Milestones di Fisica

Riunione ALICE – Referee INFN
Roma 9-10 Luglio, 2025

F. Fionda
University & INFN, Cagliari

Many thanks to:
A. Calivà, N. Jacazio, L. Barioglio, C. De Martin, F. Ercolessi, F. Colamaria, A. Rossi, C. Terrevoli, A. Palasciano, M. Faggin,
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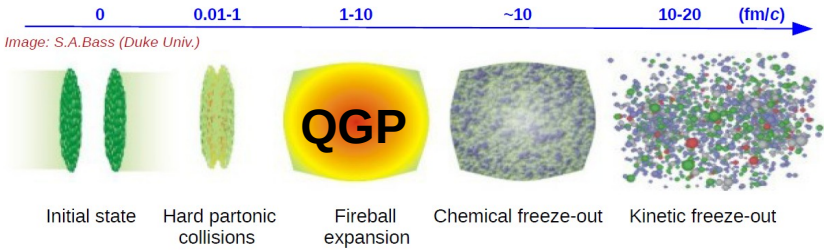
The physics of ALICE in one slide...

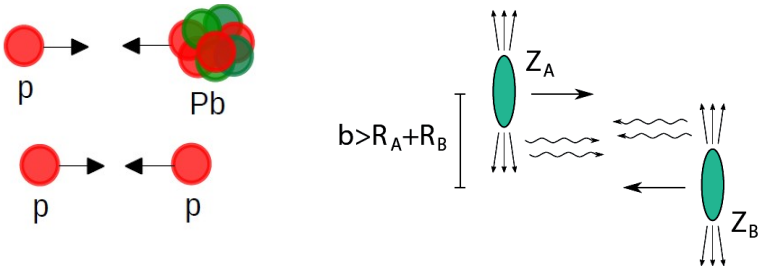
- Broad and multi-disciplinary physics program through the study of different collision systems !

Heavy-ion collisions



- Properties of QGP and its dynamical evolution
- Interaction with medium constituents
- Hadronization in medium

Small and (ultra)peripheral systems



- Test / constrain QCD-based models
- Initial state & reference for HI collisions
- Collectivity and QGP-like effects in small systems

Hadronic correlations and composite objects formation

- Hadron-hadron correlations and interactions studies using femtoscopy
- (Anti)(hyper)nuclei production

Contributions beyond QCD physics

- Neutron stars and equation of state
- Contribution to dark matter research
- Cosmic rays

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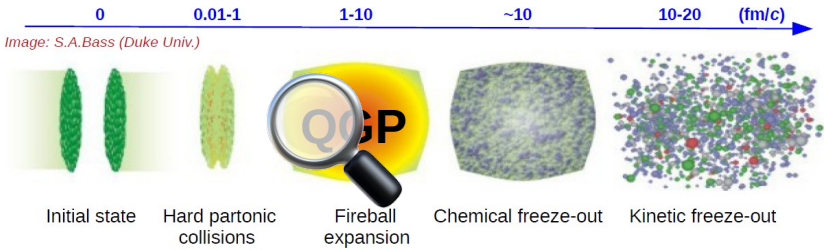
Heavy-ion collisions



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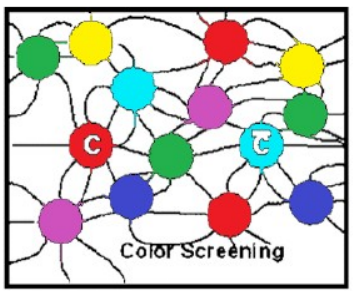
Quarkonia as probes of QGP in heavy-ion collisions

In-medium dissociation (color Debye screening)

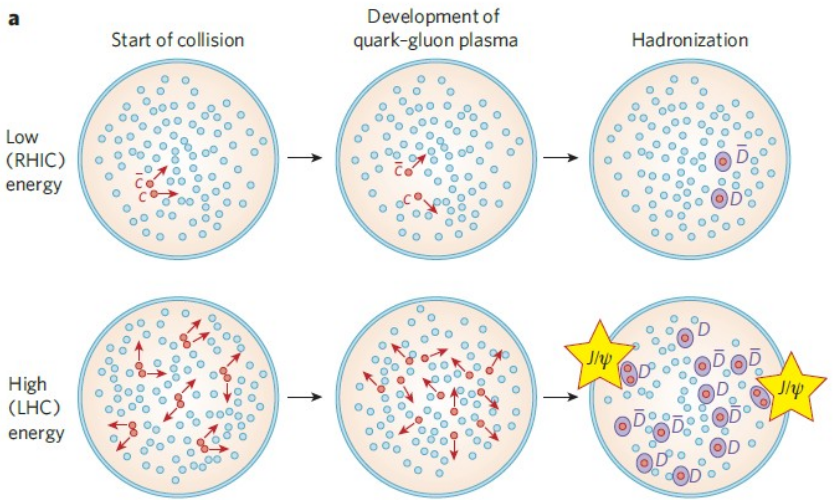
Matui & Satz, Phys.Lett. B178 (1986) 416-422



vs

Regeneration of quarkonia

Braun-Munzinger and Stachel, PLB 490 (2000) 196
Thews et al., PRC 63 (2001) 054905

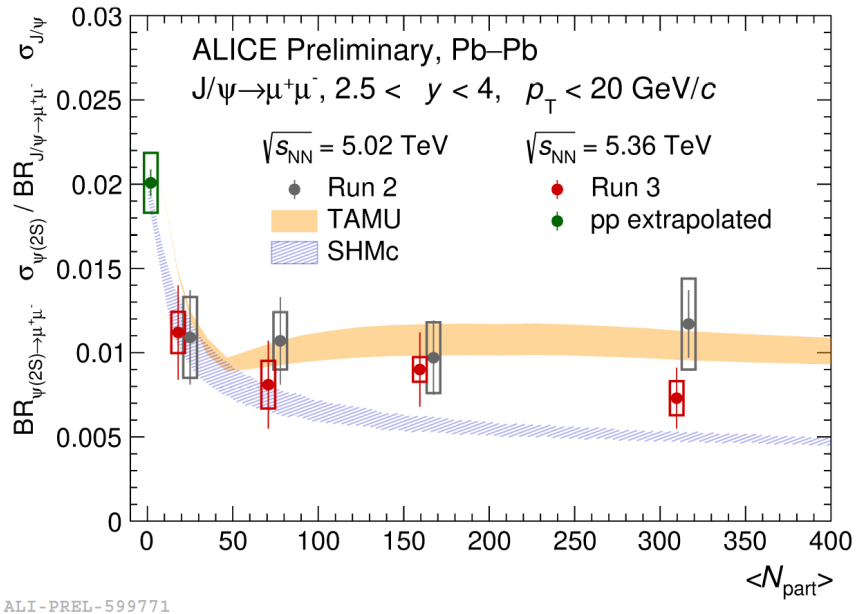


Nature 448 (2007) 302-309

- ✔ Sequential dissociation: stronger suppression expected for Ψ(2S) compared to J/Ψ (ground state)
- ✔ Charmonium excited-to-ground state ratios useful to disentangle among production models

Ψ(2S)-to-J/Ψ in Pb-Pb at 5.36 TeV – preliminary (Run 3)

Milestone #8, DQ [data prevista completamento: 30-06-2025]=> 100%



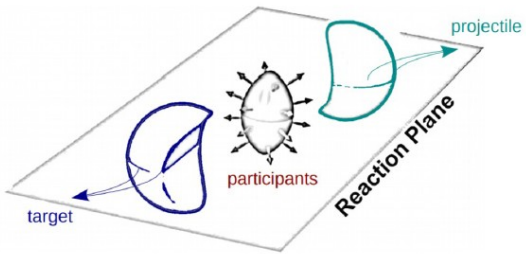
ALI-PREL-599771

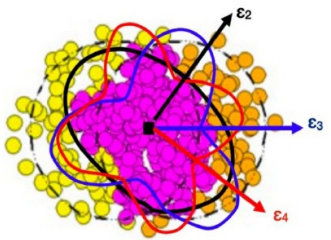
- ✔ Factor ~2 suppression wrt pp collisions
- ✔ No strong centrality dependence
- ✔ Improved precision in Run3 compared to Run2 (→ expected to further improve by adding 2024 Pb-Pb statistics)
- ✔ SHMc and TAMU qualitatively describe the trend as a function of centrality (expressed in terms of $\langle N_{part} \rangle$

PRL 132 (2024) 042301
PLB 797 (2019) 134836, A. Andronic et al.
PLB 664:253-257,2008 R. Rapp et al.

Anisotropic flow of identified hadrons

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cdot \cos[n(\varphi - \Psi_{RP})] \qquad v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$





Decomposed transverse projection of participant region in Fourier series

✔ **Initial spatial anisotropy:**

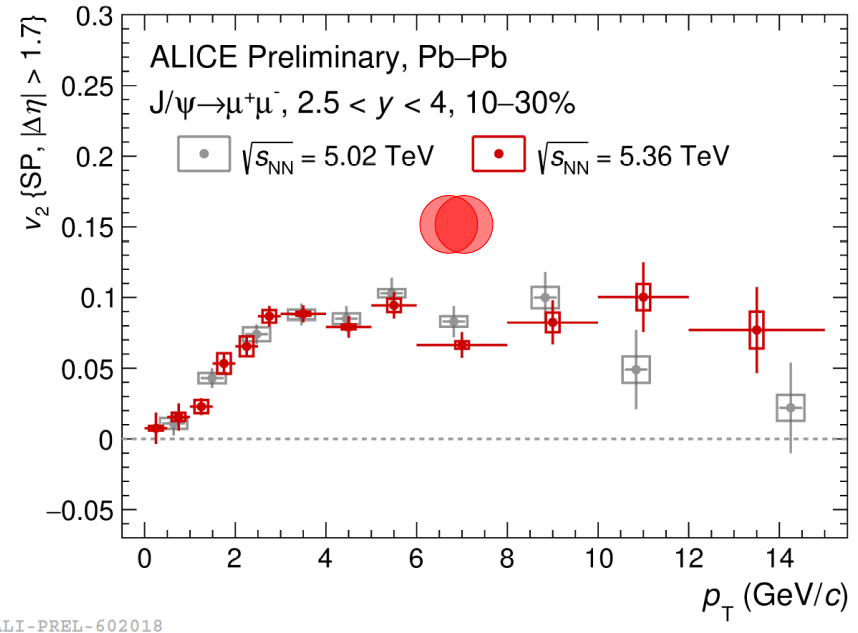
- Almond shape of the participant region → generates ellipticity (ε_2)
- Energy density fluctuations in the overlap region → generates triangularity (ε_3)
- Higher harmonics → mainly arising from the combination of the lower order components

