The 19th International Conference on Strangeness in Quark Matter

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SQM2021

Prompt and non-prompt D_s^+ production in pp and Pb–Pb with ALICE

19th International Conference on Strangeness in Quark Matter

Fabio Catalano on behalf of the ALICE Collaboration

20th May 2021

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DiSAT

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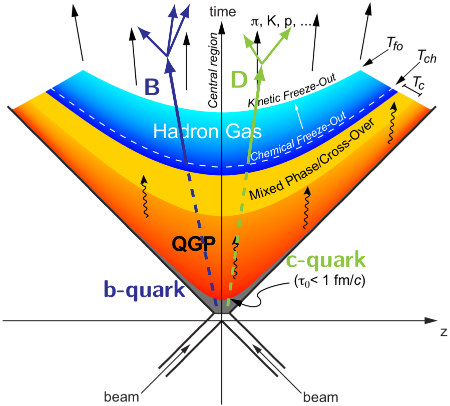
ALICE

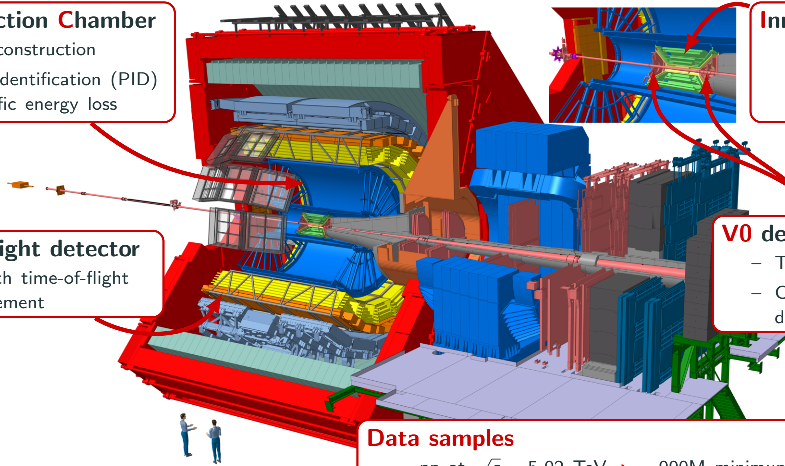
Heavy flavours in pp and Pb–Pb collisions

- Large masses of charm and beauty quarks ➔ produced in hadronic collisions from hard parton-scattering processes

- **proton-proton collisions**
  - test of perturbative-QCD calculations
  - insights on heavy-flavour hadronisation
  - reference for p-Pb and Pb–Pb measurements

- **Pb–Pb collisions**
  - heavy quarks produced before quark-gluon plasma (QGP) formation
  - experience the full evolution of the system
  - strongly interacting with the medium





Time Projection Chamber

- Track reconstruction
- Particle identification (PID) via specific energy loss

Inner Tracking System

- Tracking
- Reconstruction of primary and decay vertices

Time of Flight detector

- PID with time-of-flight measurement

V0 detectors

- Trigger
- Centrality and event-plane determination

Data samples

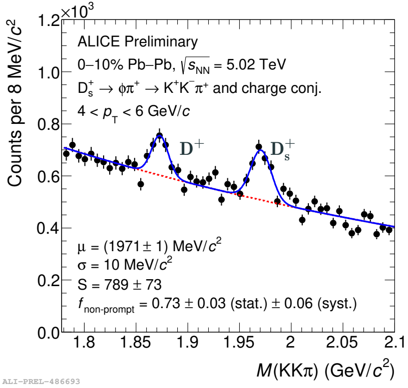
- pp at $\sqrt{s} = 5.02$ TeV → $\sim$ 990M minimum-bias events
- Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV → $\sim$ 100M central events
  $\sim$ 85M semicentral events

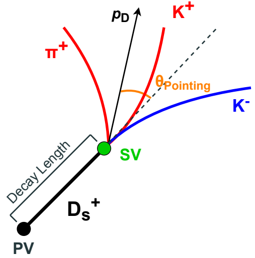
D_s^+-meson reconstruction

D_s^+ mesons are measured via their resonant hadronic decay

Meson	M (GeV/c^2)	$c\tau$ (μm)	Decay	BR (%)
D_s^+ ($c\bar{s}$)	~ 1.968	~ 151	$\phi(\to K^-K^+)\pi^+$	~ 2.24

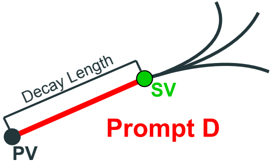
P.A. Zyla et al. (PDG) PTEP 2020 8, 083C01 (2020)

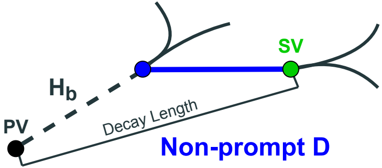




- Candidates built from triplets of tracks at midrapidity ($|\eta| < 0.8$) with proper charge-sign combination
- To reduce the combinatorial background
  - particle identification of decay tracks
  - geometrical and kinematic selections based on displaced decay-vertex topology
- Machine learning (ML) tools for candidate selection

- D_s^+ mesons
  - Prompt, from charm-quark hadronisation or excited charm-hadron decays
  - Non-prompt, from beauty-hadron decays





- Non-prompt D_s^+ mesons → beauty-quark production
  - $\sim 50\%$ from B_s^0 decays and $\sim 50\%$ from non-strange B

P.A. Zyla et al. (PDG) PTEP 2020 8, 083C01 (2020)

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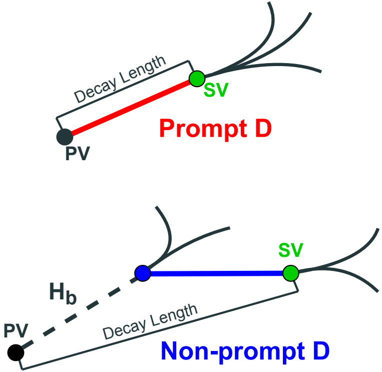
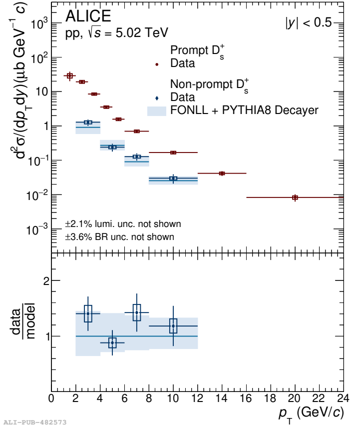
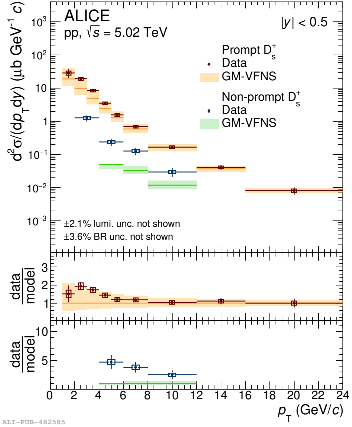


- Non-prompt D_s^+ mesons → B_s^0-meson production
  - $\sim 50\%$ from B_s^0 decays and $\sim 50\%$ from non-strange B
- Possible to disentangle prompt and non-prompt D_s^+
  - beauty hadrons have $c\tau \simeq 500\ \mu m$
  - non-prompt D_s^+ on average more displaced from the interaction vertex
  - different topology and kinematic features
- ML to separate prompt D_s^+ mesons, non-prompt D_s^+ mesons and combinatorial background

