Measurement of D_s-meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE at the LHC

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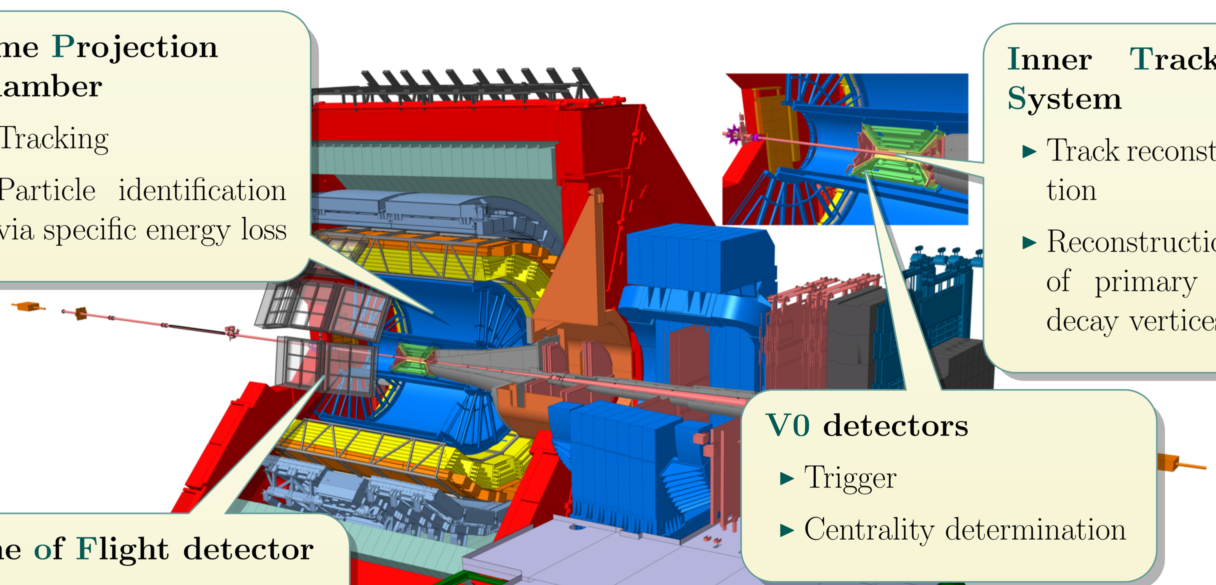
The ALICE detector



Time Projection Chamber
- Tracking
- Particle identification via specific energy loss

Inner Tracking System
- Track reconstruction
- Reconstruction of primary and decay vertices

V0 detectors
- Trigger
- Centrality determination

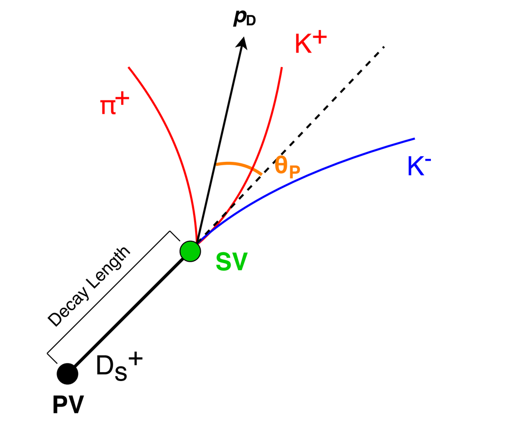
Time of Flight detector
- Particle identification with time-of-flight

Data sample: Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
- Collected in 2018
- Central events (0 − 10%) ∼ 89 M
- Semi-central events (30 − 50%) ∼ 76 M

Physics motivation

- Charm and beauty quarks are produced in hard-scattering processes on short time scales
- They experience the full evolution of the Quark-Gluon Plasma (QGP) created in ultra-relativistic heavy-ion collisions interacting with the medium constituents → **probes of the QGP properties**
- The study of **D_s mesons** gives **insights into the heavy-quark hadronization mechanism** in the medium

D_s-meson reconstruction



- **D_s^+** meson measured via its **resonant hadronic decay** [1]:

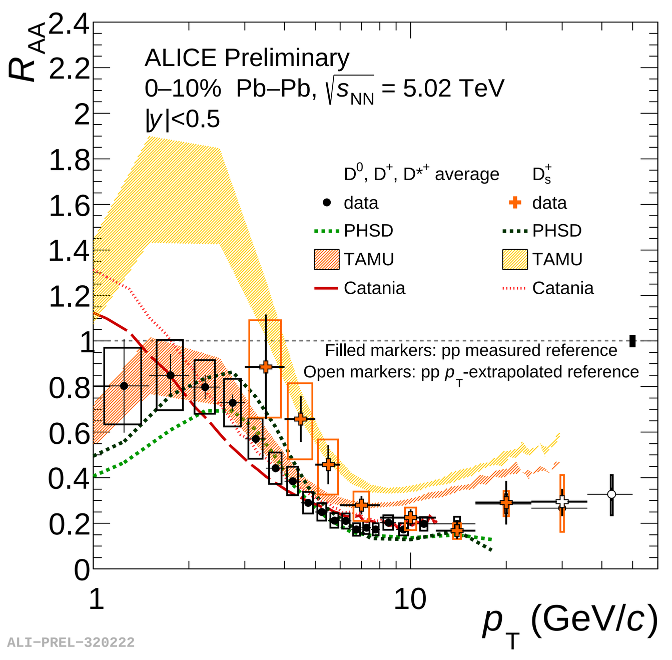
$$D_s^+ \to \phi(\to K^+K^-)\pi^+, \quad BR = (2.27 \pm 0.08)\%, \quad c\tau \simeq 150\ \mu m$$

- The D_s-decay vertex displaced by a few hundred μm from the primary vertex is reconstructed by combining triplets of charged particles
- Particle identification of decay tracks and geometrical selection of decay topology to reduce the background
- Efficiency correction from MC simulations using HIJING [2] events enriched with Pythia [3] $c\bar{c}$ and $b\bar{b}$ pairs
- Beauty feed-down subtraction based on FONLL [4] calculations

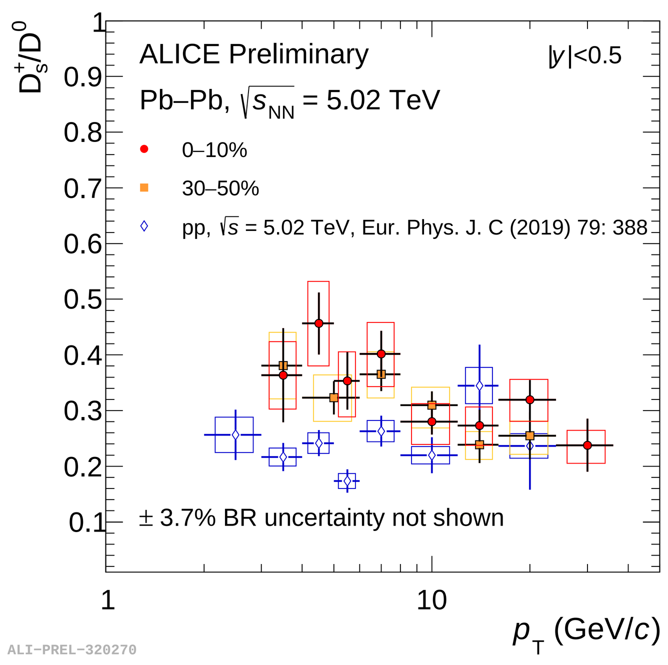
D_s yield in Pb-Pb collisions

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA}\rangle}\frac{dN_{AA}/p_T}{d\sigma_{pp}/p_T}$$

- $\langle T_{AA}\rangle$: average nuclear overlap function, proportional to the number of binary nucleon-nucleon collisions per AA collision
- The $\boldsymbol{R_{AA}}$ is **sensitive to modifications of D-meson yield and $\boldsymbol{p_T}$ spectra** due to the hot and dense medium
- Large suppression at $p_T \gtrsim 4$ GeV/c for non-strange D mesons in the 10% most central Pb-Pb collisions due to charm-quark in-medium energy loss
- Hint of **smaller suppression for D_s** w.r.t. non-strange D mesons → expected in case of **hadronization via coalescence** due to the enhanced production of s quarks in the QGP
- The TAMU [5] transport model fairly describes this effect at $p_T < 8$ GeV/c

