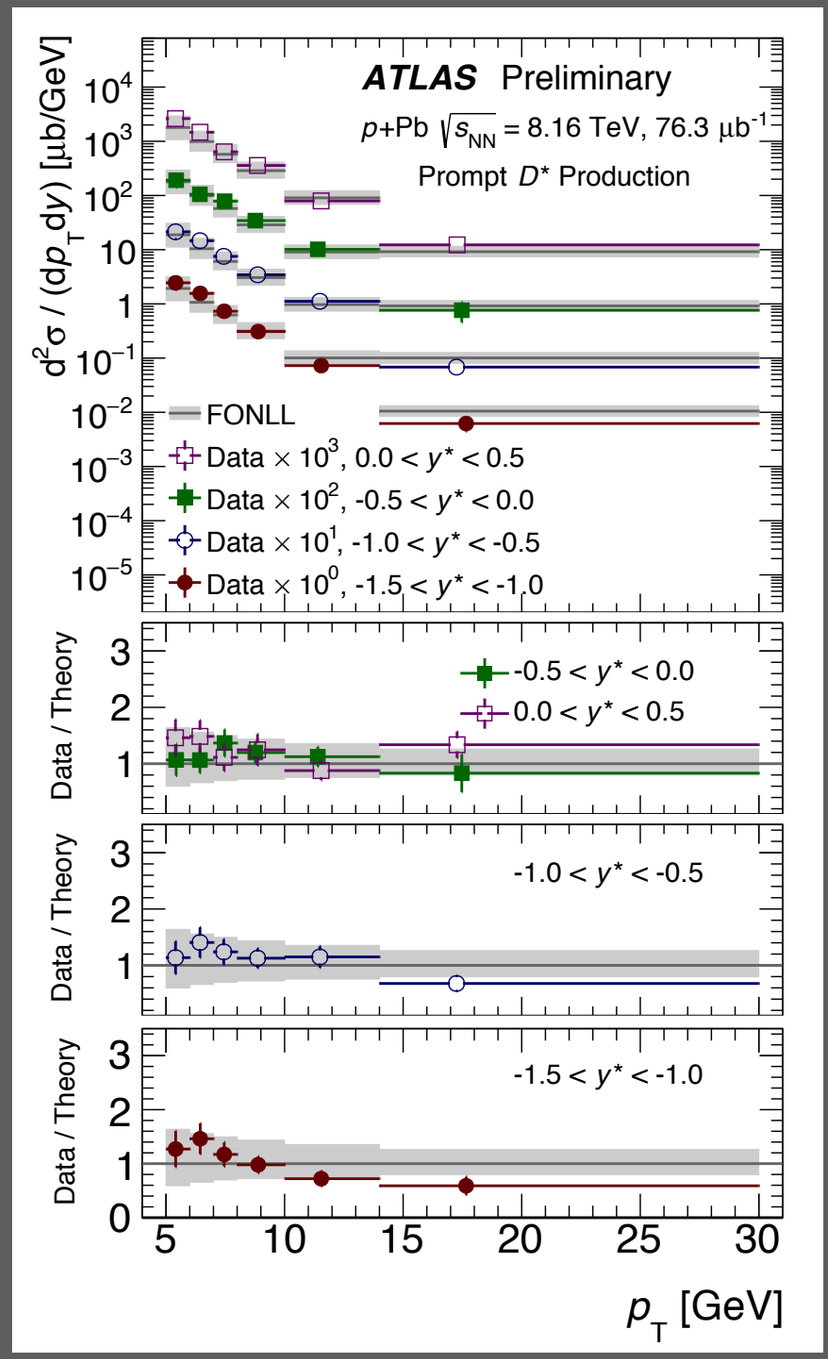