→ low-p_T: sensitive to bulk QGP properties

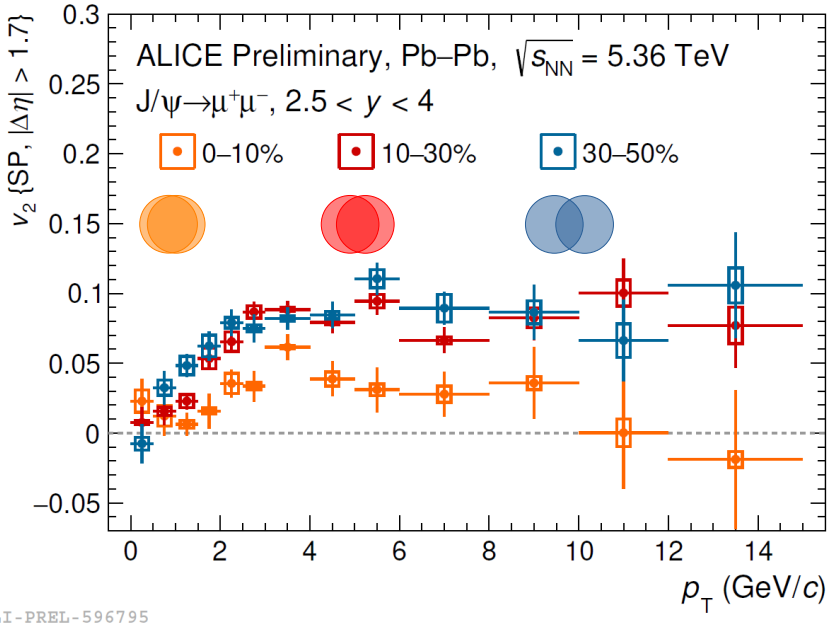
→ high-p_T: sensitive to the in medium energy loss (path-length dependence)

J/Ψ flow in Pb-Pb at 5.36 TeV - preliminary (Run 3)

Milestone #7, DQ [data prevista completamento: 30-06-2025]=> 100%



ALI-PREL-602018

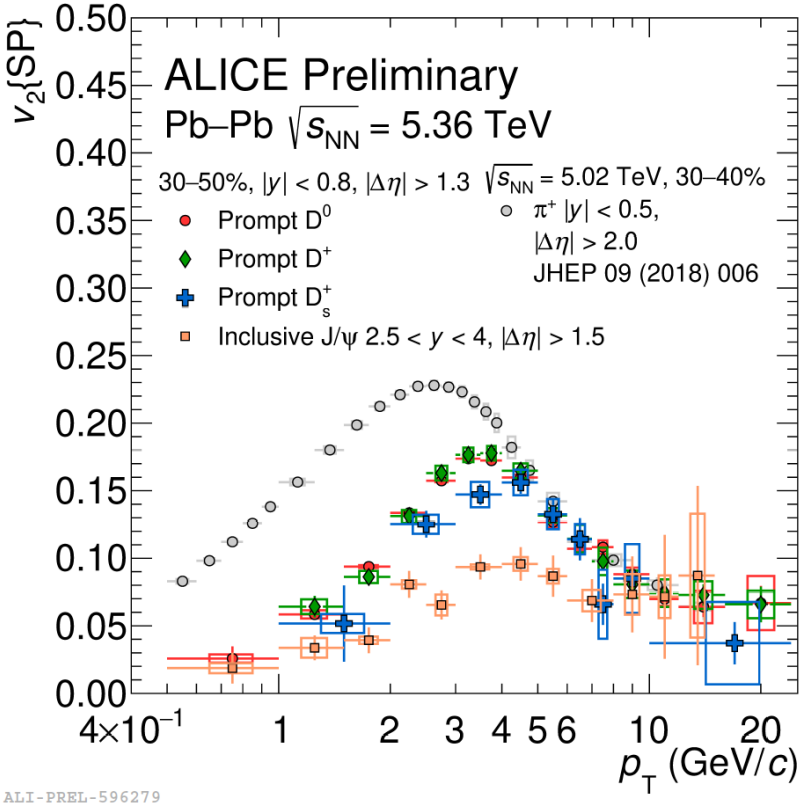


ALI-PREL-596795

- ✔ Improved granularity of Run3 wrt Run2
- ✔ No sign of energy dependence
- ✔ Increasing v_2 from central to semicentral

Charm hadron flow in Pb-Pb at 5.36 TeV – preliminary (Run 3)

Milestone #1, HF [data prevista completamento: 31-12-2025]=> 100%



- Prompt D-meson (D^0,D^+,D^+_s) flow measured using full 2023 Pb-Pb statistics (first measurement of D^0 below 1 GeV/c)
- Clear mass ordering observed below ~3 GeV/c → expected from hydrodynamical evolution
- Larger v_2 for open-charm wrt hidden-charm (and hint of D^+_s v_2 < D^0/D^+ v_2) at intermediate p_T → contribution of bulk + coalescence ?
- Common v_2 for p_T > 8 GeV/c → in-medium energy loss

Charm hadron flow in Pb-Pb at 5.36 TeV – preliminary (Run 3)

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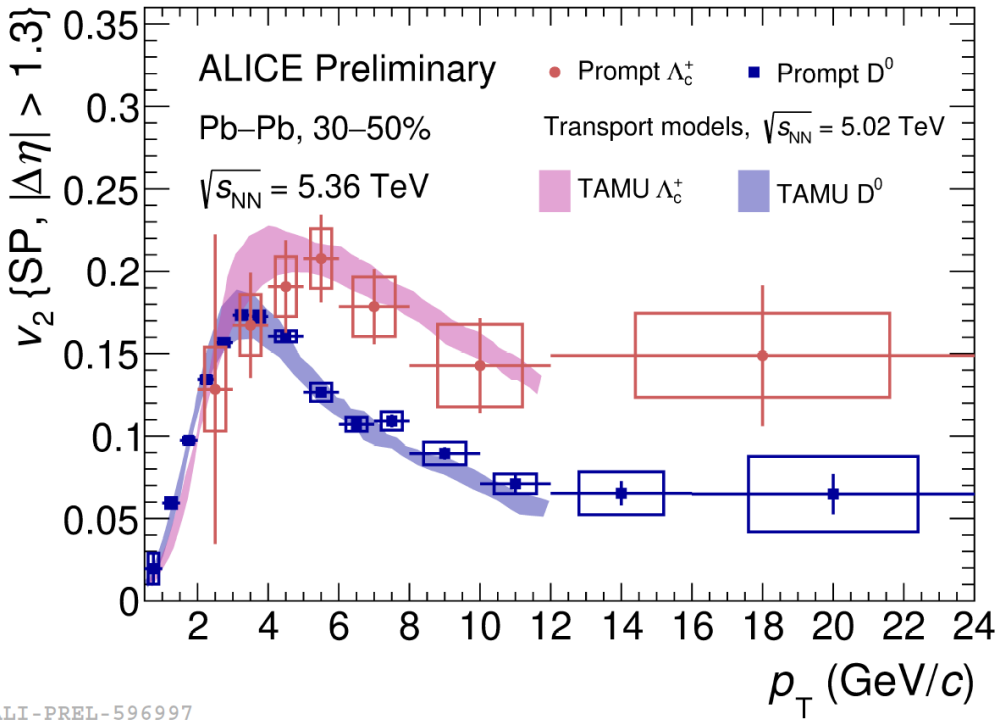
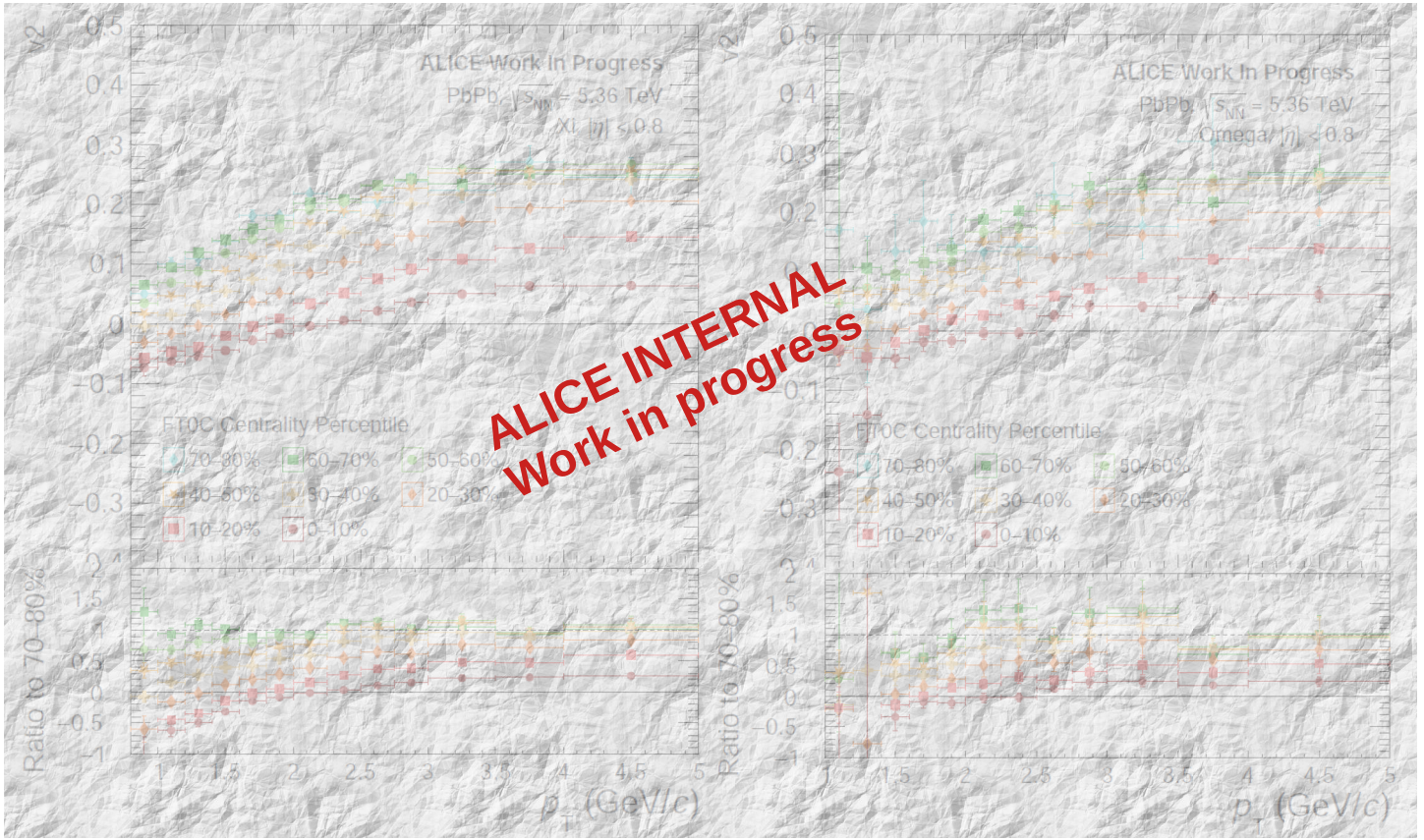


