Heavy-flavour leptons and non-prompt D mesons to investigate beauty-quark interaction in the QGP with ALICE

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on behalf of the ALICE Collaboration

Universität Heidelberg

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FSP ALICE
Erforschung von
Universum und Materie

UNIVERSITÄT
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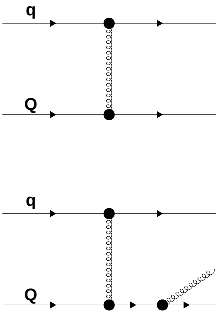
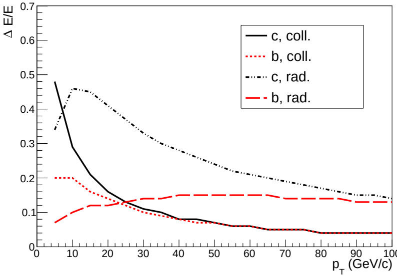
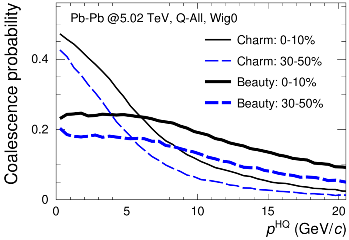
ALICE

Modeling of quark–medium interactions





Andronic et al., EPJ C (2016) 76:107



Li et al., Eur. Phys. J. C (2020) 80:1113

- Interaction with medium often modeled as scatterings
- Can distinguish elastic and radiative processes

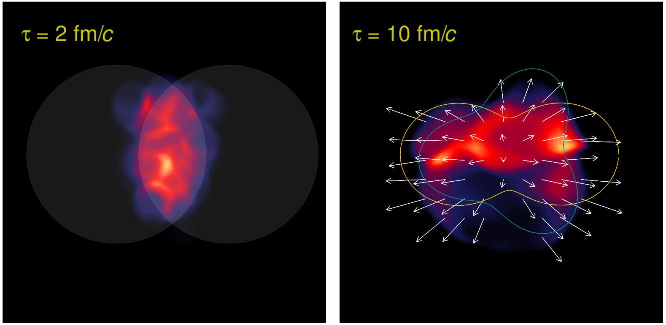
- Collisional processes more important at low p_{T}
- Larger energy loss for lower mass quarks expected

HF Hadronization:
Annalena Kalteyer
28.3., 16:50

- Hadronization – which particle species is produced and at which momentum?
- Fragmentation: other valence quarks created from vacuum
- Recombination: other valence quarks from medium

Heavy quarks throughout a heavy-ion collision

CERN Courier May/Jun 2021



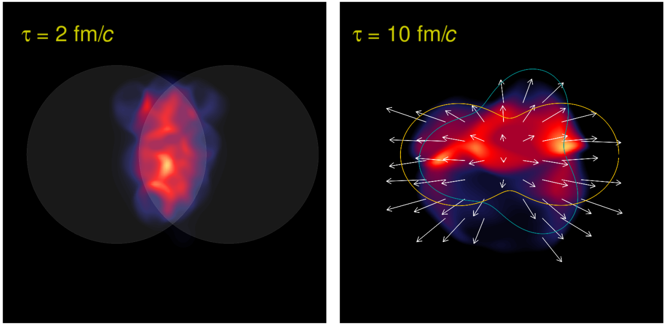
Initial hard scatterings → Pre-equilibrium → QGP evolution → Freeze-out → Hadronic phase

- Important measurements: nuclear modification factors R_{AA} and flow coefficients v_n
- Typically: suppression at high p_{T} from energy loss; peak at low p_{T} from radial flow
- Affected by transport, but also nPDFs, shadowing and hadronization
- Expected QGP signatures: anisotropic flow, modification of p_{T} distributions

non-prompt ⇔ feeddown from beauty hadrons

Heavy quarks throughout a heavy-ion collision

CERN Courier May/Jun 2021



Heavy quark mass large compared to:

- Λ_{QCD} – allows perturbative calculations
- T_{QGP} – no thermal production; production in initial hard scatterings
- Energy exchange with medium – easier modeling of interactions

Initial hard scatterings → Pre-equilibrium → QGP evolution → Freeze-out → Hadronic phase