D_s^+ production in pp collisions at 5 TeV — pQCD calculations

D mesons: arXiv:2102.1360





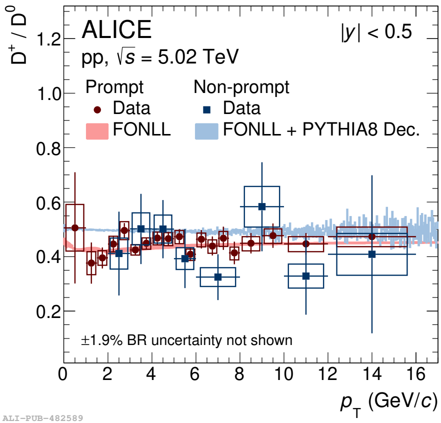
FONLL: M. Cacciari et al. JHEP 1210 137 (2012)
PYTHIA8: T. Sjöstrand et al. JHEP 05 026 (2006)
GM-VFNS: G. Kramer et al, Nucl. Phys. B 925 415-430 (2017)
T. Kneesch et al. Nucl. Phys. B 799 34-59 (2008)

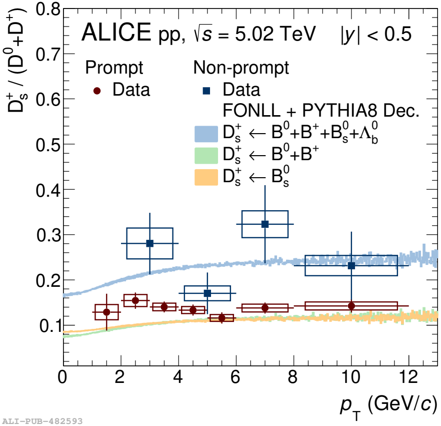
- GM-VFNS calculations describe within uncertainties the prompt D_s^+-meson measurement
- FONLL calculations not available for prompt D_s^+

- Non-prompt D_s^+ compatible with FONLL central values and underestimated by GM-VFNS
  - FONLL ➔ $f(b \to H_b)$ FFs from e^+e^- and PYTHIA8 to describe $H_b \to D_s^+ + X$ decays
  - GM-VFNS ➔ "single-step" description of $b \to D_s^+ + X$ using FF from e^+e^- measurements

D-meson yield ratios in pp collisions

FONLL: M. Cacciari et al. JHEP 1210 137 (2012) PYTHIA8: T. Sjöstrand et al. JHEP 05 026 (2006) D mesons: arXiv:2102.1360





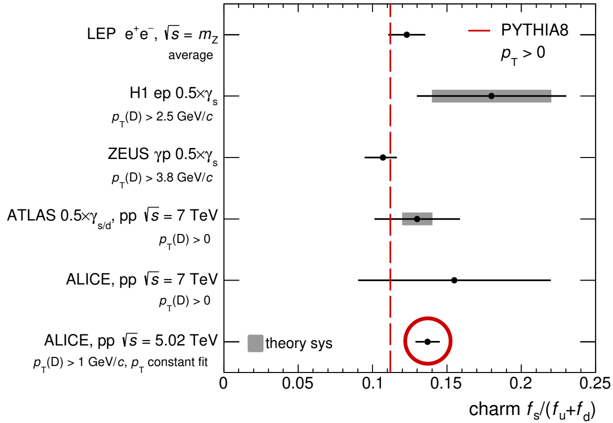
- D-meson ratios flat in p_T and in good agreement with FONLL calculations
  - Compatible prompt and non-prompt D^+/D^0 ratios
  - $D_s^+/(D^0+D^+)$ ratio higher for non-prompt D mesons. Substantial B_s^0-decay contribution

Charm-quark fragmentation fractions in pp collisions

PYTHIA8: P. Skands et al. EPJC 74 3024 (2014)
LEP: L. Gladilin EPJC 75 19 (2015)
H1: EPJC 38 447-459 (2005)

ZEUS: JHEP 09 058 (2013)
ATLAS: Nucl. Phys. B 907 717-763 (2016)
ALICE, 7 TeV: PLB 718 279-294 (2012)

D mesons: arXiv:2102.1360



ALI−PUB−482597

- Charm-quark $f_s/(f_u + f_d)$ ratio from constant fit to prompt $D_s^+/(D^0 + D^+)$
- Very precise measurement in agreement with previous observations
- Compatible with PYTHIA8 Monash-13 tune simulations (2.7 σ)

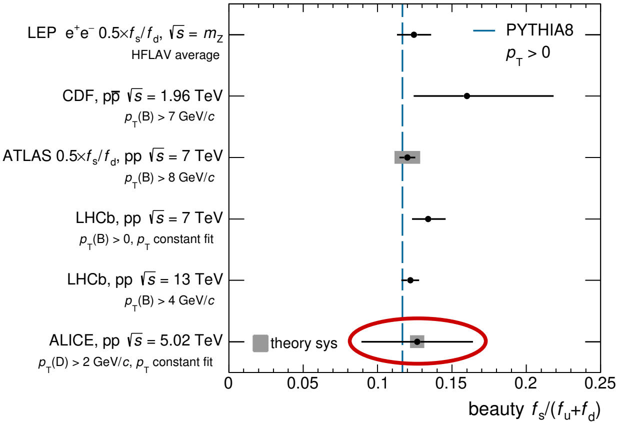
$$\left(\frac{f_s}{f_u + f_d}\right)_{\text{charm}} = 0.137 \pm 0.005\ (\text{stat}) \pm 0.008\ (\text{tot.syst})$$

Beauty-quark fragmentation fractions in pp collisions

PYTHIA8: P. Skands et al. EPJC 74 3024 (2014)
LEP: Y. Amhis et al. (HFLAV) arXiv:1909.12524
CDF: Phys. Rev. D 77 072003 (2008)

ATLAS: PRL 115 262001 (2015)
LHCb, 7 TeV: Phys. Rev. D 85 032008 (2012)
LHCb, 13 TeV: Phys. Rev. D 100 031102 (2019)

D mesons: arXiv:2102.1360



ALI−PUB−482601

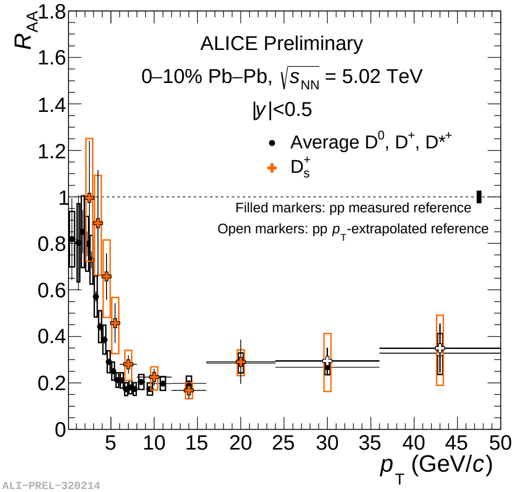
- Beauty-quark $f_s/(f_u + f_d)$ from constant fit to non-prompt $D_s^+/(D^0 + D^+)$ ratio
- Correction to account for non-prompt D_s^+ mesons from B^0 and B^+ decays
- Value compatible with previous measurements and PYTHIA8

$$\left(\frac{f_s}{f_u + f_d}\right)_{\text{beauty}} = 0.127 \pm 0.036\,(\text{stat}) \pm 0.014\,(\text{tot.syst})$$

Strange and non-strange prompt D-meson R_{AA}

- Strong suppression of D-meson R_{AA} in central Pb–Pb collisions
  - factor ~ 5 in magnitude at $8 - 12\ \mathrm{GeV}/c$
- Hint of reduced suppression for $\mathrm{D_s^+}$ w.r.t. non-strange D mesons at $p_\mathrm{T} < 8\ \mathrm{GeV}/c$
  - expected for hadronization via coalescence + strangeness enhancement in the QGP

    I. Kuznetsova et al. EPJ C51 113 (2007)



Strange and non-strange prompt D-meson R_{AA}

PHSD: T. Song et al. PRC 92 014910 (2015)   TAMU: M. He et al. PLB 735 445-450 (2014)   Catania: S. Plumari et al. EPJC 78 348 (2018)