ALI-PREL-596997

- First prompt charm baryon (Λ_c^+) v_2 measurement in Pb-Pb collisions !
- Compatible with D^0 v_2 for p_T < 4 GeV/c
- Clear baryon-meson splitting (significance: 3.6σ) visible for p_T > 4 GeV/c → first evidence in the charm sector !
- Well reproduced by transport models

Strange particle flow in Pb-Pb at 5.36 TeV – preliminary (Run3)

Milestone #12, LF [data prevista completamento: 31-12-2025]=> 30%



- First measurements already in a very good shape
- Significantly increased granularity in p_T / centrality wrt Run2
- To be done:
  - Check in-plane and out-of-plane efficiencies vs centrality
  - Finalize systematic uncertainties

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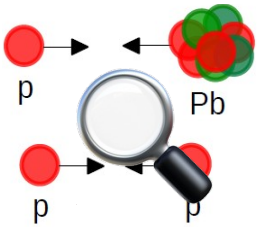

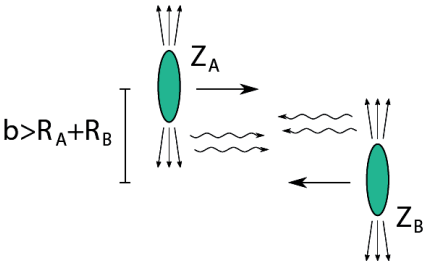

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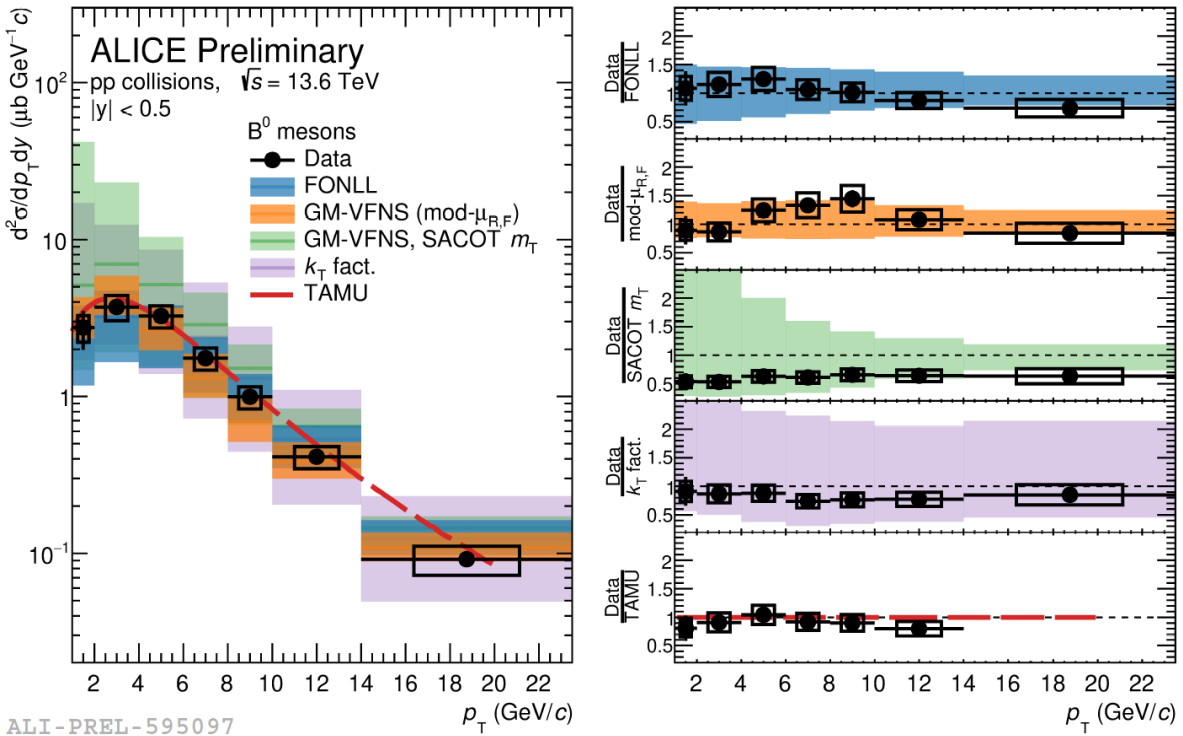
B-meson production cross section in pp at 13.6 TeV - publication (Run3)

Milestone #3, HF [data prevista completamento: 31-12-2025]=> 50%

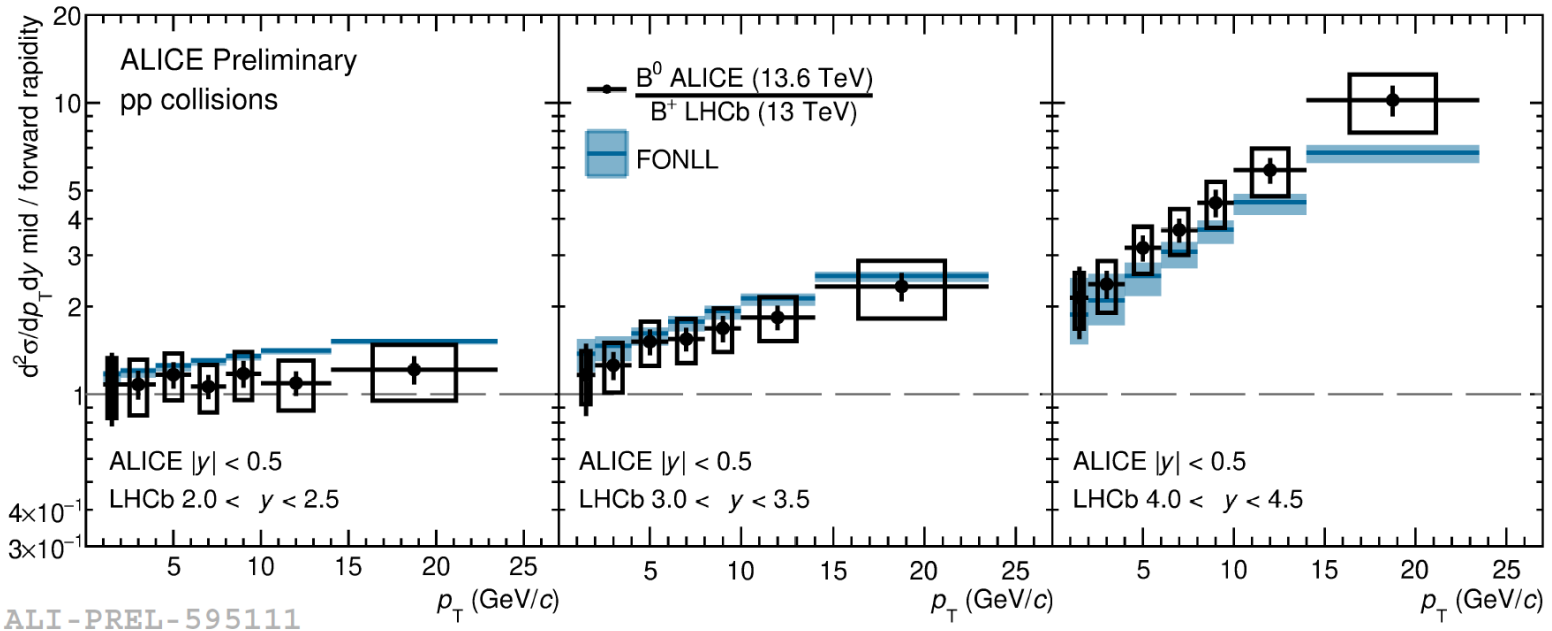


- B^0 production cross section based on exclusive reconstruction in pp triggered data
  - First measurement at LHC down to such very low p_T (> 1 GeV/c)
  - agreement within uncertainties with pQCD calculations and TAMU predictions

B-meson production cross section in pp at 13.6 TeV - publication (Run3)

Milestone #3, HF [data prevista completamento: 31-12-2025]=> 50%

- Investigating rapidity dependence of B-meson production via mid(ALICE)-to-forward(LHCb) rapidity cross section ratio



- Hint of different slopes in data wrt FONLL

Status:
- paper proposal approved by the ALICE collaboration in June
- first draft of the paper ready, currently under internal review

Luminosity determination on VdM scans of pp 2023 (Run3) - preliminary

Milestone #17, Lumi [data prevista completamento: 31-12-2025]=> 50%

- ✔ Crucial ingredient for cross section normalization!