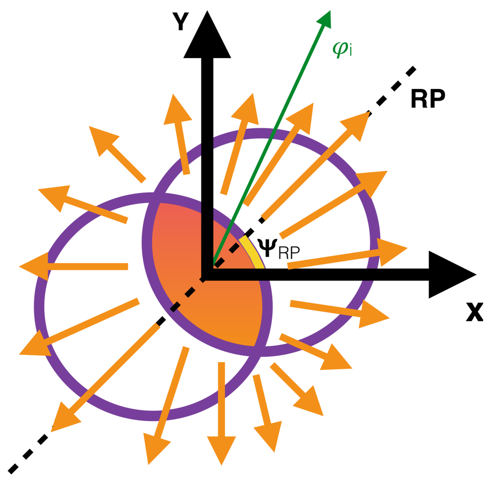


- Possible **modification of charm-quark hadronization** in presence of the QGP also **studied comparing the D_s^+/D^0 yield ratios** in Pb-Pb and pp collisions



- At $p_T < 6$ GeV/c, the D_s^+/D^0 ratio in Pb-Pb collisions is larger than that measured in pp collisions by about two standard deviations
- At $p_T > 8$ GeV/c, the D_s^+/D^0 ratios measured in Pb-Pb and pp collisions are compatible within uncertainties

Azimuthal anisotropy



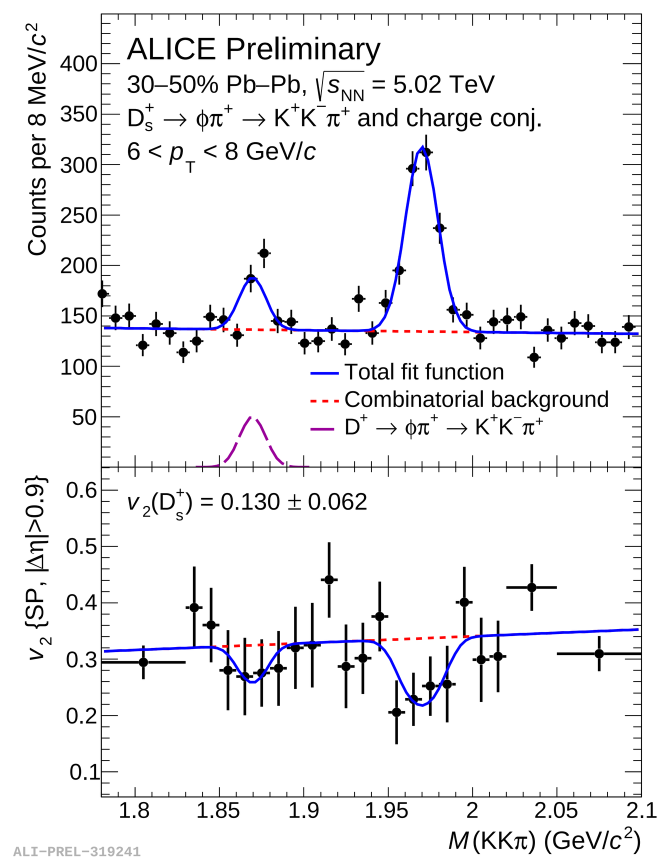
- **Elliptic flow $\boldsymbol{v_2}$**: the second Fourier coefficient of the azimuthal distribution of final-state particles with respect to the reaction plane Ψ_{RP}