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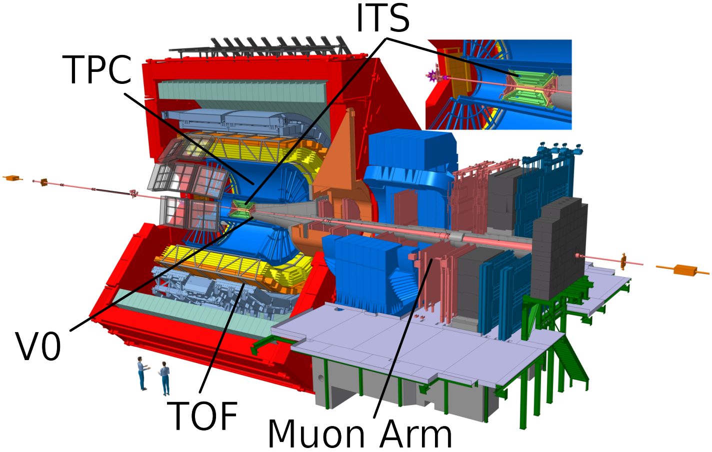
non-prompt ⇔ feeddown from beauty hadrons

The ALICE detector

Measurements at midrapidity ($|\eta| < 0.8$):

- **I**nner **T**racking **S**ystem: tracking and reconstruction of primary vertex and track impact parameter
- **T**ime **P**rojection **C**hamber: tracking and particle identification via $\mathrm{d}E/\mathrm{d}x$
- **T**ime-**O**f-**F**light Detector: particle Identification



For heavy–flavour decay muon measurements ($-4 < \eta < -2.5$):

- Muon spectrometer: triggering and tracking

Relevant hadronic channels

$\mathrm{D}^0 \rightarrow \mathrm{K}^- \pi^+$

$\mathrm{D}^+ \rightarrow \mathrm{K}^- \pi^+ \pi^+$

$\mathrm{D}_s^+ \rightarrow \phi\pi^+ \rightarrow \mathrm{K}^- \mathrm{K}^+ \pi^+$

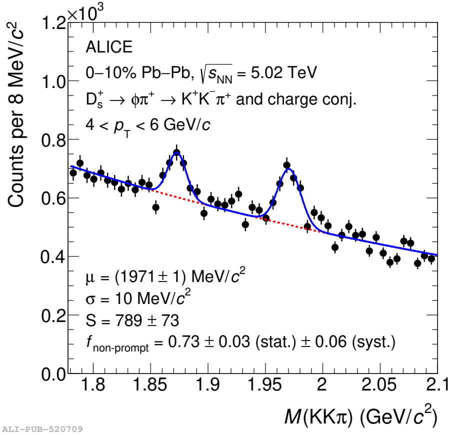
Semileptonic channels:

$\mathrm{c}, \mathrm{b} \rightarrow \mathrm{X} + \mu$

$\mathrm{b} \rightarrow \mathrm{X} + e$

D meson measurements

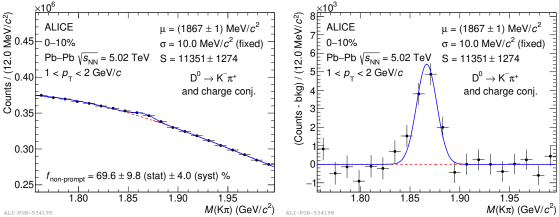
- Measurements based on invariant mass distributions
- Extraction via fit of signal and background
- Background suppressed by ALICE PID capabilities



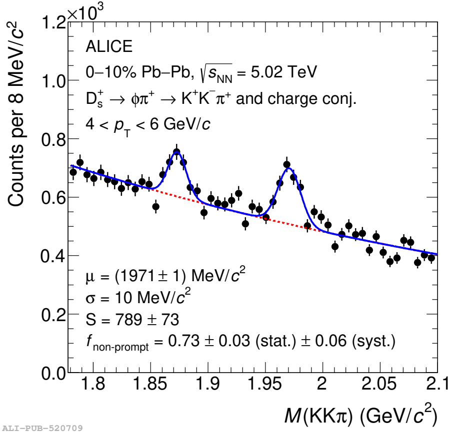
arXiv:2204.10386

D meson measurements

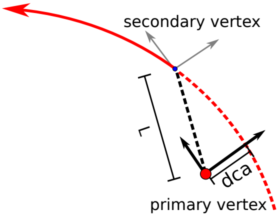
- Measurements based on invariant mass distributions
- Extraction via fit of signal and background
- Background suppressed by ALICE PID capabilities
- Good reconstruction even at low p_T in central Pb–Pb collisions