Luminosity from a ref. process (luminomiter)

$$\mathscr{L} = \frac{R_{\text{ref}}}{\sigma_{\text{ref}}}$$

Luminosity from beams

$$\mathscr{L} = f_{\text{LHC}}\, N_1 N_2 \int f_1(x,y) f_2(x,y)\,\mathrm{d}x\mathrm{d}y$$

LHC frequency; Intensity of colliding bunches in beam 1 and 2; Probability density distributions of each bunch in the transverse plane

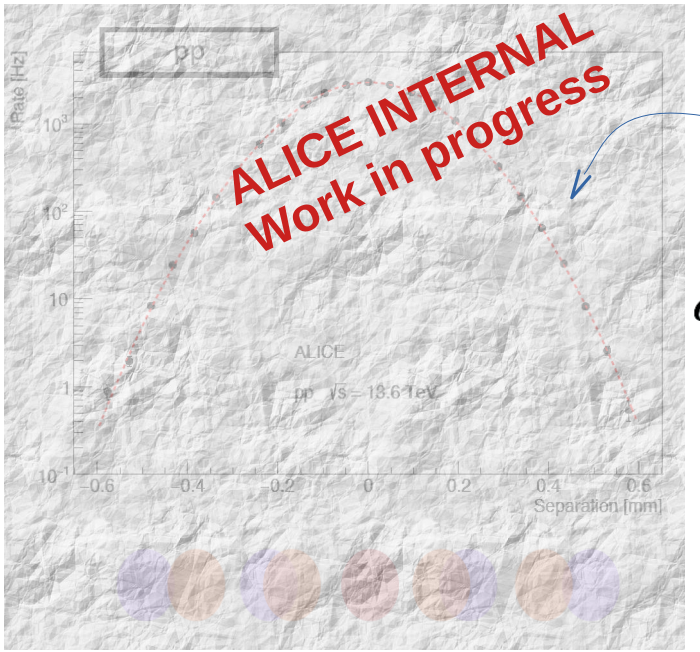
If factorisation assumed: $f_i(x,y) = f_{ix}(x) f_{iy}(y)$

$$= \frac{f_{\text{LHC}}\, N_1 N_2}{h_x h_y}$$

Effective beam widths

$$h_x = \frac{1}{\int f_{1x}(x) f_{2x}(x)\,\mathrm{d}x}, \quad h_y = \frac{1}{\int f_{1y}(y) f_{2y}(y)\,\mathrm{d}y}$$

Van Der Meer scan:
Scan one beam across the other in one direction to obtain the effective beam width



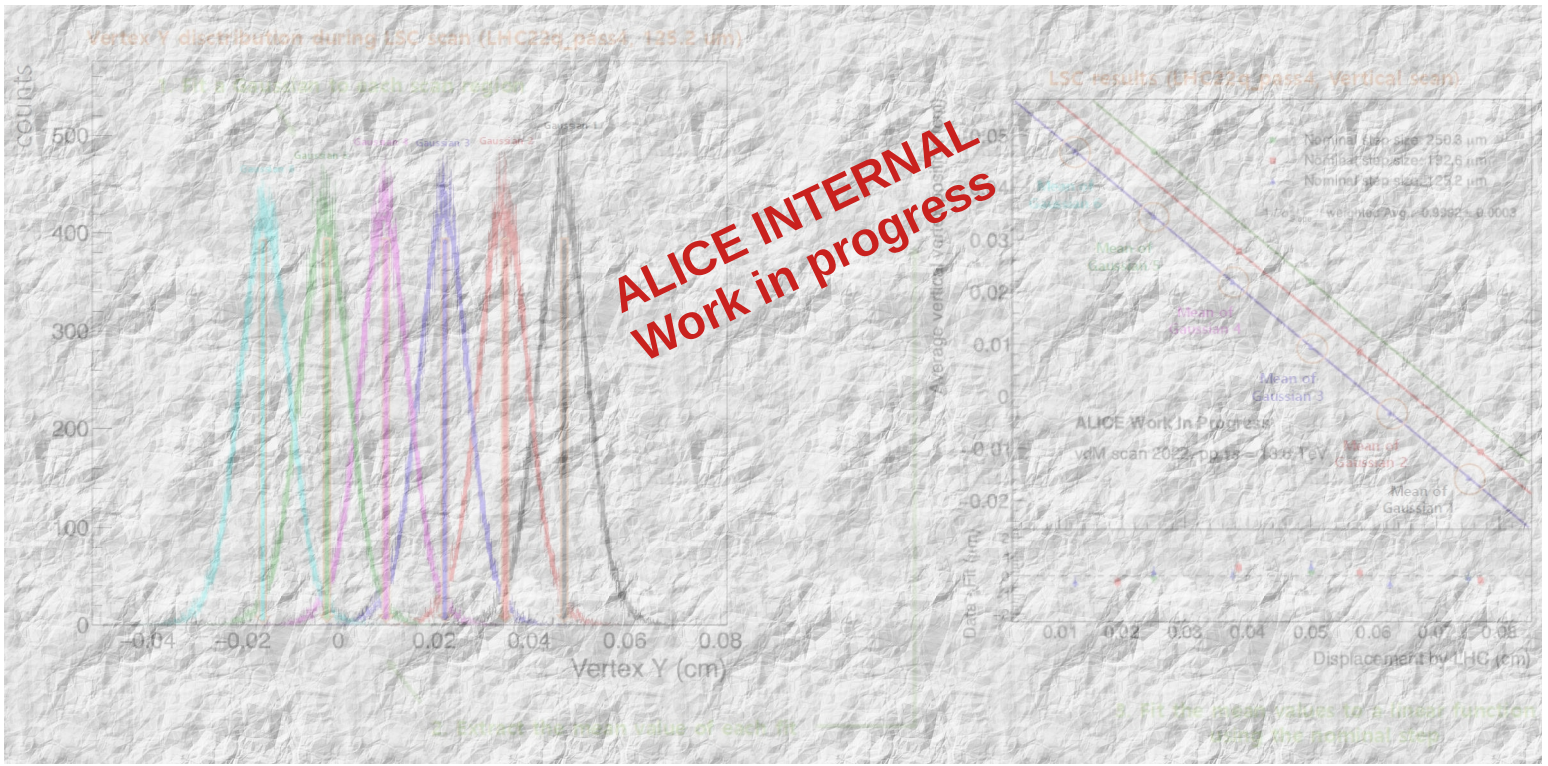
$$\sigma_{\text{ref}} = \frac{R_{\text{ref}}(0,0)\, h_x h_y}{f_{\text{LHC}} N_1 N_2}$$

Luminosity determination on VdM scans of pp 2023 (Run3) - preliminary

Milestone #17, Lumi [data prevista completamento: 31-12-2025]=> 50%

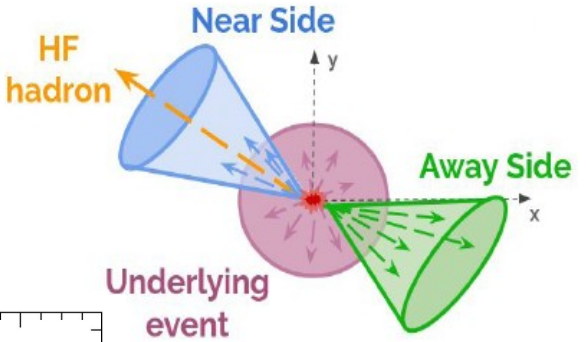
Status:

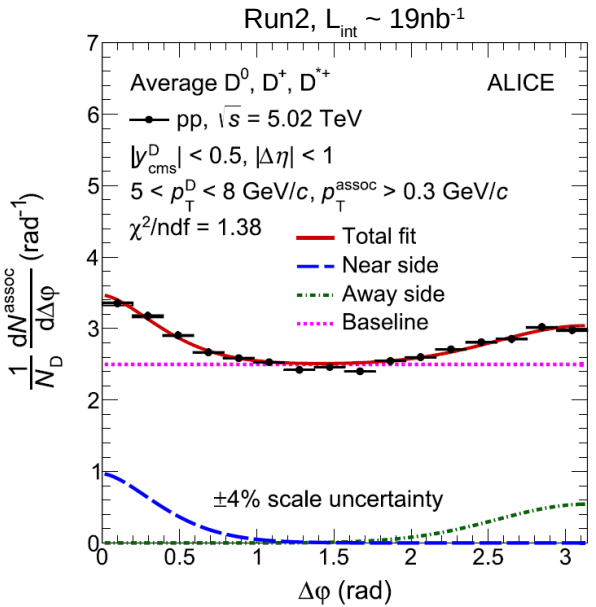
- ✔ Main analysis performed
- ✔ Corrections (ongoing):
  - Ghost-charge and satellite-charge correction factor
  - Length-scale calibration factor
  - Non-factorisation correction factor
- ✔ Systematic uncertainties to be finalized

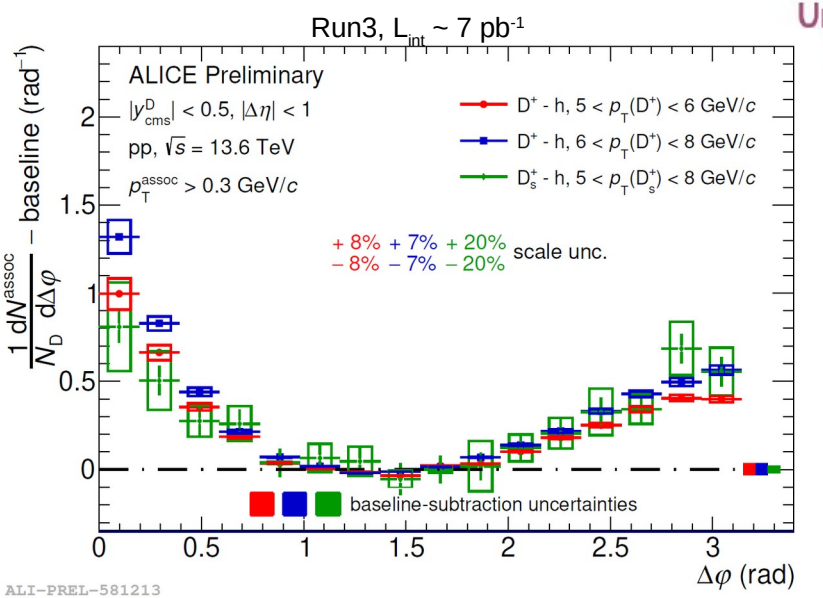


Correlations of HF hadrons with charged particles

- Shed light on fragmentation processes of heavy flavour quarks into hadrons (mesons and baryons)
- Investigate jet shape and particle composition
- Sensitive to production mechanisms → validation of parton-shower models and Monte Carlo generators