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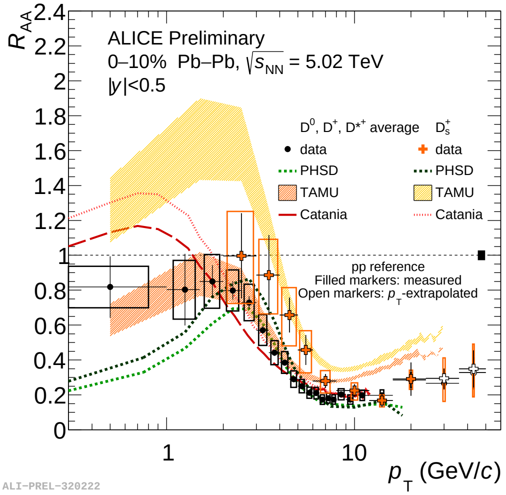
  - expected for hadronization via coalescence + strangeness enhancement in the QGP
  I. Kuznetsova et al. EPJ C51 113 (2007)
- Charm-quark transport models including coalescence describe the hierarchy

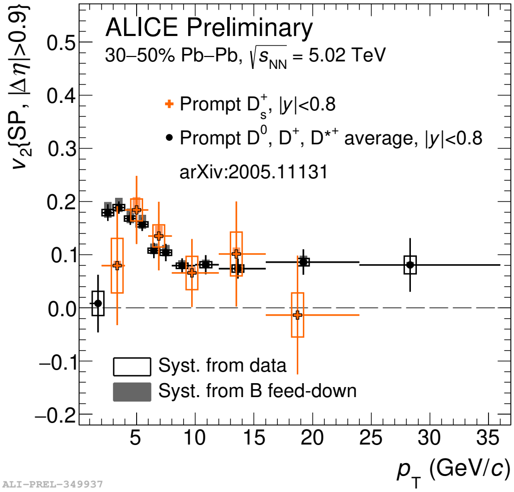
$$R_{AA}(D_s^+) > R_{AA}(D)$$



Strange and non-strange prompt D-meson elliptic flow

Non-strange D: PLB 813 136054 (2021)

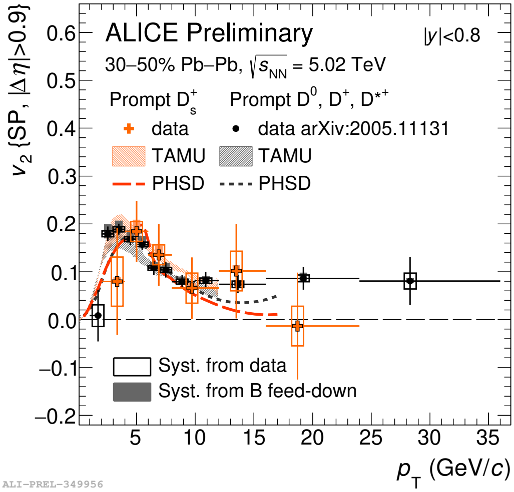
- Positive v_2 of prompt D mesons ➔ charm quarks participate in the QGP collective motion
- No significant difference between strange and non-strange D mesons



Strange and non-strange prompt D-meson elliptic flow

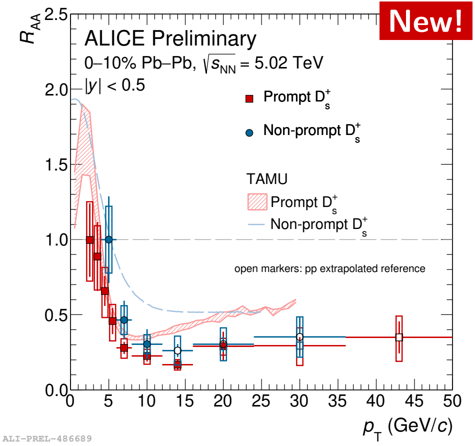
Non-strange D: PLB 813 136054 (2021) TAMU: M. He et al. PRL 124 042301 (2020) PHSD: T. Song et al. PRC 92 014910 (2015)

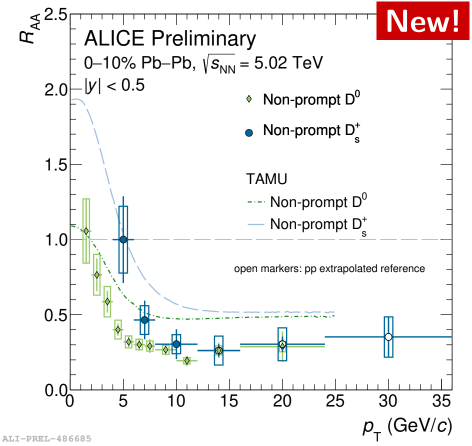
- Positive v_2 of prompt D mesons → charm quarks participate in the QGP collective motion
- No significant difference between strange and non-strange D mesons
- Strange and non-strange D-meson elliptic flow reproduced by TAMU and PHSD models



Non-prompt D_s^+-meson R_{AA}

TAMU: M. He et al. PLB 735 445-450 (2014)

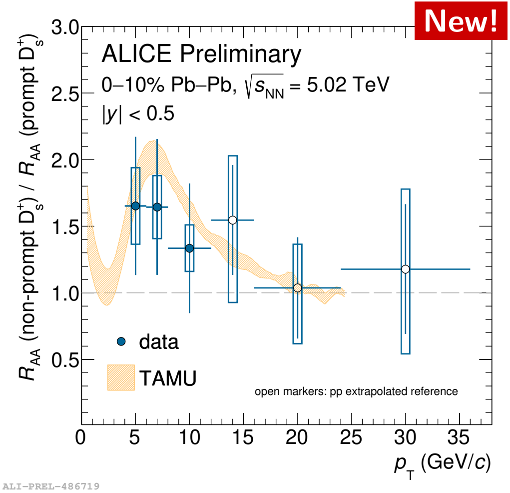




- First measurement of non-prompt D_s^+ mesons in central (0-10%) Pb–Pb collisions
- Hint of larger R_{AA} than prompt D_s^+ and non-prompt D^0 mesons in the low p_T region

Non-prompt and prompt D-meson R_{AA}

TAMU: M. He et al. PLB 735 445-450 (2014)



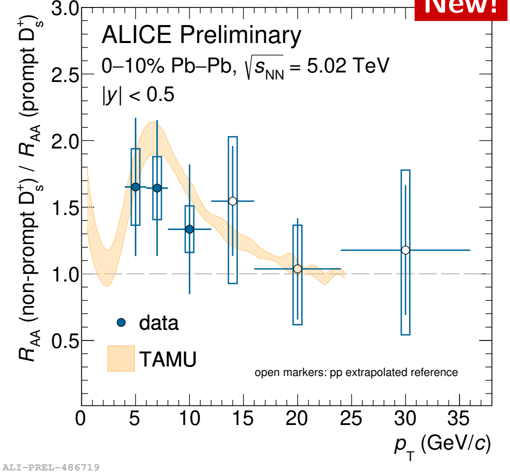
- Indication of smaller suppression of D_s^+ mesons from B-meson decays than prompt ones below ~ 8 GeV/c
  - described by TAMU model predictions
- Interplay of charm and beauty energy loss and recombination in the medium