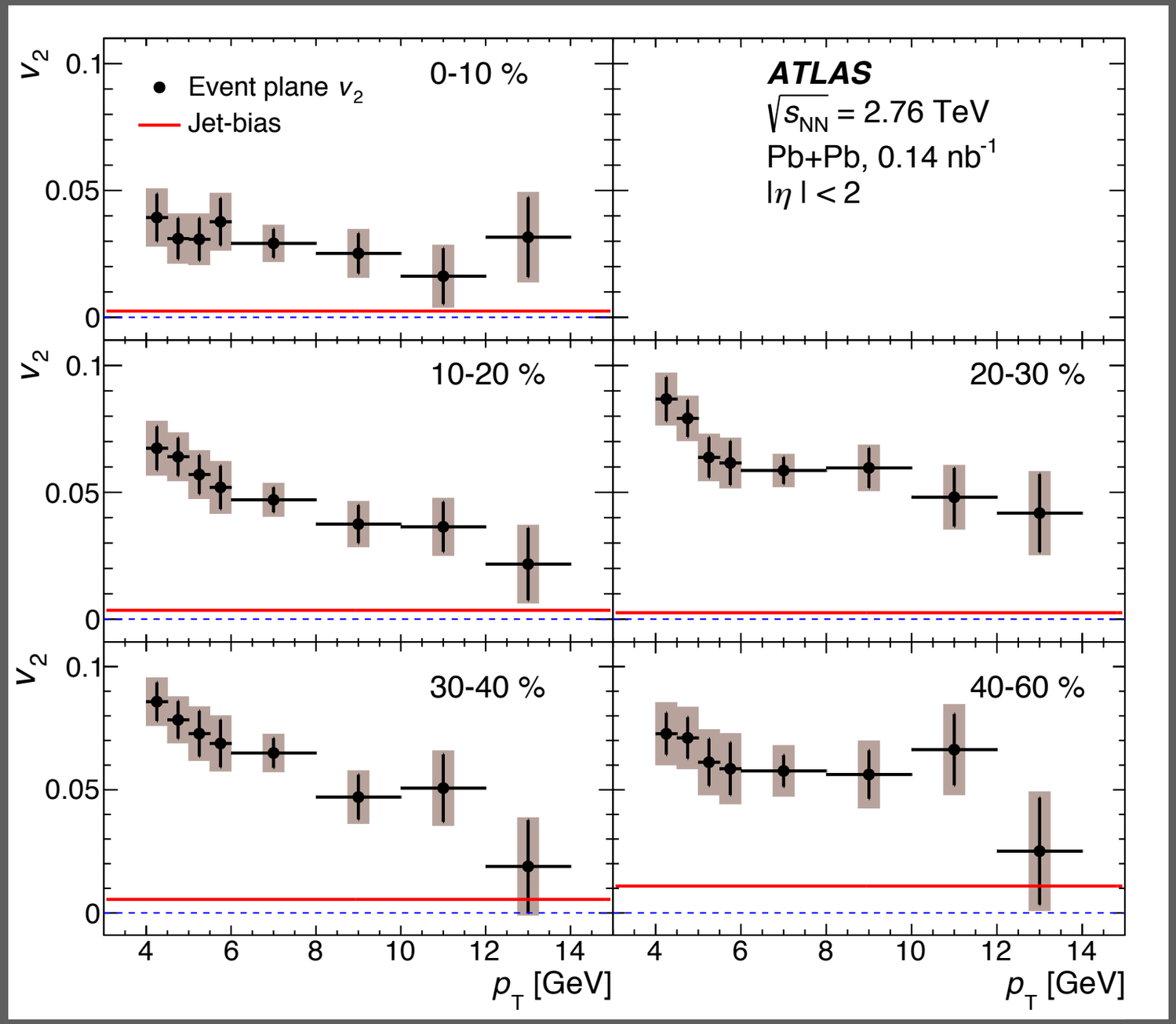
Cross sections