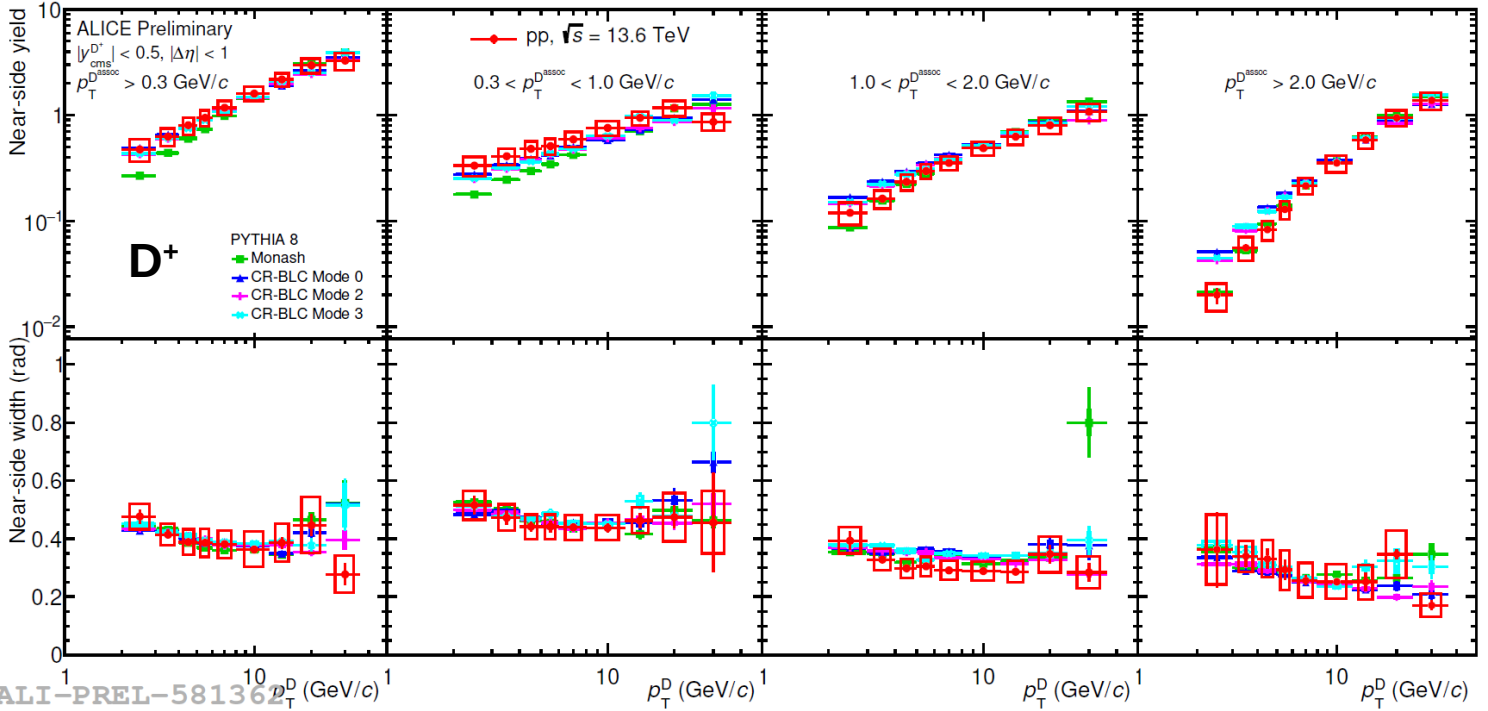
Dmeson-charged particle azimuthal correlations in pp at 13.6 TeV - preliminary (Run3)

Milestone #4, HF [data prevista completamento: 30-09-2025]=> 100%

Yields →

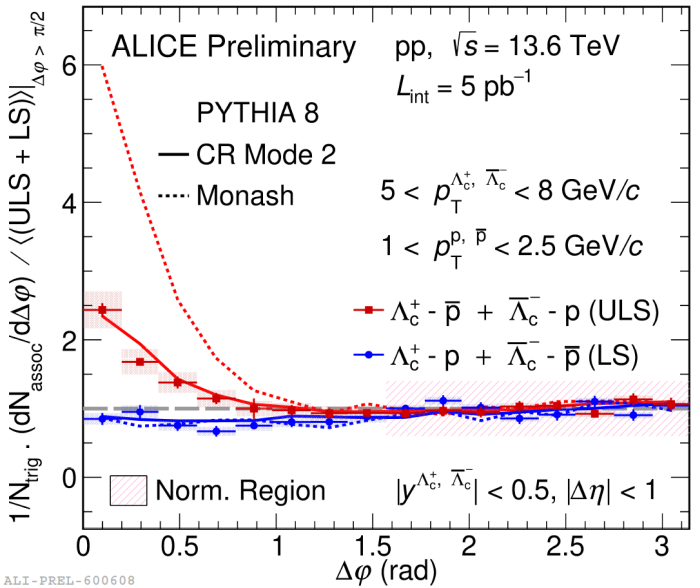
- ✔ Pythia8 with different tunes provides a fair description of the evolution of NS yields and widths as a function of $p_T(D^+)$ in different regions of p_T^{assoc}

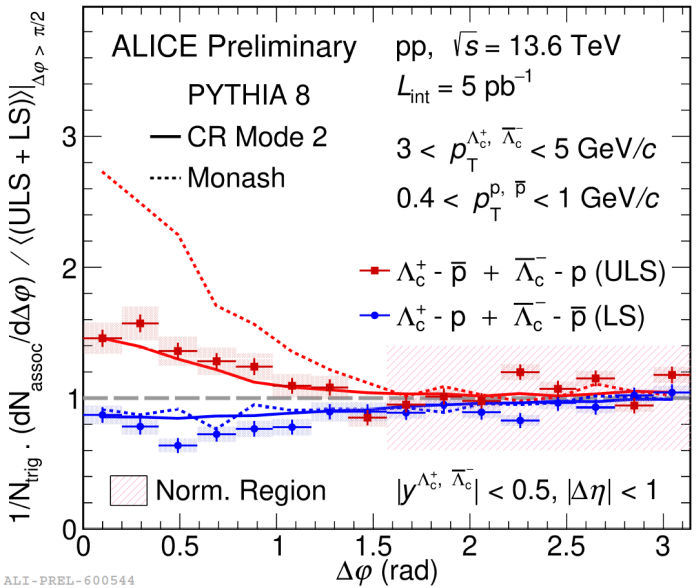
Widths →



Λ_c^+ – proton correlations in pp at 13.6 TeV – preliminary (Run3)

Milestone #4, HF [data prevista completamento: 30-09-2025]=> 100%

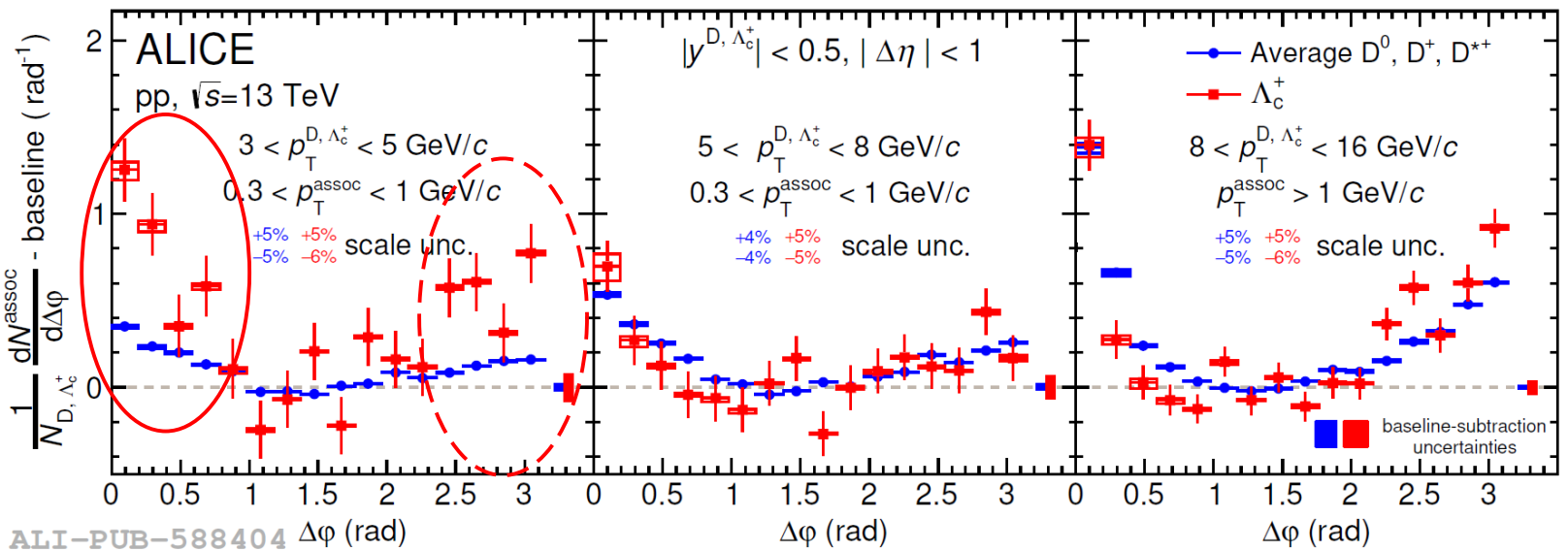




- ✔ Clear correlation in the NS visible in the unlike-sign (ULS) Λ_c^+-proton pairs, absent in case of like-sign (LS) Λ_c^+-proton pairs → local baryon number conservation ?
- ✔ Similar effect visible in PYTHIA8: enhanced in Monash tune; CR Mode 2 reproduces better the trend observed in the data

Λ_c^+ - charged particle correlations in pp at 13 TeV - publication (Run2)

Milestone #2, HF [data prevista completamento: 30-06-2025]=> 100%



- ✔ Good agreement between Δϕ distribution for D mesons and Λ_c^+ for $p_T(D,\Lambda_c^+) > 5$ GeV/c
- ✔ Enhancement observed for NS yield in case of Λ_c^+ wrt D mesons at low D-meson p_T ($3 < p_T < 5$ GeV/c)