Non-prompt and prompt D-meson R_{AA}

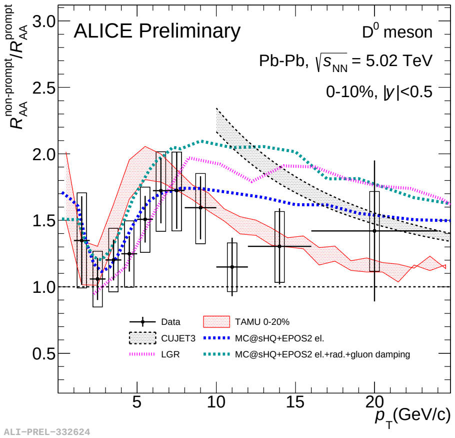
LGR: S. Li et al. EPJC 80 7 671 (2020)
CUJET3.0: J. Xu et al. JHEP 02 169 (2016)
TAMU: M. He et al. PLB 735 445-450 (2014)
MC@sHQ+EPOS: M. Nahrgang et al. PRC 89 014905 (2014)

J. Park, earlier today

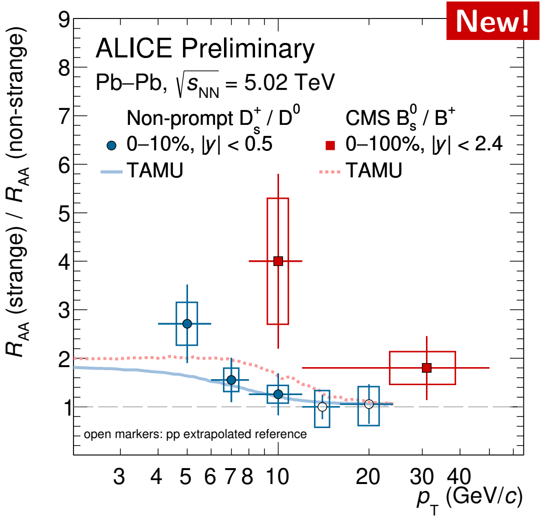
New!



► D^0-meson R_{AA} → hint of $\Delta E_c > \Delta E_b$



CMS: PLB 796 168-190 (2019) TAMU: M. He et al. PLB 735 445-450 (2014)

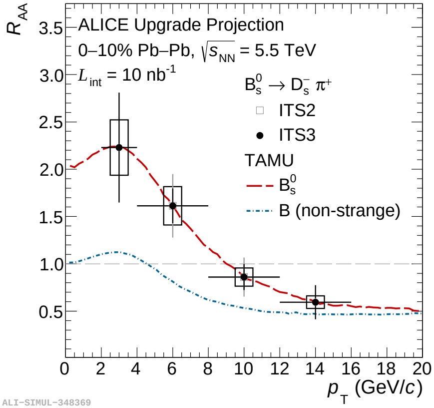


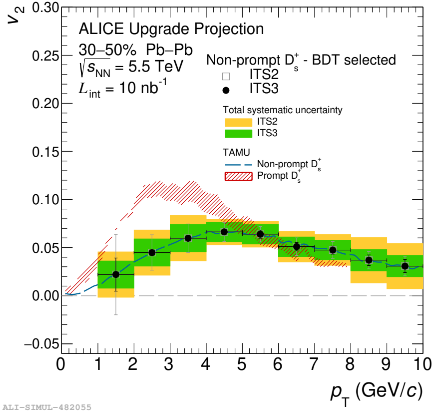
ALI-PREL-486727

- $R_{AA}(D_s^+)/R_{AA}(D^0)$ ratio for non-prompt above one at low p_T
  - B_s^0-production enhanced by beauty hadronisation via coalescence
- TAMU model describes the observed trend
- Larger $R_{AA}(B_s^0)/R_{AA}(B^+)$ ratio than non-prompt D
  - D_s^+ from non-strange B-meson decays
  - different decay kinematics

F. Reidt, 19th May 14:25

- Major upgrade of ALICE detectors and read-out electronics ongoing
  - increase collected Pb-Pb luminosity by more than 50 times
  - upgraded Inner Tracking System (ITS2) ➔ improved track and secondary-vertex resolution

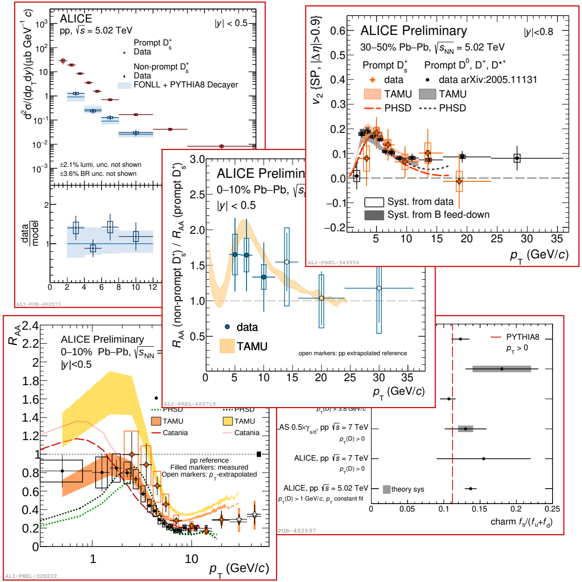




- Measurements of B^0_s R_{AA} and non-prompt D^+_s v_2 possible with good precision

Conclusions

- Prompt and non-prompt D_s^+ mesons measured in pp collisions
  - potential to constrain pQCD calculations
  - precise study of charm and beauty hadronisation
- In Pb–Pb collisions
  - non-prompt D_s^+ measured for the first time
  - insights into heavy-flavour recombination
  - charm quarks participate in the QGP collective motion
- Just an appetizer for ALICE measurements of Run 3 with upgraded detectors and larger data samples



Backup

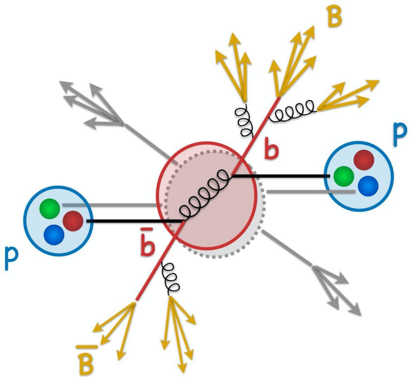
Heavy flavours in proton-proton collisions

- Heavy flavours (c and b quarks) produced in hadronic collisions from hard-scattering processes

- Production described with perturbative QCD calculations based on the factorisation theorem

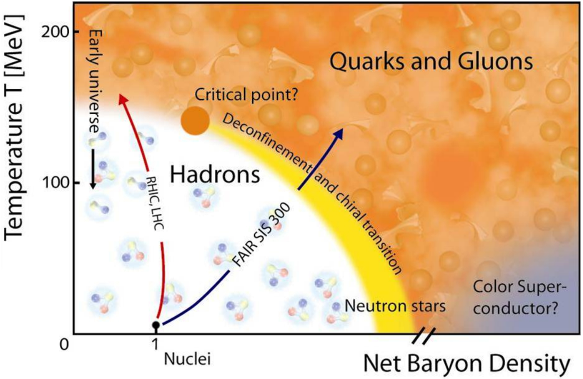
$$\sigma_{\mathrm{hh}\to\mathrm{Hh}} = PDF(x_{\mathrm{a}}, Q^2)\ PDF(x_{\mathrm{b}}, Q^2) \otimes \sigma_{\mathrm{ab}\to\mathrm{q\bar{q}}} \otimes D_{\mathrm{q}\to\mathrm{h}}(z_{\mathrm{q}}, Q^2)$$

Parton distribution functions (non perturbative)
Partonic cross section (perturbative)
Fragmentation functions (non perturbative)



Quark-Gluon Plasma in ultra-relativistic heavy-ion collisions

Quantum chromodynamics (QCD) calculations predict a phase transition of nuclear matter to a colour-deconfined medium, the quark–gluon plasma (QGP), under extreme conditions of temperature and/or density



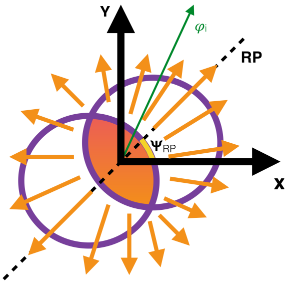
- The QGP can be created in the laboratory by ultra-relativistic heavy-ion collisions