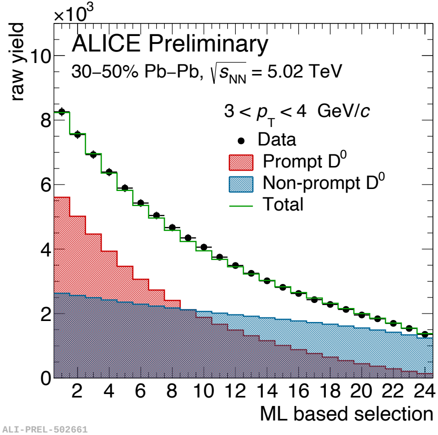


JHEP 12 (2022) 126



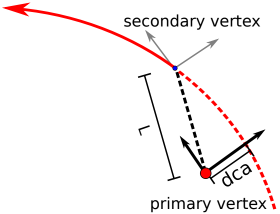
arXiv:2204.10386



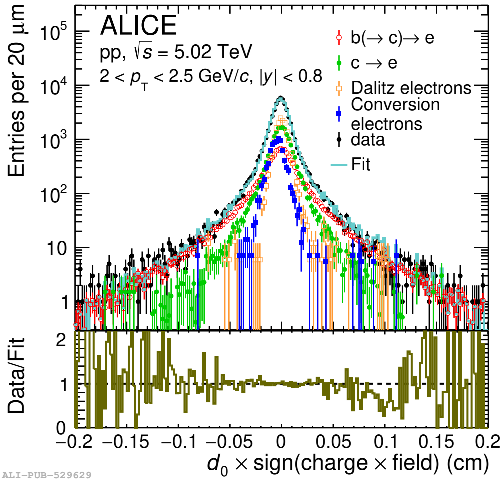


- Separate prompt and non-prompt: impact parameter, decay length, pointing angle etc.
- Also include PID variables → suppress stochastic background
- Find selection criteria using machine learning (ML) like XGboost, efficiencies from MC simulations
- Estimate prompt and non-prompt fraction in full sample from cut variations

See also poster by Mingyu Zhang

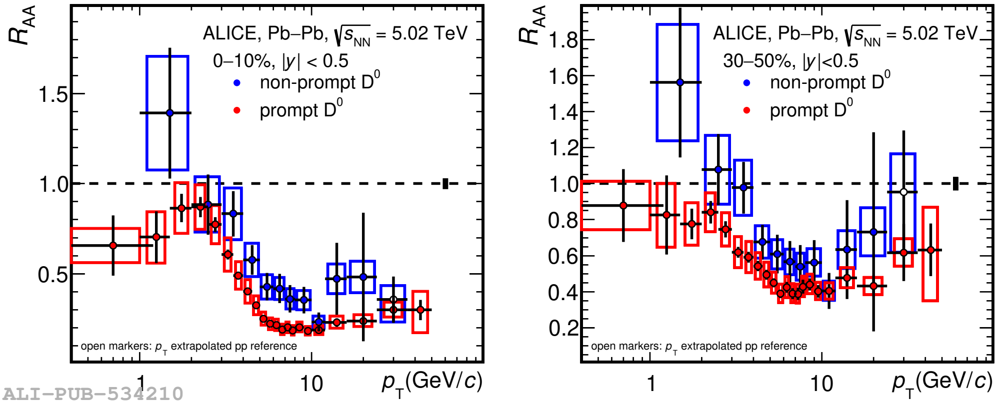


- Electrons from
  - charm hadron decays $(c \to e)$
  - beauty hadron decays $(b(\to c) \to e)$
  - photon conversions $(\gamma \to e^+e^-)$
  - others (e.g. $\pi^0 \to \gamma e^+e^-$)
- Separated by impact parameter distribution
- Contribution of photon conversions and Dalitz decays can be constrained from e^+e^- pair invariant mass distribution