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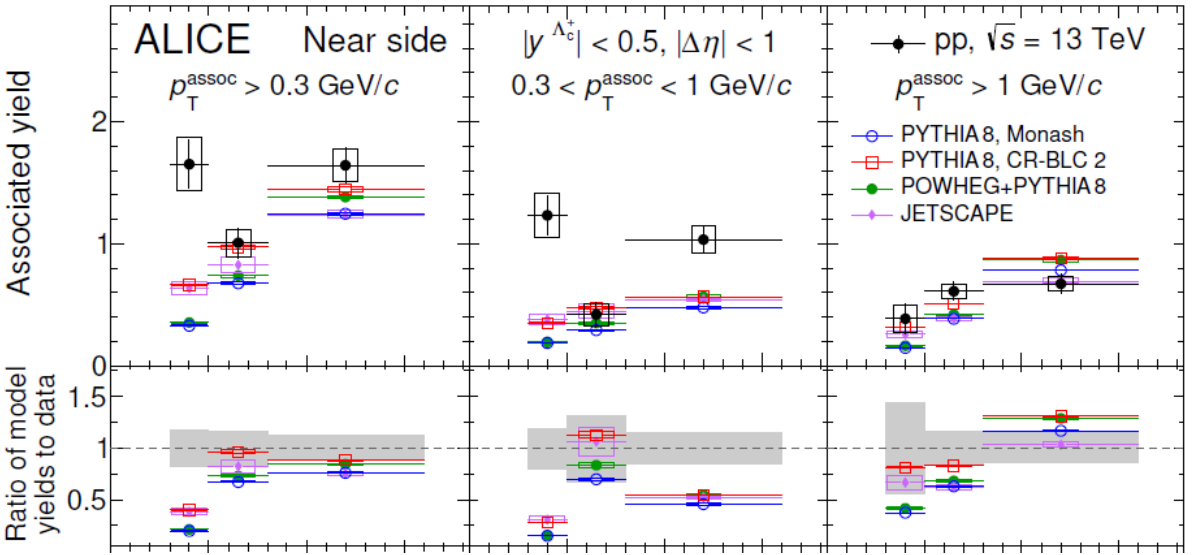
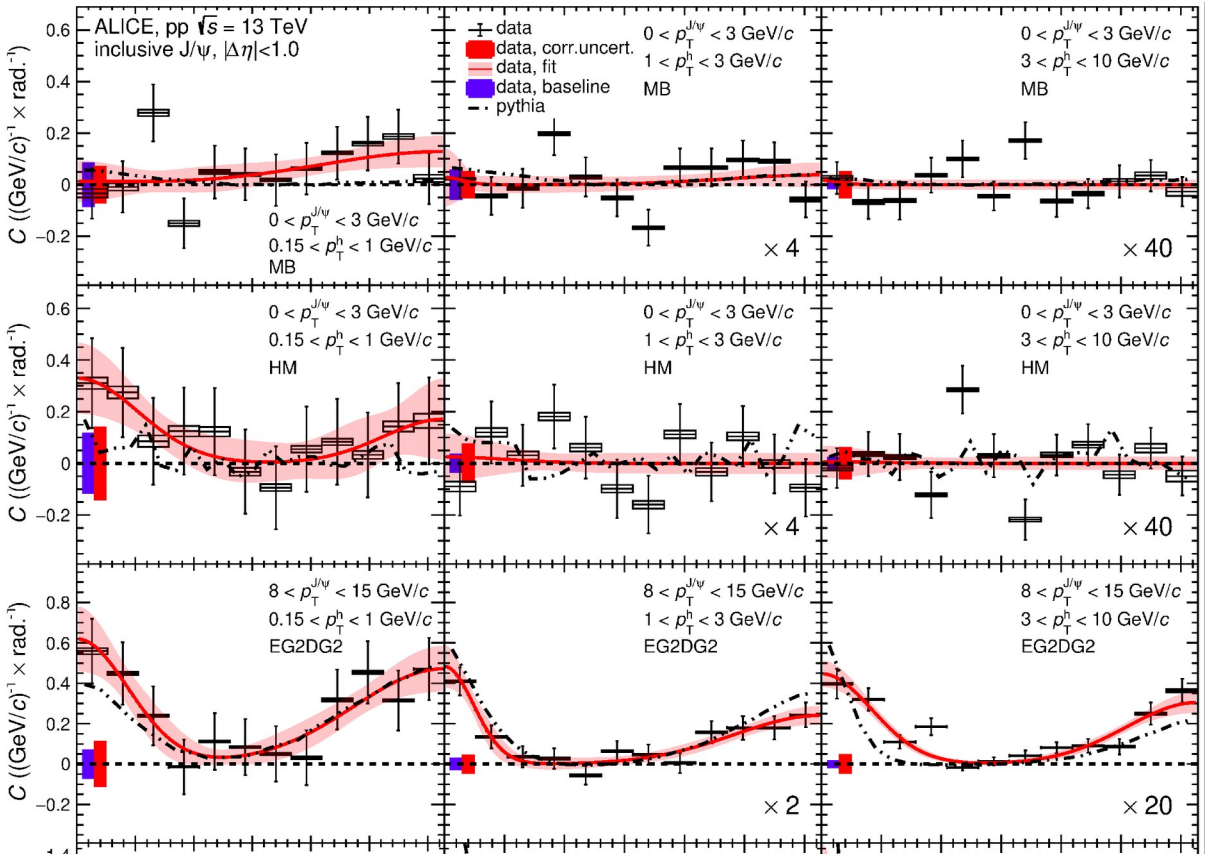


Paper accepted by PLB
(Phys. Lett. B 868 (2025) 139681)

- ✔ Good agreement between Δφ distribution for D mesons and Λ_c^+ for $p_T(D,\Lambda_c^+) > 5$ GeV/c
- ✔ Enhancement observed for NS yield in case of Λ_c^+ wrt D mesons at low D-meson p_T ($3 < p_T < 5$ GeV/c)
- ✔ PYTHIA8 CR-BLC 2, which provides a fair description for Dmeson-hadron correlations (as well as Λ_c^+-to-D^0 ratio vs p_T), does not describe Λ_c^+-hadron correlation NS yields

Prompt and non-prompt J/Ψ-hadron correlations in pp at 13 TeV - publication (Run2)

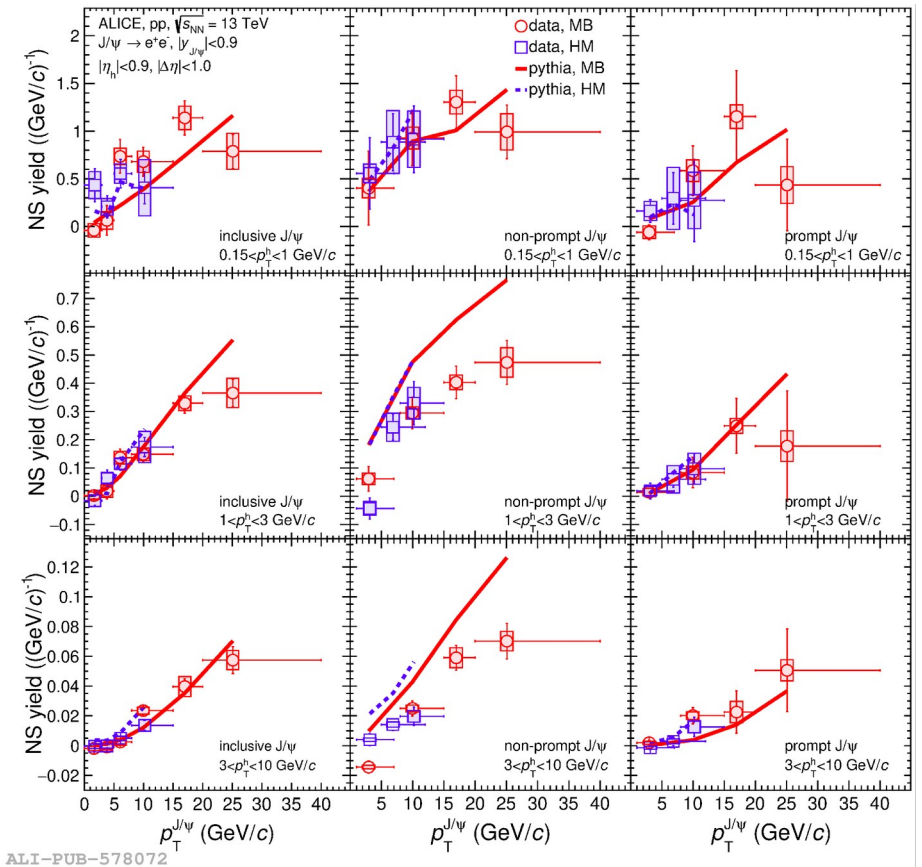
Milestone #5, DQ [data prevista completamento: 30-06-2025]=> 100%



- ✔ Exploit full collected Run2 statistics (MB, HM and EMCal triggered data)
- ✔ No significant multiplicity dependence observed within uncertainties

Prompt and non-prompt J/Ψ-hadron correlations in pp at 13 TeV - publication (Run2)

Milestone #5, DQ [data prevista completamento: 30-06-2025]=> 100%

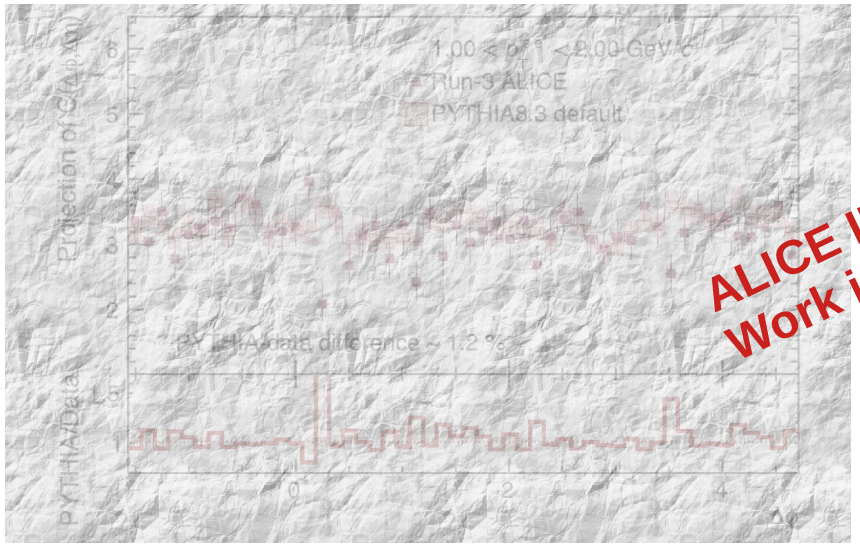


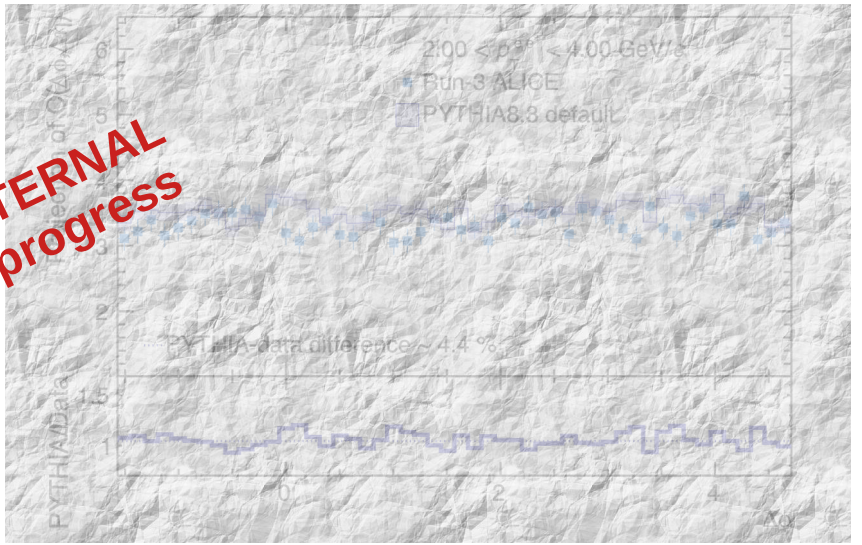
- ✔ Exploit full collected Run2 statistics (MB, HM and EMCal triggered data)
- ✔ No significant multiplicity dependence observed within uncertainties
- ✔ PYTHIA8 calculations in general show a good agreement with data, but some tension is observed.