Heavy flavours in Pb–Pb collisions — Observables

Heavy flavours propagate through the QGP and interact with the medium constituents

- **Energy loss via elastic scatterings and gluon radiation**
  - nuclear modification factor R_{AA}

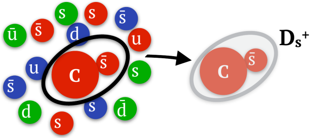
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll}^{AA} \rangle} \frac{dN_{AA}/p_T}{dN_{pp}/p_T}$$



- **Participation in the fireball collective motion**
  - azimuthal anisotropy of produced particle momenta

$$v_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$$

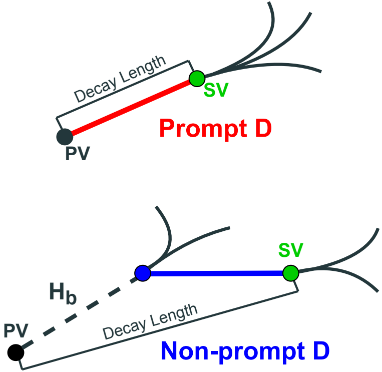
- **Hadronisation via recombination in the medium**
  - p_T-dependent yield ratios, R_{AA} and v_2 of different hadron species



Prompt and non-prompt D_s^+ mesons

P.A. Zyla et al. (PDG) PTEP 2020 8, 083C01 (2020)

- D_s^+ mesons
  - Prompt, from charm-quark hadronisation or excited charm-hadron decays
  - Non-prompt, from beauty-hadron decays

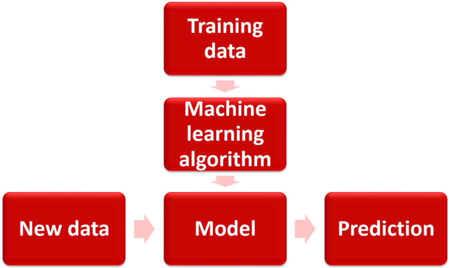


- Non-prompt D mesons ➔ beauty-quark production and hadronisation
  - different B-meson contributions for each D species

	from B^0	from B^+	from B_s^0
non-prompt D^0	$\sim$ 40%	$\sim$ 60%	–
non-prompt D^+	$\sim$ 75%	$\sim$ 25%	–
non-prompt D_s^+	$\sim$ 25%	$\sim$ 20%	$\sim$ 55%

(PDG BRs and FFs from $Z \to b\bar{b}$ decays, contributions from baryons negligible)

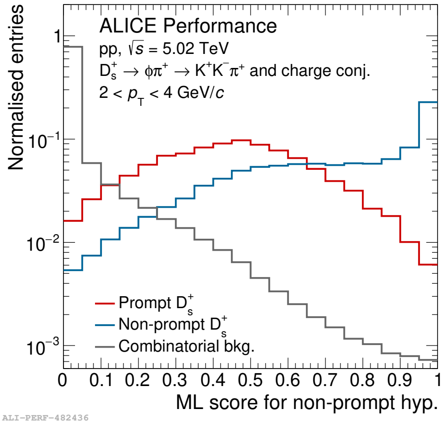
- Supervised ML models "learn" to make predictions from a set of examples, where the correct classification is known
- They can perform more complex selections w.r.t. the linear selections traditionally used



- To train the model a training set is needed. It is built from
  - Monte Carlo productions → prompt and non-prompt D mesons
  - data collected by the experiment → combinatorial background from sidebands of invariant-mass distribution
- After the training, the ML model is used to predict the class of unknown particle candidates

Analysis tools — Multi-class classification

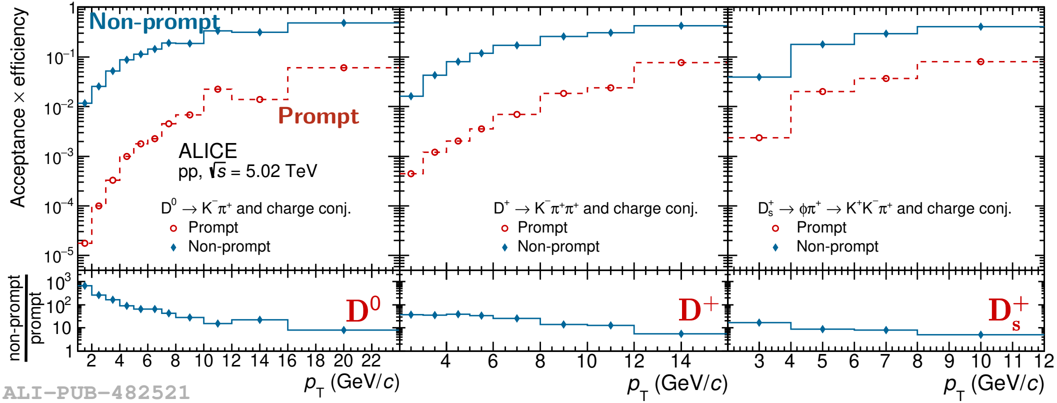
- Multi-class Boosted Decision Trees (BDT) employed to separate prompt D mesons, non-prompt D mesons and combinatorial background
  - different BDTs for D^0, D^+ and D_s^+ mesons and for different transverse-momentum (p_T) intervals



Prompt/Non-prompt D_s^+ from MC, bkg. from data

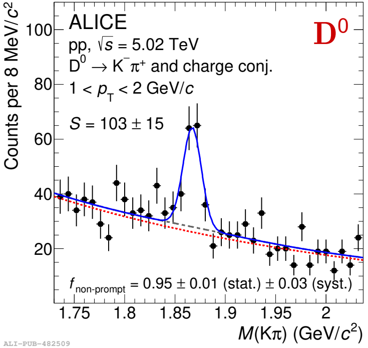
- BDT input: candidate kinematic, geometrical and PID quantities
- BDT output: 3 scores related to the candidate probability to be prompt, non-prompt and background
- Selections applied on these scores to reduce combinatorial background and reject prompt or non-prompt D mesons

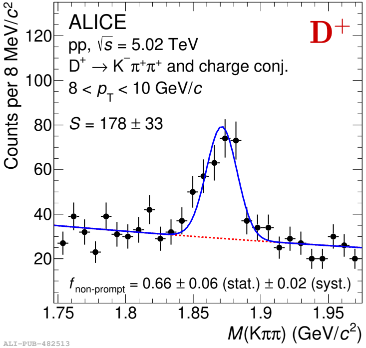
Non-prompt D mesons — Selection efficiencies

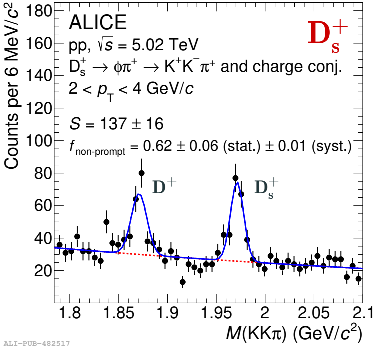


- Non-prompt D-meson measurements ➔ selections on BDT scores tuned to suppress the prompt contribution and enhance the non-prompt one in the raw yields
- Prompt efficiencies smaller by a factor $\sim 5 - 700$ depending on the species and p_T

Non-prompt D mesons — Raw-yield extraction



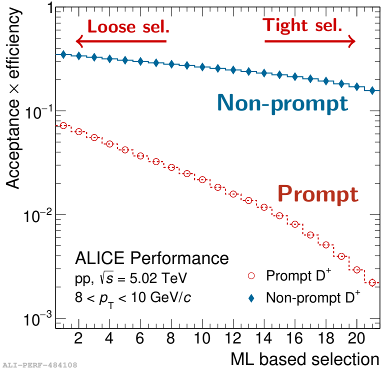




- D^0, D^+ and D_s^+ yields extracted from fit to the invariant-mass distributions of particle candidates
- Enhanced fraction of non-prompt D mesons in the raw yields ➔ estimated with a data-driven approach