arXiv:2211.13985

Non-prompt D^0 mesons in Pb–Pb collisions



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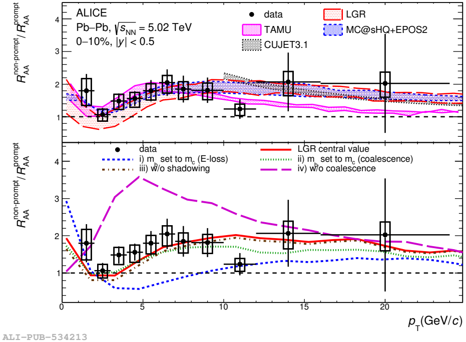
- p_T-integrated R_{AA} is $1.00 \pm 0.10(\text{stat.}) \pm 0.13(\text{syst.})^{+0.08}_{-0.09}(\text{extr.}) \pm 0.02(\text{norm.})$ (0-10%)
- Prompt-and non-prompt contributions increasingly suppressed towards high p_T
- The measurements have correlated uncertainties → largely cancel in ratio

Non-prompt to prompt D^0 nuclear modification factor



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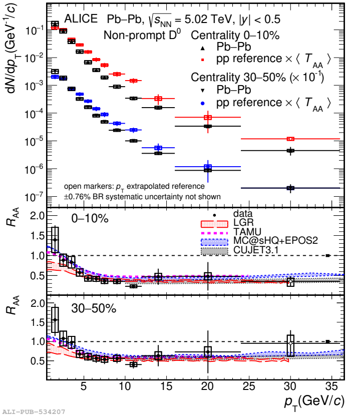
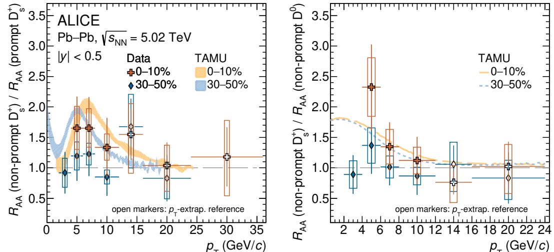


- Significantly higher R_{AA} for non-prompt D^0 mesons than for prompt ones
- Models which describe the ratio include quark mass dependence in energy loss and coalescence

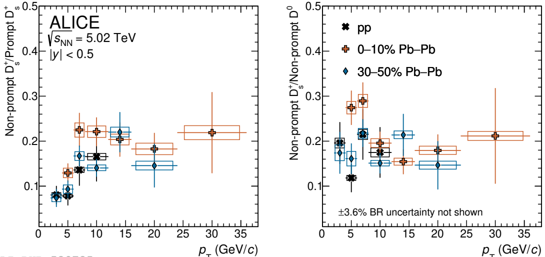
TAMU: Fries and Rapp Phys. Lett. B 735 (2014) 445–450
Cujet3.1: Shi et al. C 43 (2019) 044101
LGR: Li et al. Eur. Phys. J. C 80 (2020) 671
MC@sHQ+EPOS2: Nahrgang et al. Rev. C 89 no. 1, (2014) 014905

R_{AA} ratios



ALI-PUB-520733

Yield ratios



ALI-PUB-520725

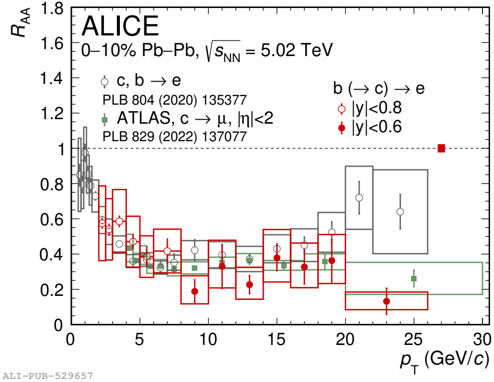
arXiv:2204.10386

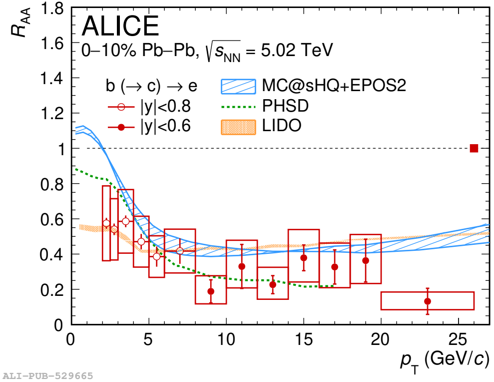
- R_{AA} ratio for D_s^+ shows similar pattern as for D^0
- Non-prompt D_s^+ may be enhanced compared to D^0 in central collisions