Paper published on JHEP (JHEP07(2025)023)

J/Ψ-hadron correlations in pp at 13.6 TeV - performance (Run 3)

Milestone #6, DQ [data prevista completamento: 31-12-2025]=> 100%





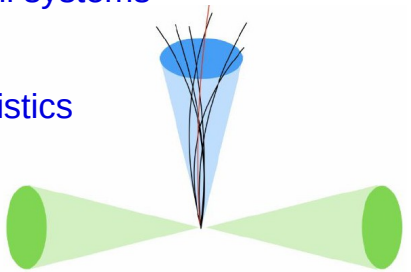
ALICE INTERNAL
Work in progress

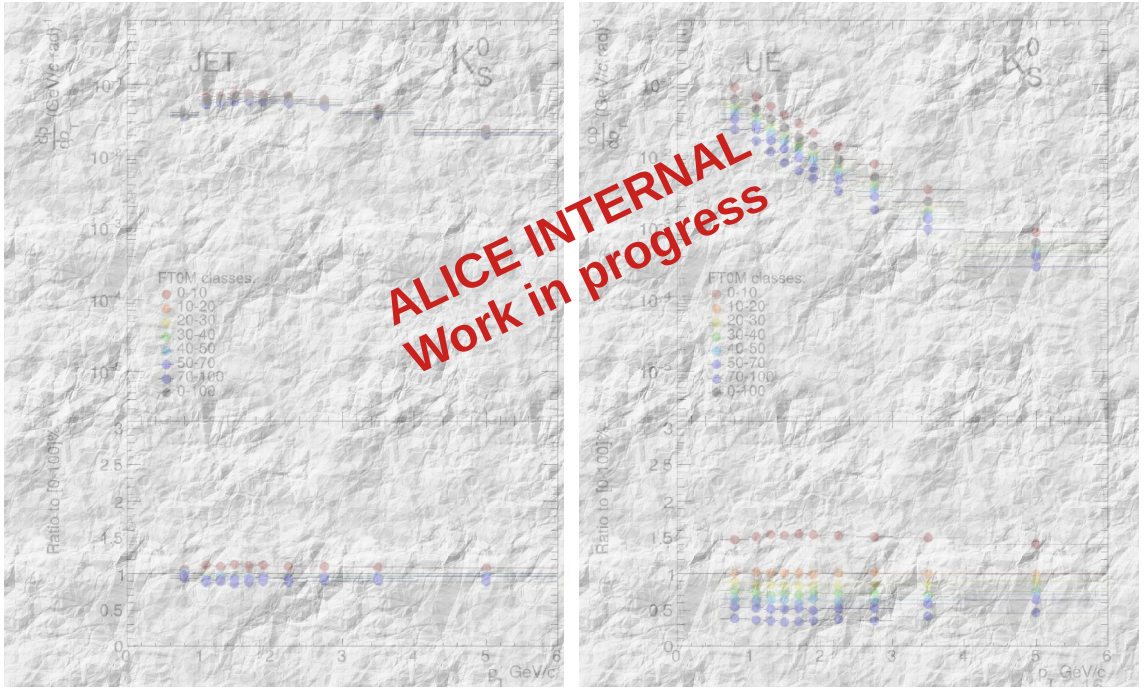
- ✔ Inclusive J/Ψ-hadron correlation distributions in good agreement with PYTHIA predictions (performance studies performed on pp 2022 data)
- ✔ Agreement with Run-2 results in similar kinematic ballpark (but with significantly higher granularity)

Strangeness production in-jet and out-of-jet in pp collisions at 13.6 TeV – preliminary (Run3)

Milestone #9, LF [data prevista completamento: 31-12-2025]=> 50%

- ✔ Interesting measurement to experimentally characterize the strangeness enhancement observed in small systems
  - pioneering work using Run 2 data
  - Investigate baryon-to-meson ratio in-jet and out-of-jet
    → significantly extend jet p_T reach and granularity wrt Run2 results thanks to the higher available statistics





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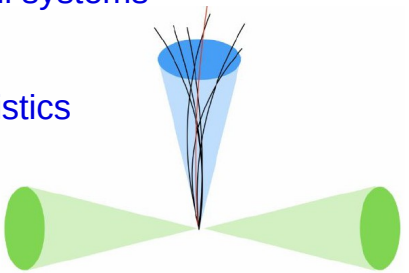
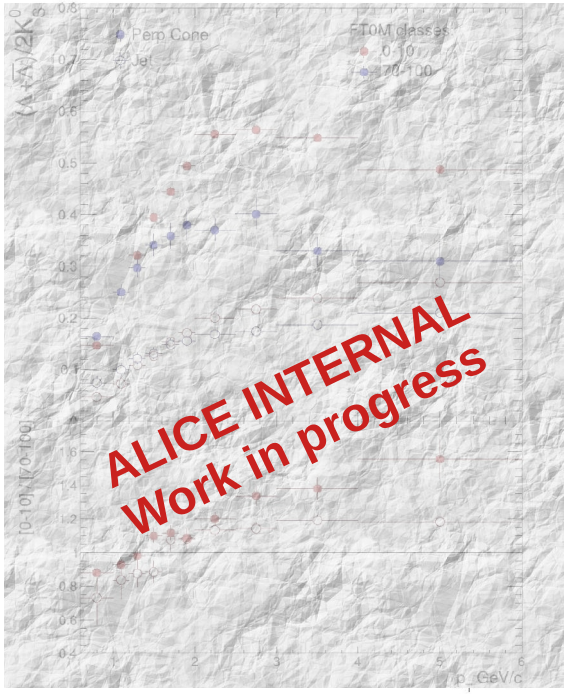
  - Investigate baryon-to-meson ratio in-jet and out-of-jet
    → significantly extend jet p_T reach and granularity wrt Run2 results thanks to the higher available statistics



- ✔ Λ-to-K^0_s ratio exhibits the known enhancement in the UE; no effect observed in the JE direction
- ✔ Evolution with multiplicity observed, significantly more pronounced for ratios in the JE direction
- ✔ Analysis for multi-strange spectra ongoing



Next steps:

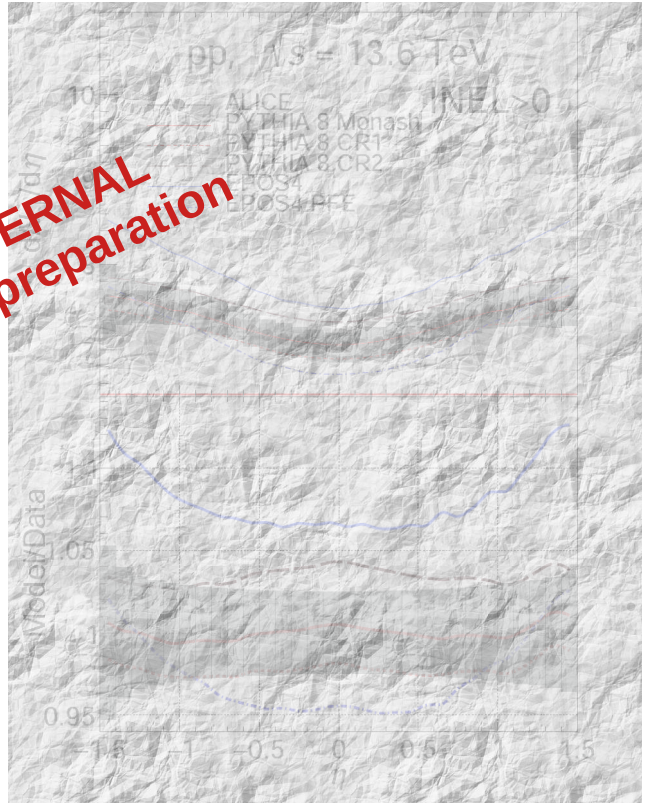
- ✔ Complete systematic uncertainty evaluation
- ✔ Implement data driven feed-down for Λ and multiplicity dependence of efficiencies

Pseudorapidity density of charged particles in pp at 13.6 TeV - publication (Run3)

Milestone #13, LF [data prevista completamento: 31-12-2025]=> 50%

- ✔ Important observable in high-energy hadronic collisions, reflecting both soft and hard scattering processes

- ⟨dNch/dη⟩ at 13.6 TeV follows the expected power-law trend vs √s, remaining consistent with previous results at lower energies



ALICE INTERNAL
Paper in preparation

Comparison with state-of-art MC models (done also vs multiplicity) suggests that further tuning is necessary in order to reduce the discrepancies

Status: proposal of publication approved by the ALICE Collaboration. Finalization of the draft ongoing.

The physics of ALICE in one slide...

- Broad and multi-disciplinary physics program through the study of different collision systems !

Heavy-ion collisions

- Properties of QGP and its dynamical evolution
- Interaction with medium constituents
- Hadronization in medium

Small and (ultra)peripheral systems

- Test / constrain QCD-based models
- Initial state & reference for HI collisions
- Collectivity and QGP-like effects in small systems

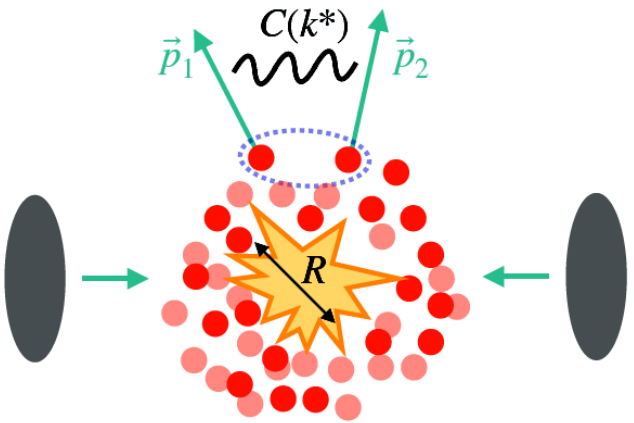
Hadronic correlations and composite objects formation

- Hadron-hadron correlations and interactions studies using femtoscopy
- (Anti)(hyper)nuclei production

Contributions beyond QCD physics

- Neutron stars and equation of state
- Contribution to dark matter research
- Cosmic rays

Femtoscopy: short physics introduction



$$2k^* = |\vec{p}_1 - \vec{p}_2|$$

k* ≡ relative momentum of the pair in its center of mass

- Particles interact with each other during system's evolution -> possibility to access the **system properties** and **interactions among particles** by measuring hadron correlations in the final state

$$C(k^*) = \frac{Norm \cdot S(k^*)}{B(k^*)}$$

→ Same event distribution (signal)