- Data and FONLL are comparable in whole kinematic range
- Relatively small modification in p+Pb

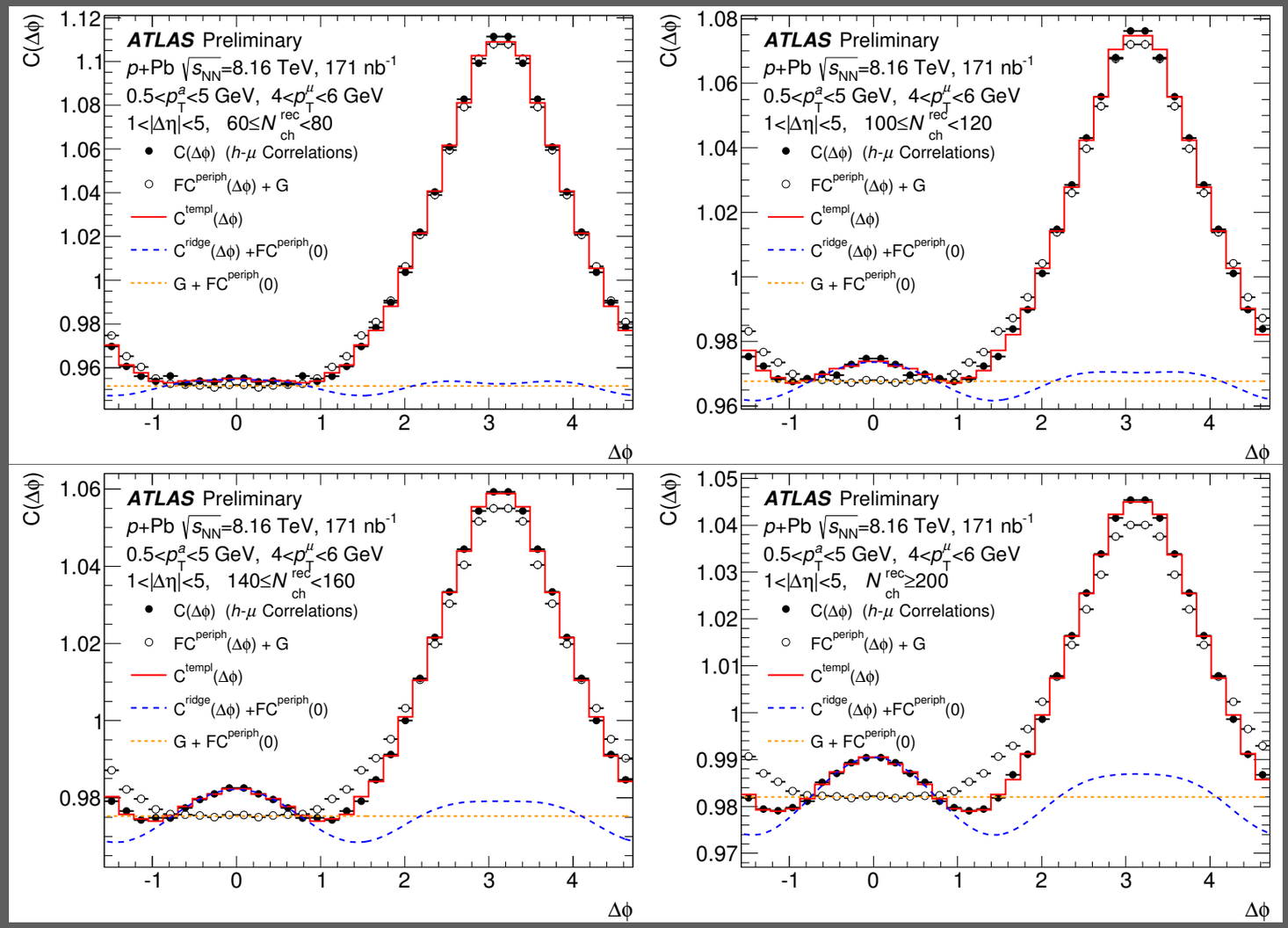
Prompt *D



Recoil jet bias estimation



Template fits — μ-*h* in p+Pb

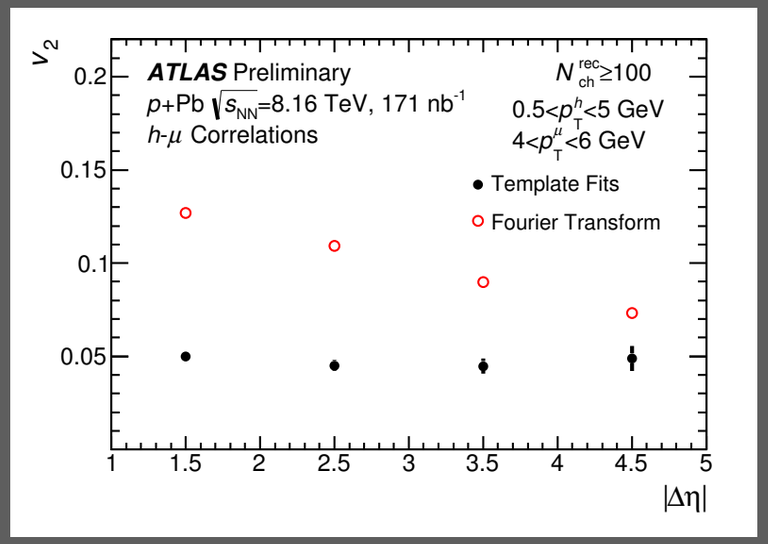


Systematics for μ-h correlation

- Choice of peripheral bin

  0-20, 20-40, 10-20, 20-30, 30-40
- Background muons
- Efficiency correction
- Track/muon selection
- Pileup
- Acceptance