Excited D_s states in pp:
Stefano Politanò
29.3., 10:00

TAMU: Fries and Rapp Phys. Lett. B 735 (2014) 445–450

$b \to e$ in Pb–Pb collisions





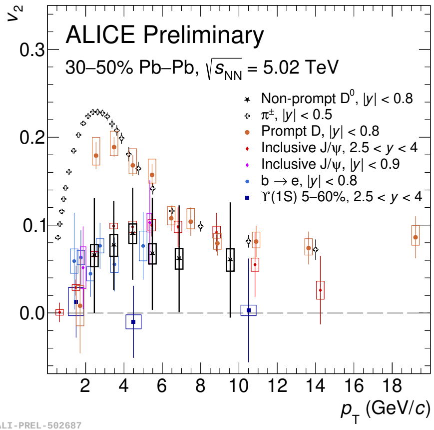
New paper: arXiv:2211.13985

- Similar R_{AA} for electrons from beauty and charm
- Points to strong interaction with medium

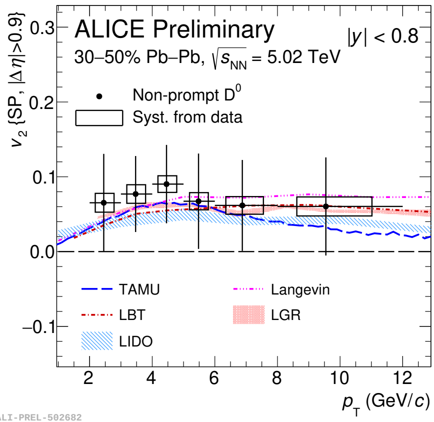
MC@sHQ+EPOS2: Nahrgang et al. Rev. C 89 no. 1, (2014) 014905
PHSD: Song et al. Phys. Rev. C 92 no. 1, (2015) 014910
LIDO: Ke et al. Phys. Rev. C 98 no. 6, (2018) 064901

- Models with QGP phase generally describe measurements
- Different beauty hadron species have similar branching ratios to electrons

Elliptic flow of non-prompt D^0 mesons



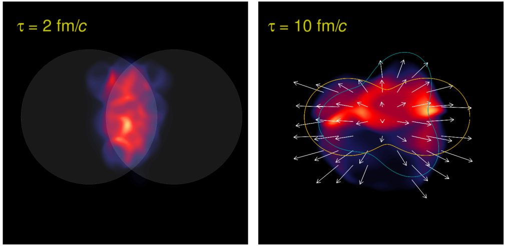
ALI-PREL-502687



ALI-PREL-502682

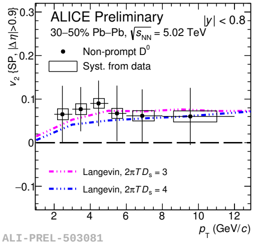
- Significant flow for non-prompt D^0 mesons (and $b \to e$)
- v_2 lower than for prompt D mesons
- Described well by theories including mass-dependent v_2

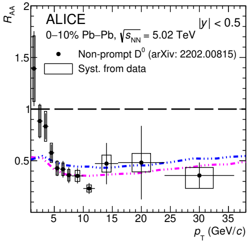
The situation in Pb–Pb collisions

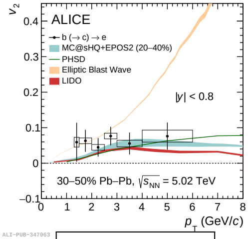


CERN Courier May/Jun 2021

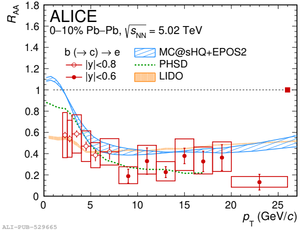
- Indication of strong interactions of beauty quarks with QGP
- Results consistent with expectation of weaker interaction for beauty than for charm quarks
- Fits into picture of quarks interacting with hydrodynamically expanding medium