Data-driven estimation of non-prompt fraction

- Define n sets of selections with different prompt and non-prompt D-meson contributions
- For each selection set the raw yield and the efficiencies are related to the corrected yields of prompt N_{prompt} and non-prompt $N_{\mathrm{non\text{-}prompt}}$ D mesons
- An algebraic system is obtained



$$\begin{cases} (\mathrm{Acc} \times \epsilon)_1^{\mathrm{prompt}} \cdot N_{\mathrm{prompt}} + (\mathrm{Acc} \times \epsilon)_1^{\mathrm{non\text{-}prompt}} \cdot N_{\mathrm{non\text{-}prompt}} = Y_1 \\ \ldots \\ (\mathrm{Acc} \times \epsilon)_n^{\mathrm{prompt}} \cdot N_{\mathrm{prompt}} + (\mathrm{Acc} \times \epsilon)_n^{\mathrm{non\text{-}prompt}} \cdot N_{\mathrm{non\text{-}prompt}} = Y_n \end{cases}$$

Data-driven estimation of non-prompt fraction

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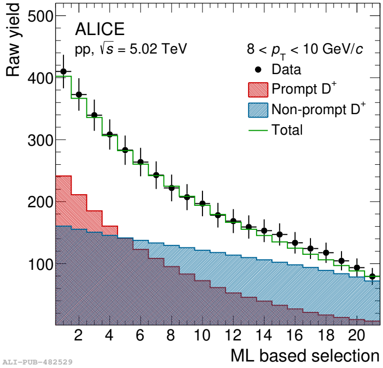
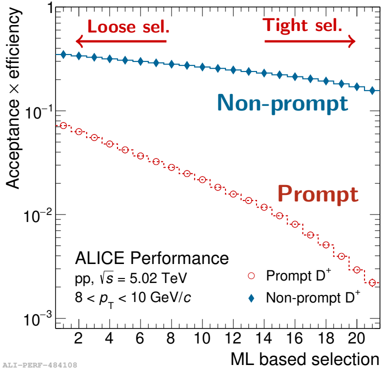




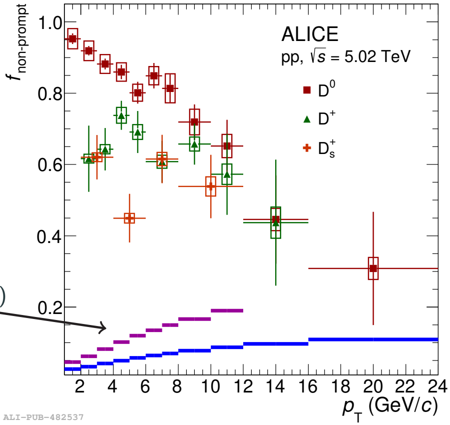
- Corrected yields of prompt and non-prompt D mesons obtained from χ^2 minimization of the system

Data-driven estimation of non-prompt fraction

- Define *n* sets of selections with different prompt and non-prompt D-meson contributions
- Corrected yields of prompt and non-prompt D mesons obtained from χ^2 minimization of the system

"Natural" $f_{\mathrm{non-prompt}}$ (FONLL + PYTHIA)

$\mathbf{D^0}$, $\mathbf{D^+}$ $\mathbf{D_s^+}$



- Non-prompt fraction $f_{\mathrm{non-prompt}}$ evaluated for a given set of selections as

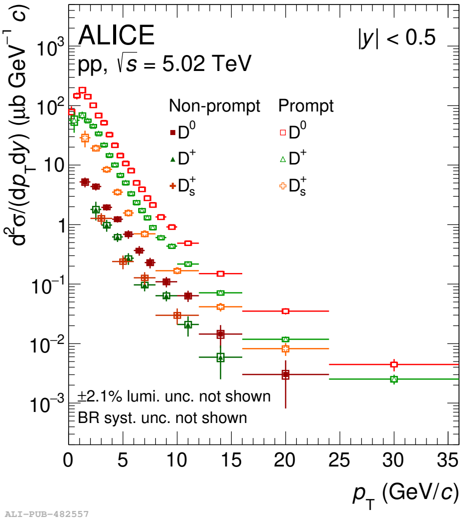
$$f^{\mathrm{i}}_{\mathrm{non\text{-}prompt}} = \frac{(\mathrm{Acc}\times\epsilon)^{\mathrm{non\text{-}prompt}}_{\mathrm{i}} \cdot N_{\mathrm{non\text{-}prompt}}}{(\mathrm{Acc}\times\epsilon)^{\mathrm{non\text{-}prompt}}_{\mathrm{i}} \cdot N_{\mathrm{non\text{-}prompt}} + (\mathrm{Acc}\times\epsilon)^{\mathrm{prompt}}_{\mathrm{i}} \cdot N_{\mathrm{prompt}}}$$

Beauty-quark fragmentation fractions

PDG: PTEP 2020 8, 083C01 (2020)

b-hadron	Fraction at Z (%)	Fraction at $\mathrm{p\bar{p}}$ (%)
$\mathrm{B^0}$, $\mathrm{B^+}$	40.8 ± 0.7	34.4 ± 2.1
$\mathrm{B_s^0}$	10.0 ± 0.8	11.5 ± 1.3
Λ_b^0	8.4 ± 1.1	19.8 ± 4.6

Results — Cross sections



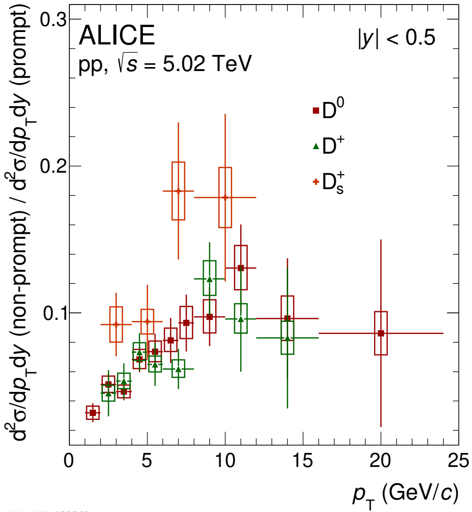
- Prompt and non-prompt D mesons measured down to very low transverse momenta
- Prompt D^0 from EPJC 79 388 (2019)
- Prompt D^+ and D_s^+ measurements updated using ML ➔ larger p_T reach w.r.t. previous results

Results — Non-prompt over prompt ratios

Prompt D^0: EPJC 79 388 (2019)

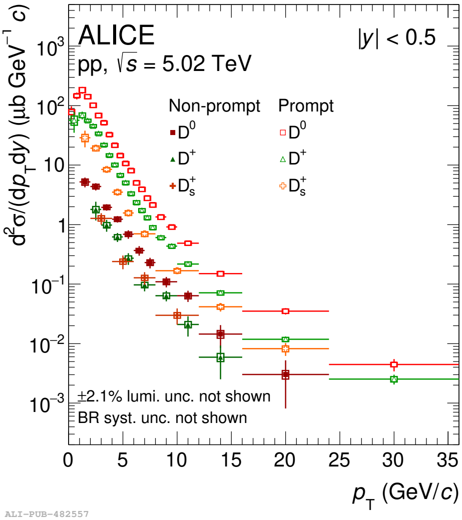
- Cross section ratios of non-prompt and prompt D mesons increase with p_T up to $12\ \mathrm{GeV}/c$
  - beauty-hadron p_T distribution harder than D mesons
- Hint of larger ratio for D_s^+ mesons
  - larger contribution of beauty-hadron decays compared to non-strange D mesons

$$b \to c\bar{c}s \qquad \bar{b} \to c\bar{c}\bar{s}$$



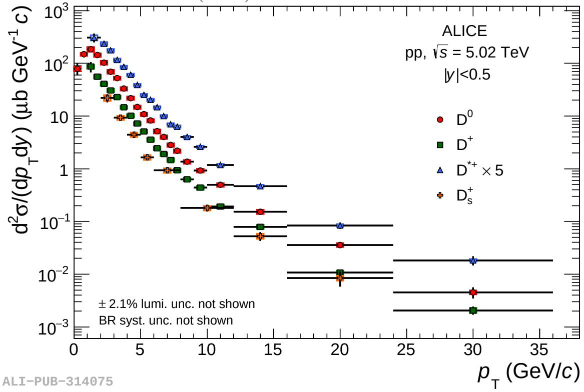
ALI-PUB-482561

Prompt D^+ and D_s^+ cross sections vs. 2019 paper



- Measurement of prompt D^+ and D_s^+ mesons updated using ML → extension to lower transverse momenta w.r.t. 2019 result