Syst Uncertainty	Value
Peripheral bin	25-15%: $N_{ch}^{rec} \in(60,100)$ 15–10%: $N_{ch}^{rec} \in(100,150)$ 10–6%: $N_{ch}^{rec} \in(150,300)$
Background Muons	16%
Trigger & Tracking Efficiency	5%
Muon Selections	2%
Pileup	1%<: N_{ch}^{rec}<250 1-5%: $N_{ch}^{rec} \in(250,300)$
Pair Acceptance	1%



systematics for muon-hadron correlation

D*-hadron correlation

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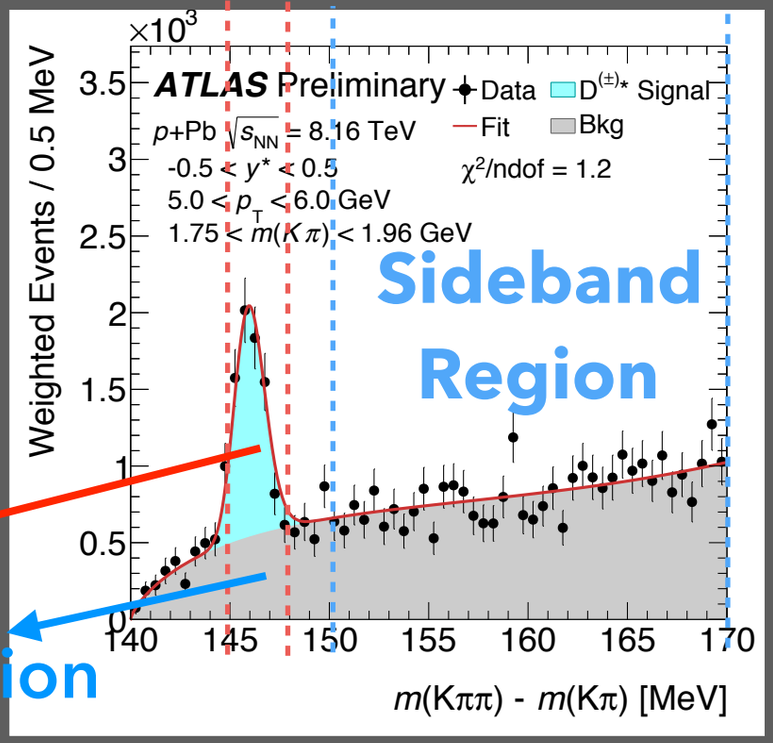
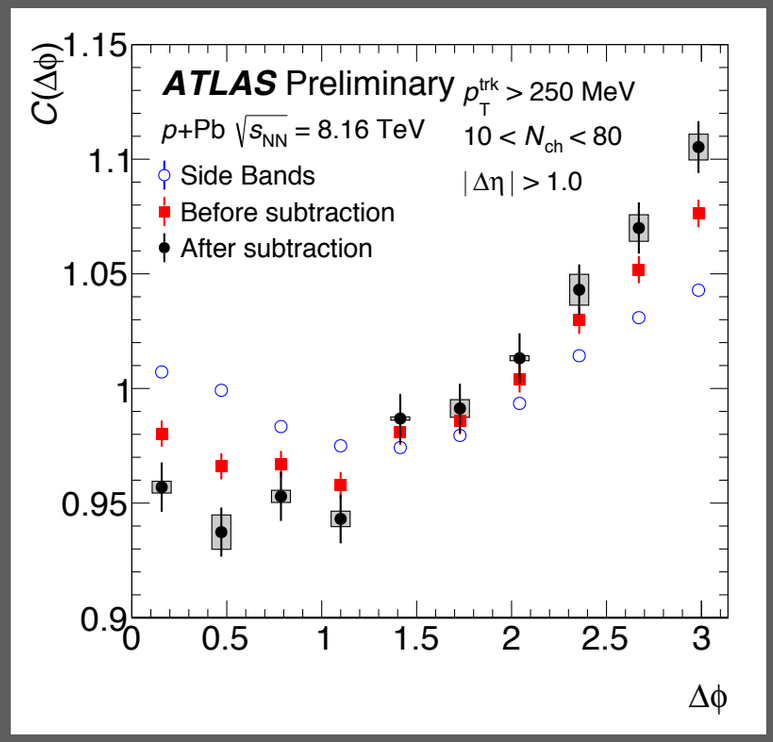
Signal Region