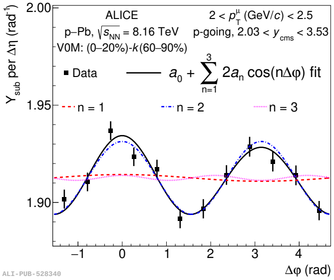
PRL 126 16 (2021)

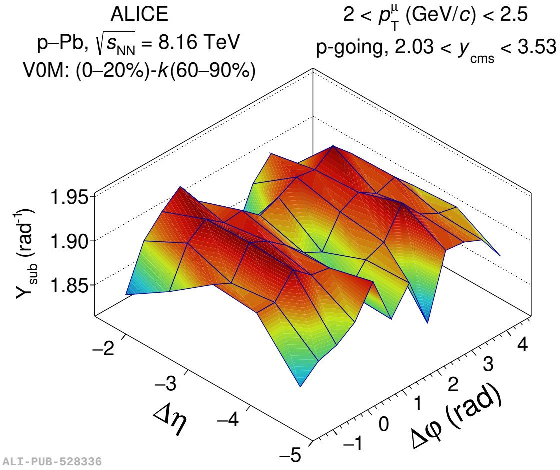


arXiv:2211.13985

Muon v_2 from two-particle correlations

- Correlate particles at mid-rapidity ($|\eta| < 1$) with muons in $-4 < \eta < -2.5$
- Distribution given relative to random, uncorrelated background
- Possible flow effects expected to occur for higher multiplicity collisions $\rightarrow$ Subtract scaled low-mult. from high-mult. case

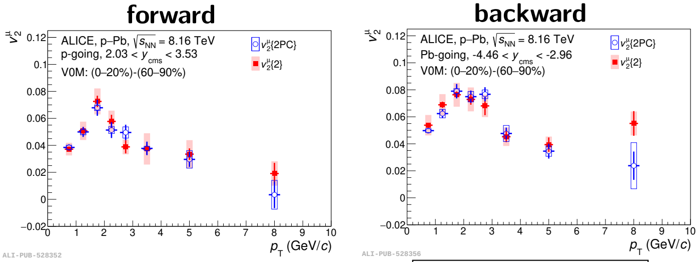




New paper: arXiv:2210.08980

Muons: Method comparison

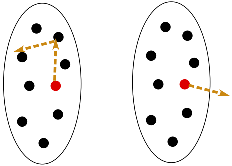
- Correlate v_2: 2-particle correlation and 2-particle cumulant methods
- Similar results, possible higher result for correlation method at high p_T
- Hint of higher elliptic flow at backward rapidity

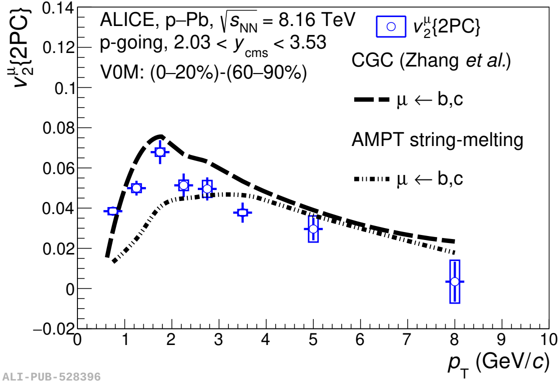


New paper: arXiv:2210.08980

Muons: Theory comparison

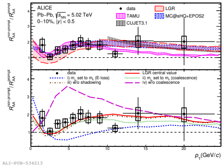
- AMPT: fluctuating initial conditions+elastic scatterings of partons+hadronization including coalescence+hadronic interactions
- Positive v_2 from anisotropic parton escape (Phys. Lett. B 753 (2016))
- Color-Glass-Condensate (CGC) based model creates elliptic flow at early times due to correlations in initial state

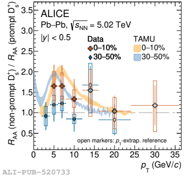


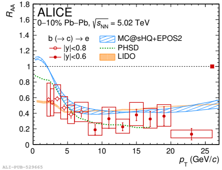


New paper: arXiv:2210.08980

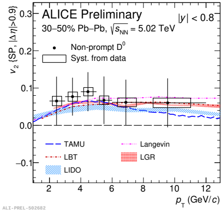
GCG: Zhang et al. Phys. Rev. D 102 no. 3, (2020) 034010
AMPT: Li et al. Phys. Rev. C 99 no. 4, (2019) 044911