$$v_2 = \langle \cos[2(\varphi - \Psi_{RP})]\rangle$$

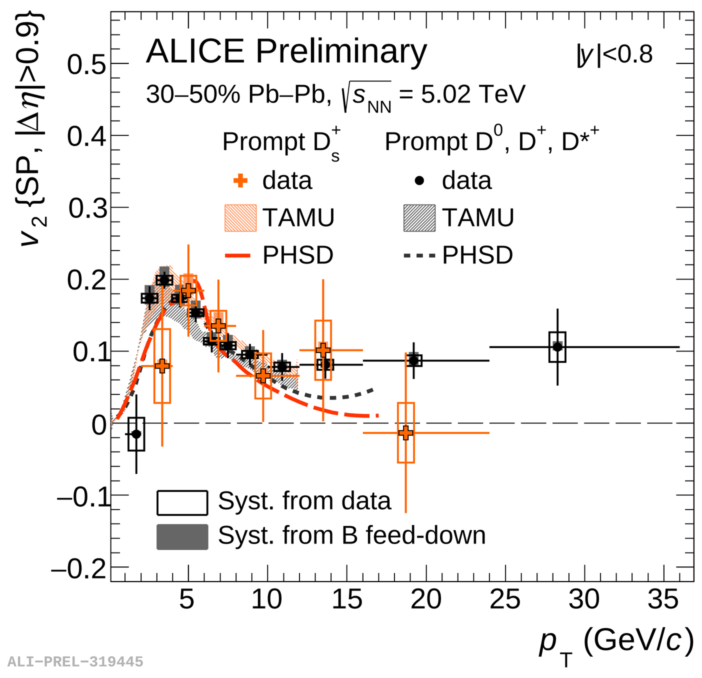
- Estimated with the **scalar-product method** based on the measurement of the flow vectors $\mathbf{Q}_2$
- v_2 evaluated in bins of invariant-mass m from the product of $\mathbf{Q}_2$ and the D_s-candidate momentum unit vector $\mathbf{u}_2$

$$v_2 = \frac{1}{R_2}\langle \mathbf{u}_2 \cdot \mathbf{Q}_2/M\rangle, \quad \mathbf{Q}_2 = \begin{pmatrix}\sum_{i=1}^{M} w_i \cos(2\varphi_i)\\ \sum_{i=1}^{M} w_i \sin(2\varphi_i)\end{pmatrix} \quad \mathbf{u}_{k,2} = \begin{pmatrix}\cos(2\varphi_k)\\ \sin(2\varphi_k)\end{pmatrix}$$

(R_2 resolution term, M detector multiplicity)



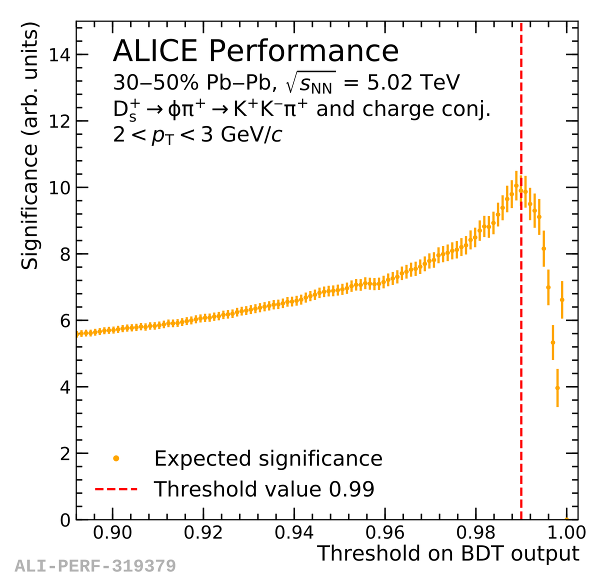
- v_2 extracted in p_T intervals via a simultaneous fit to $v_2(m)$ and invariant-mass distributions of D_s candidates
- Second peak (left) → D^+-meson decays in the same decay channel