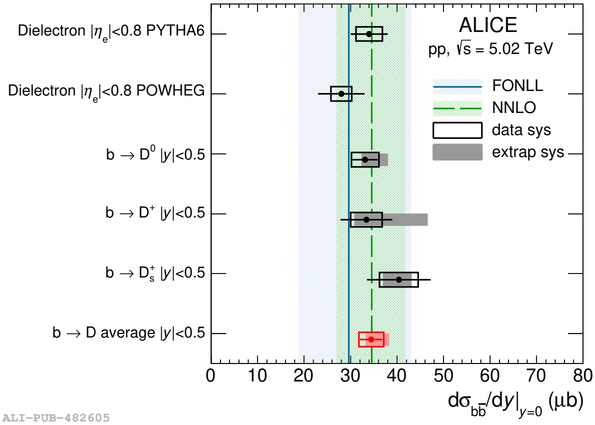
EPJC 79 388 (2019)



Results — Beauty-quark production cross section

Dielectron: Phys. Rev. C 102 055204 (2020) FONLL: M. Cacciari et al. JHEP 1210 137 (2012) NNLO: S. Catani et al. JHEP 03 029 (2021)

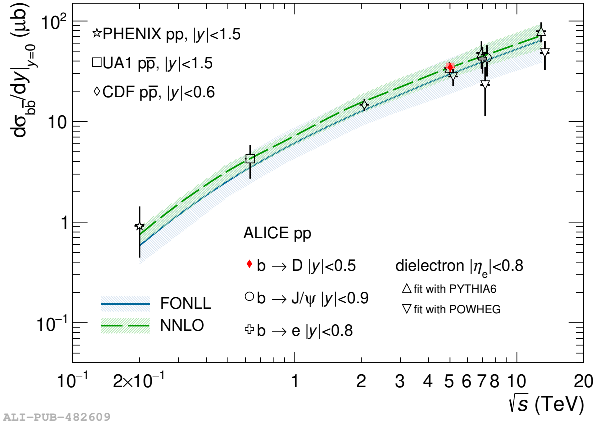
- p_T-differential non-prompt D-meson measurement → p_T-integrated cross section → $b\bar{b}$ production cross section at midrapidity



- D-meson average compatible with previous ALICE measurements
- Good agreement with FONLL and calculations including NNLO QCD radiative corrections

$$\left.\frac{d\sigma_{b\bar{b}}}{dy}\right|_{|y|<0.5} = 34.5 \pm 2.4(\text{stat})\ ^{+4.7}_{-2.9}(\text{tot.syst})\ \mu\text{b}$$

Results — Beauty-quark production cross section



PHENIX: PRL 103 082002 (2009)
UA1: PLB 256 121–128 (1991)
CDF: Phys. Rev. D 75 012010 (2007)
b → J/Ψ: JHEP 11 065 (2012)
b → e: PLB 721 13-23 (2013)
Dielectron, 5 TeV: PRC 102 055204 (2020)
Dielectron, 7 TeV: JHEP 09 064 (2018)
Dielectron, 13 TeV: PLB 788 505-518 (2019)
FONLL: M. Cacciari et al. JHEP 1210 137 (2012)
NNLO: S. Catani et al. JHEP 03 029 (2021)

- Beauty-quark production described by FONLL and NNLO calculations over a wide interval of center-of-mass energies

Beauty FF ratio and cross section corrections

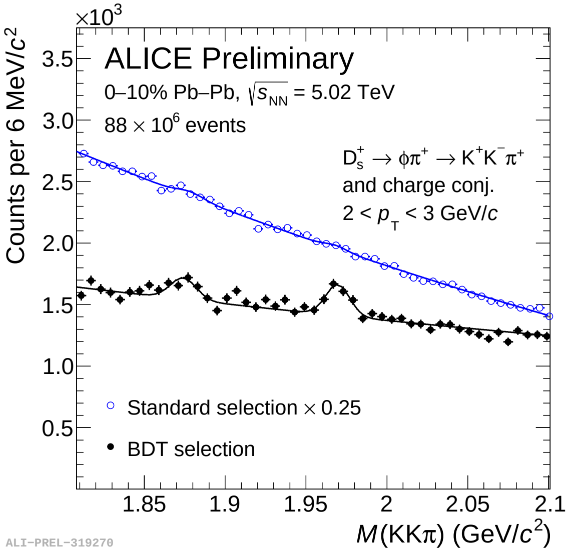
- Correction for beauty-quark FF ratio

$$\left(\frac{f_\mathrm{s}}{f_\mathrm{u}+f_\mathrm{d}}\right)_\mathrm{beauty} = \left[\frac{N(\mathrm{D_s^+} \leftarrow \mathrm{B_s^0})}{N(\mathrm{D_s^+} \leftarrow \mathrm{H_b})} \cdot \frac{N(\mathrm{D^0},\mathrm{D^+} \leftarrow \mathrm{H_b})}{N(\mathrm{D^0},\mathrm{D^+} \leftarrow \mathrm{B^{0,+}})}\right]^{\mathrm{FONLL+PYTHIA\ 8}} \cdot \left(\frac{\mathrm{D_s^+}}{\mathrm{D^0}+\mathrm{D^+}}\right)_\mathrm{non-prompt}$$

- Extrapolation factor for beauty-quark cross section

$$\alpha_\mathrm{extr}^{\mathrm{b\bar{b}}} = \frac{\mathrm{d}\sigma_{\mathrm{b\bar{b}}}/\mathrm{d}y\Big|_{|y|<0.5}^{\mathrm{FONLL}}}{\sigma_{\mathrm{b\rightarrow D}}^{\mathrm{FONLL+PYTHIA\ 8}}(p_\mathrm{T}^\mathrm{min} < p_\mathrm{T} < p_\mathrm{T}^\mathrm{max}, |y| < 0.5)}$$

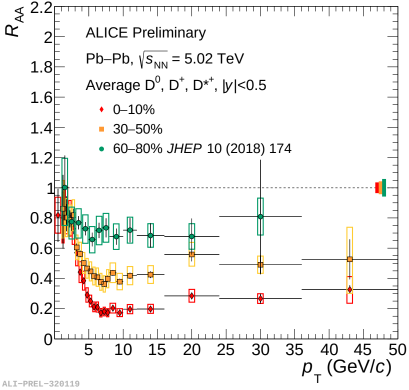
Selections improved with machine learning