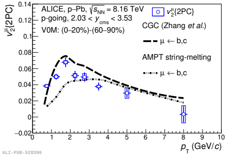






- In **Pb–Pb**, R_{AA} and v_2 point to substantial interaction of beauty quarks with the medium
- Most successful models include collisional and radiative, mass dependent interaction in expanding medium
- In **p–Pb**, similar to lighter particles: no strong modification of p_{T} spectra, but substantial collective behavior in flow coefficients
- Different mechanisms might be able to describe effect, but no clear consensus
- In **Run 3**: full reconstruction of beauty hadrons; muons from beauty hadron decays

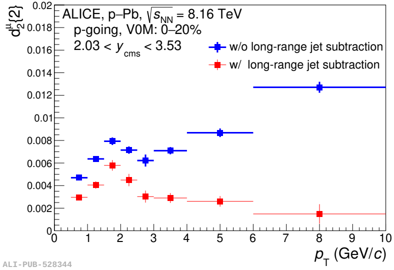


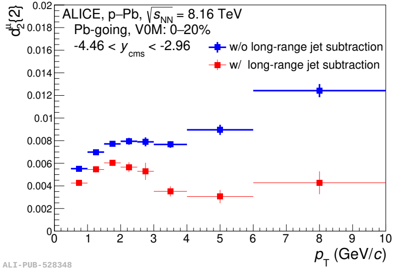


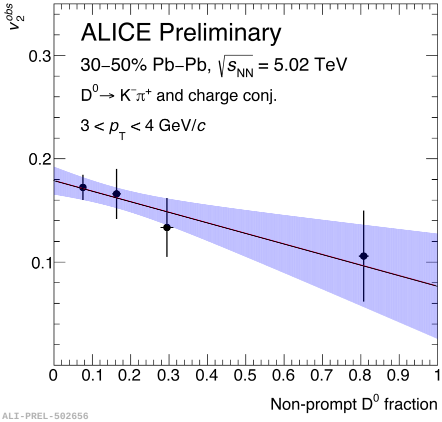
Appendix

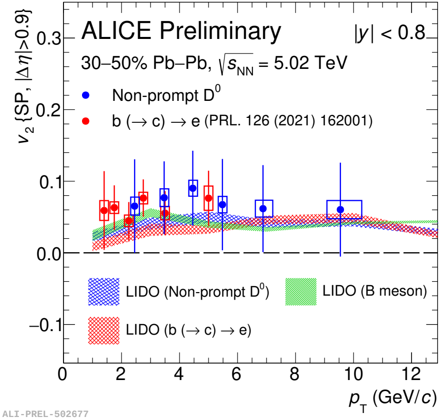
Appendix: Subtracting low mult for cumulant method

- Shows suppression of jet-like contributions



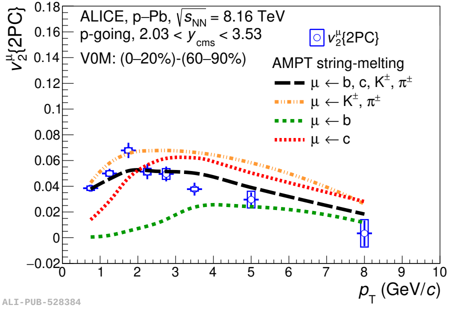


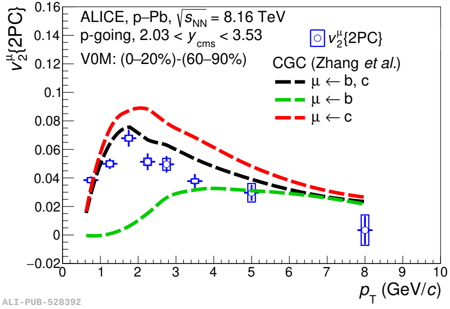




- Small change from hadron v_2 to that of the decay particles

Appendix: Muon elliptic flow contributions





- The GCG-based model does not include contributions from light particle decays

Appendix: Upgrade projections