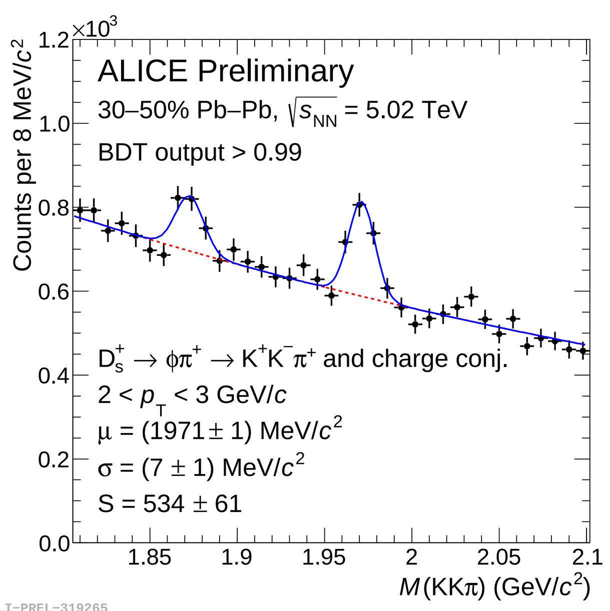
- At $p_T > 2$ GeV/c non-strange D-meson v_2 larger than 0 → **charm quarks participate in the collective expansion** of the medium
- D_s v_2 compatible with that of non-strange D mesons within uncertainties
- Both TAMU [5] and PHSD [6] well describe the observed D_s and non-strange D-meson v_2. Hadronization via quark recombination included in both models

D_s-yield extraction with machine learning

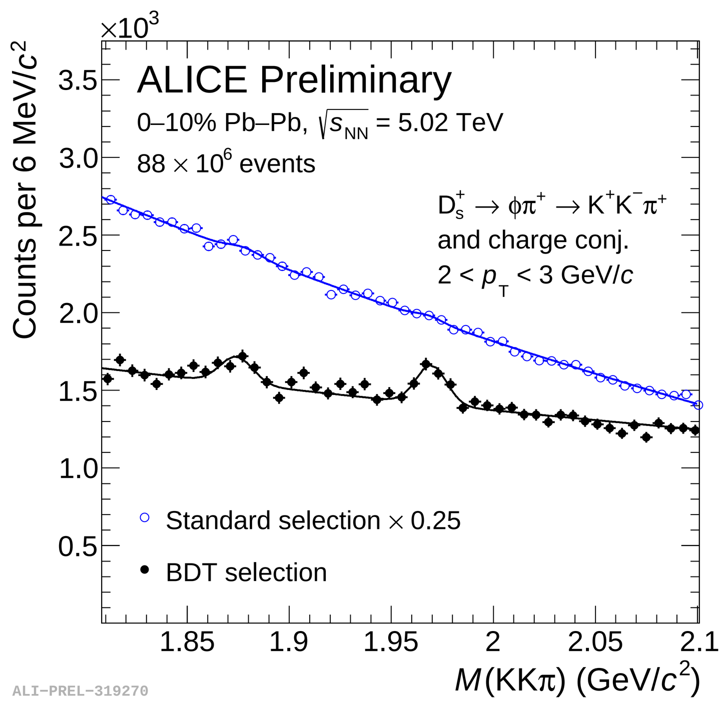
- **Replace linear selections with** a **machine learning** (ML) model → non-linear and more complex selections
- ML models "learn" to make predictions from a set of examples where the correct classification is known
- Training based on signal (S), from MC simulations, and background (B), sidebands of the invariant-mass distribution



- **Boosted Decision Trees** (BDT) [7] **used** in this case
- BDT output → probability of D_s candidate to be signal
- Threshold on BDT output chosen considering the expected significance $(S/\sqrt{S+B})$ → Significance estimated using: theoretical expectations, model selection efficiency and background rejection
- Set a threshold value providing good expected significance and high selection efficiency



- Signal extracted from a fit to the invariant-mass distribution of D_s candidates with a BDT output above the chosen value
- **Good signal extraction** both in 0 − 10% and 30 − 50% centrality classes



- **The D_s signal is extracted also in $2 < p_T < 3$ GeV/c where the peak is not observed with the standard selections**
- Possible to improve the extracted signal significance w.r.t. the standard analysis, in the common p_T region

References

[1] PDG, Phys. Rev. D 98 (2018) 030001
[2] X. Wang et al., Phys. Rev. D 44 (1991) 3501
[3] T. Sjöstrand et al., JHEP 0605 (2006) 026
[4] M. Cacciari et al., JHEP 9805 (1998) 007
[5] M. He et al., arXiv:1905.09216
[6] T. Song et al., Phys. Rev. C 93 (2016) 034906
[7] T. Chen et al., CoRR abs/1603.02754 (2016)