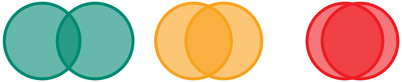


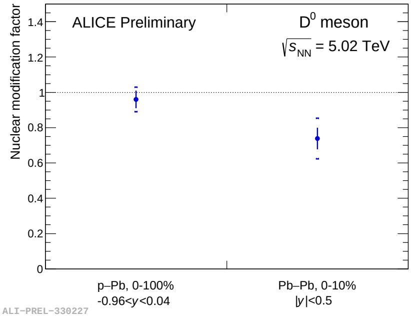
ALI-PREL-319270

- Example from Pb–Pb collisions
- Using ML selections it is possible to extract the signal in a region ($2 < p_{\rm T} < 3$ GeV/c) where the linear selections do not give a clear D_s^+ peak

Non-strange D-meson R_{AA}



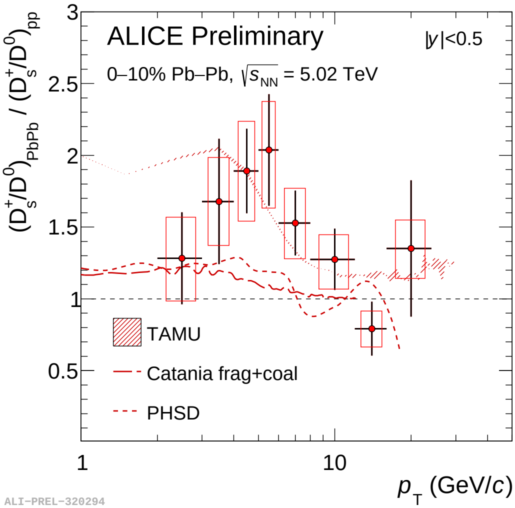




- Hierarchy in the D-meson R_{AA} suppression: increasing from peripheral to semi-central and central Pb–Pb collisions
- Integrated R_{AA} around (below) unity in p-Pb (Pb–Pb) ➔ observed suppression due to final state effects

Prompt D_s^+-meson abundance in Pb–Pb collisions

PHSD: T. Song et al. PRC 92 014910 (2015) TAMU: M. He et al. PLB 735 445-450 (2014) Catania: S. Plumari et al. EPJC 78 348 (2018)



- Indication of higher D_s^+/D^0 ratio in Pb–Pb compared to pp at $p_T < 8$ GeV$/c$
- D_s^+ enhancement qualitatively described by transport models including charm-quark recombination in a strangeness-rich medium
- Quantitative differences between TAMU, PHSD and Catania
  - more precise Run 3 data will permit to discriminate

D-meson elliptic flow in Pb-Pb collisions

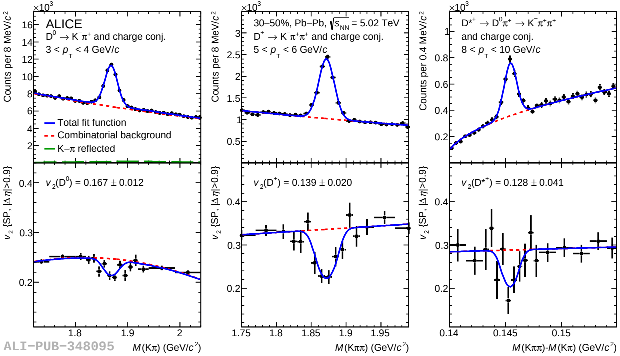
- D-meson v_2 measured at mid-rapidity ($|y| < 0.8$) with the scalar-product (SP) method

$$v_2\{SP\} = \frac{\langle \boldsymbol{u}_2 \cdot \boldsymbol{Q}_2^{\mathrm{A}} / M^{\mathrm{A}} \rangle}{\sqrt{\frac{\langle \boldsymbol{Q}_2^{\mathrm{A}} / M^{\mathrm{A}} \cdot \boldsymbol{Q}_2^{\mathrm{B}} / M^{\mathrm{B}} \rangle \langle \boldsymbol{Q}_2^{\mathrm{A}} / M^{\mathrm{A}} \cdot \boldsymbol{Q}_2^{\mathrm{C}} / M^{\mathrm{C}} \rangle}{\langle \boldsymbol{Q}_2^{\mathrm{B}} / M^{\mathrm{B}} \cdot \boldsymbol{Q}_2^{\mathrm{C}} / M^{\mathrm{C}} \rangle}}}$$

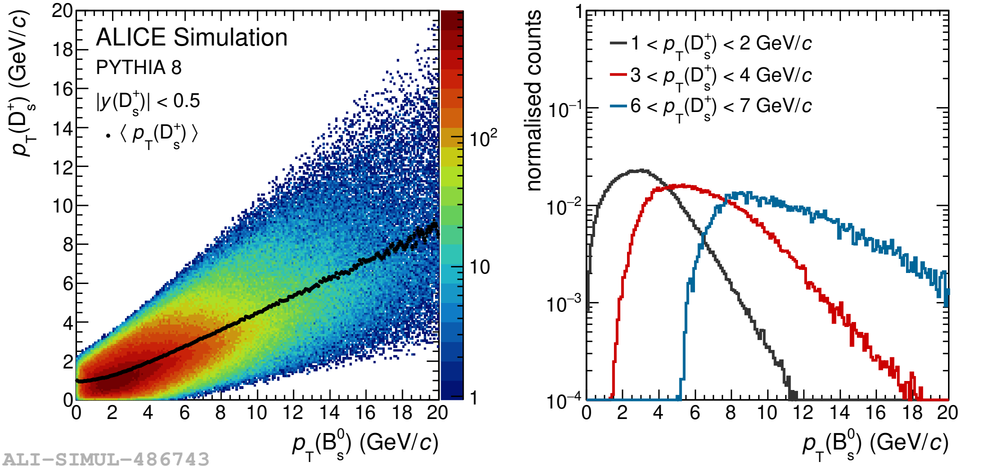
where $\boldsymbol{Q}_2 = \sum_{j=0}^{M} w_j e^{i2\varphi_j}$ and $\boldsymbol{u}_{2,D} = e^{i2\varphi_D}$

- Sub-events:
  - A: V0C ($-3.7 < \eta < -1.7$)
  - B: V0A ($2.8 < \eta < 5.1$)
  - C: TPC ($|\eta| < 0.8$))
- v_2 of the signal extracted from a v_2 vs mass fit

$$v_2(M) = \frac{S}{S+B} v_2^{sig} + \frac{B}{S+B} v_2^{\mathrm{bkg}}$$



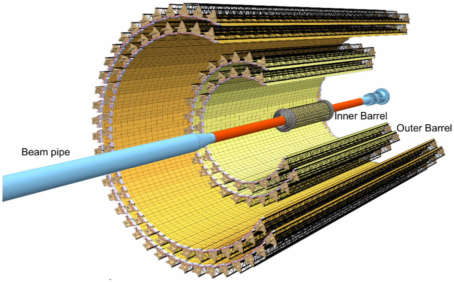
D_s^+ vs B_s^0 transverse momentum



Prospects for Run 3 and beyond

- Major upgrade of ALICE detectors and read-out electronics ongoing
  - increase collected Pb-Pb luminosity by more than one order of magnitude
- Inner Tracking System (ITS) upgrades crucial for heavy-flavour measurements

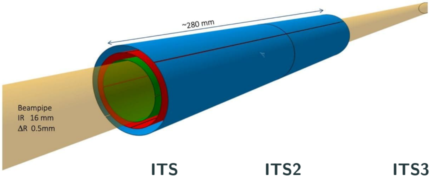
- Run 3 ➔ completely new detector (ITS2)



J. Phys. G 41 087001 (2014)

- Run 4 ➔ three truly cylindrical layers based on ultra-thin curved silicon-pixel sensors (ITS3)

CERN-LHCC-2019-018



	ITS	ITS2	ITS3
# of layers	6	7	7
X/X_0	1.14%	0.38%	0.05%
innermost radius	39 mm	22 mm	18 mm
pixel size	$50 \times 425\ \mu m^2$	$30 \times 30\ \mu m^2$	$\mathcal{O}(15 \times 15\ \mu m^2)$