D*-h correlation

h-h correlation

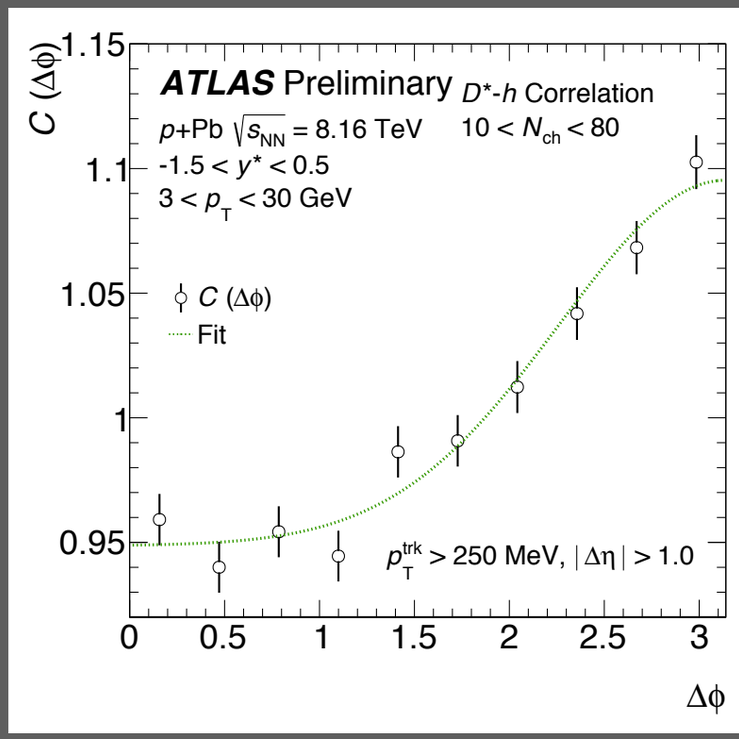


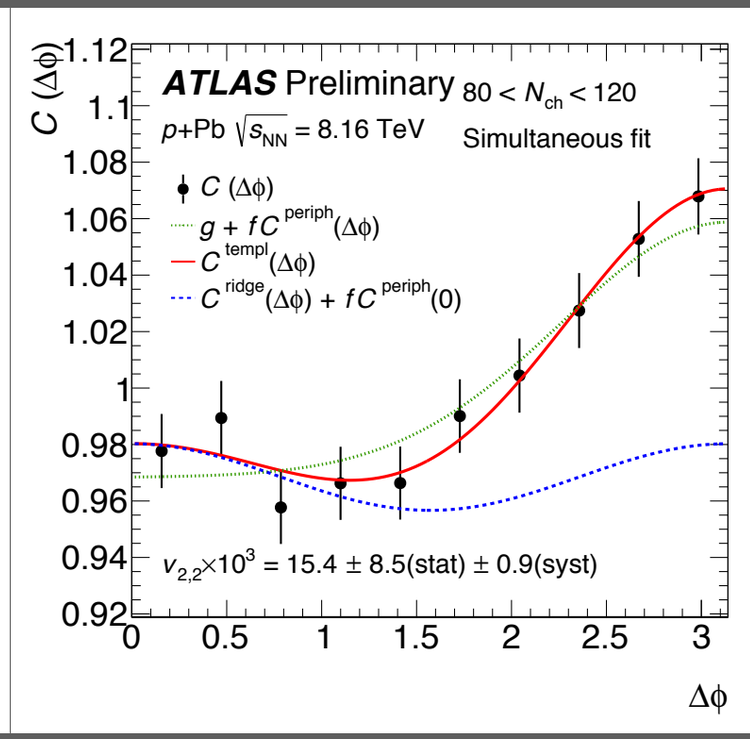


- Event collected by MinBias and high multiplicity triggers
- Third soft pion from *D** decay with p_T > 250 MeV for larger *D** fiducial volume (**3** < p_T < 30 GeV and -1.5 < y* < 0.5)
- Charged particles p_T > 0.25 GeV, $\Delta\eta$ > 1 for more statistics for 2PC
- Using sideband region 150 < Δm < 170 MeV to estimation the background correlation function

D*-h correlation fit

- Assuming weak multiplicity dependence of near-side D*-h long range correlation
- Peripheral reference bin $10 < N_{ch} < 80$
- Simultaneous template fit method applied to low and high N_{ch} single correlation functions





Sideband subtraction

$$C(\Delta\phi;\text{Signal}) = \frac{1}{f_{sig}} \cdot \{C(\Delta\phi;\text{Signal + Background}) - (1 - f_{sig})C(\Delta\phi;\text{Sideband})\}$$

- Systematics:
- Statistical uncertainty in f_{sig}
- N_{ch} dependence of f_{sig}
- Δm dependence of sideband correlation