→ Mixed event distribution (background)

- Theoretical description of the femtoscopic correlation function is given by the Koonin-Pratt equation [1]

$$C_{th}(k^*, R_{inv}) = \int d^3r \, S(r, R_{inv}) \cdot |\Psi|(r, k^*)^2$$

Source function → spatial distribution of particles in a particle emitting source of size R_{inv}

→ **study source size**

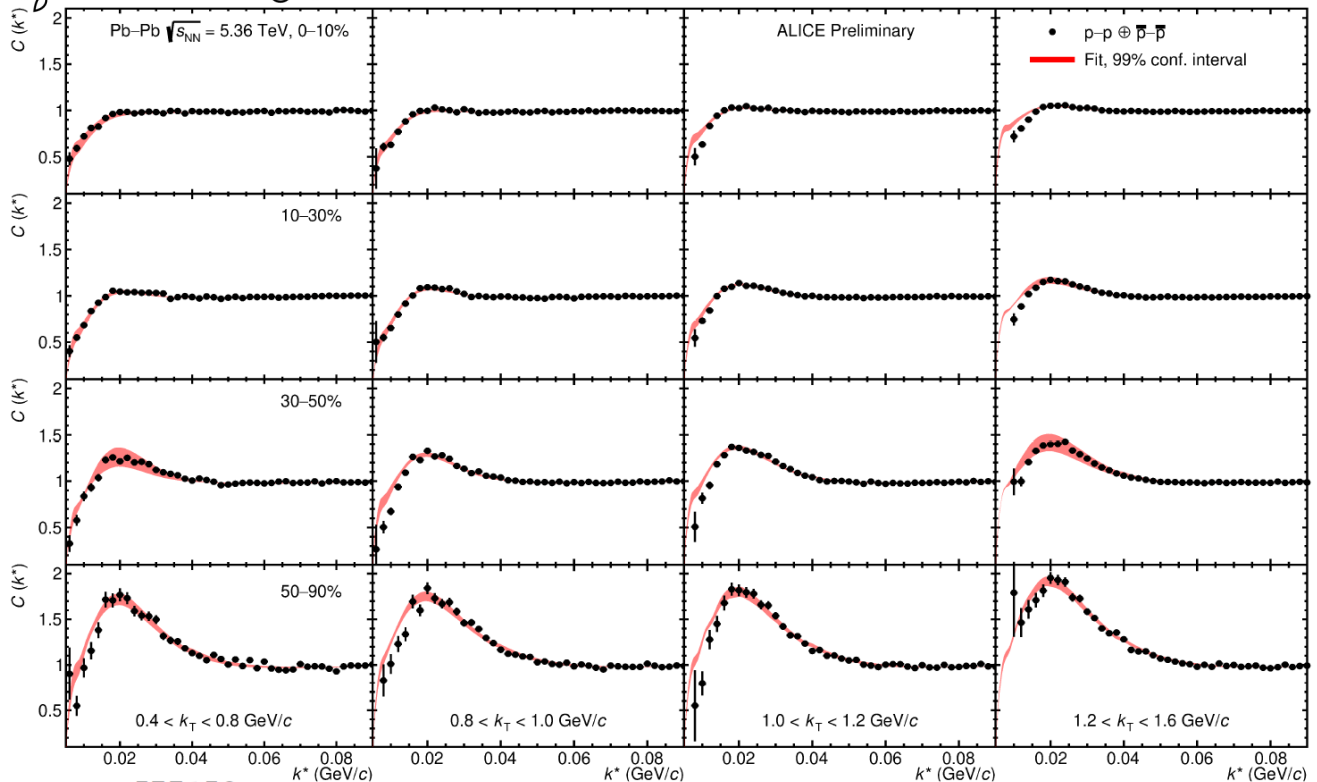
Wave function → interaction between particles in a pair

→ **study strong interaction potential models**

[1] S. E. Koonin, Phys. Lett. B 70, 43 (1977); S. Pratt, Phys. Rev. D 33, 1314 (1986).

p-p femtoscopy in Pb-Pb at 5.36 TeV (Run3) - preliminary

Milestone #16, CF [data prevista completamento: 31-12-2025]=> 100%



- ✔ R_{inv} extracted from the CF fits

$$C_{\exp}(R_{inv}, k^*) = N\left[1-\lambda\left(C_{th}(R_{inv}, k^*)-1\right)\right]$$

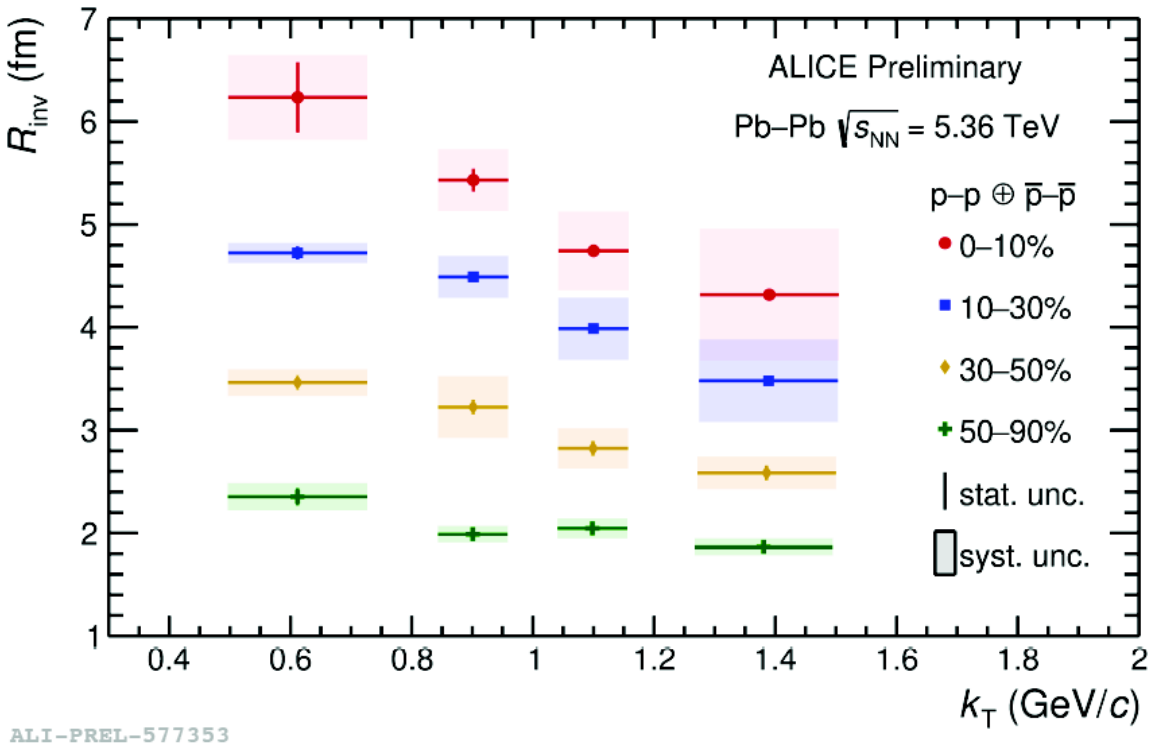
$R_{inv} \rightarrow$ *1D radius*

$\lambda \rightarrow$ *corr. strenght*

$N \rightarrow$ *normalisation*

p-p femtoscopy in Pb-Pb at 5.36 TeV (Run3) - preliminary

Milestone #16, CF [data prevista completamento: 31-12-2025]=> 100%



- R_{inv} extracted from the CF fits

$$C_{exp}(R_{inv}, k^*) = N\left[1-\lambda\left(C_{th}(R_{inv}, k^*)-1\right)\right]$$

$R_{inv} \rightarrow$ *1D radius*

$\lambda \rightarrow$ *corr. strenght*

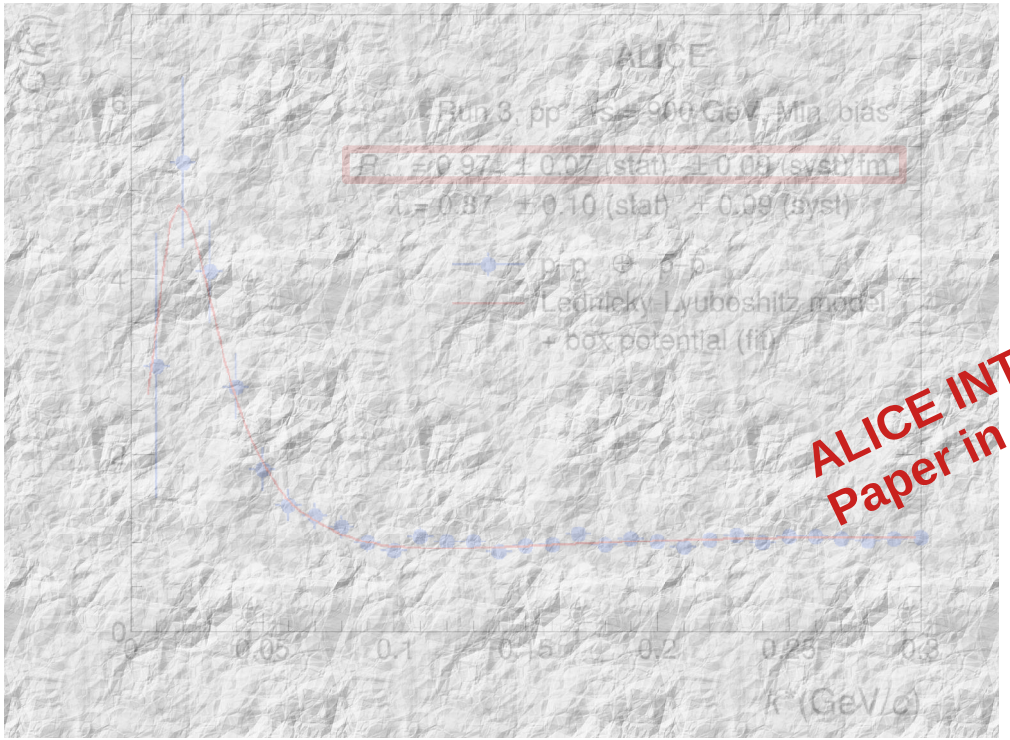
$N \rightarrow$ *normalisation*

- Smaller effective size for more peripheral events
- Decreasing R_{inv} with increasing k_T → "explosive" behaviour (less pronounced in more peripheral events)

$$k_T = \frac{1}{2} \cdot |\boldsymbol{p}_{T,1} + \boldsymbol{p}_{T,2}|$$

p-p femtoscopy in pp at 900 GeV (Run3) - publication

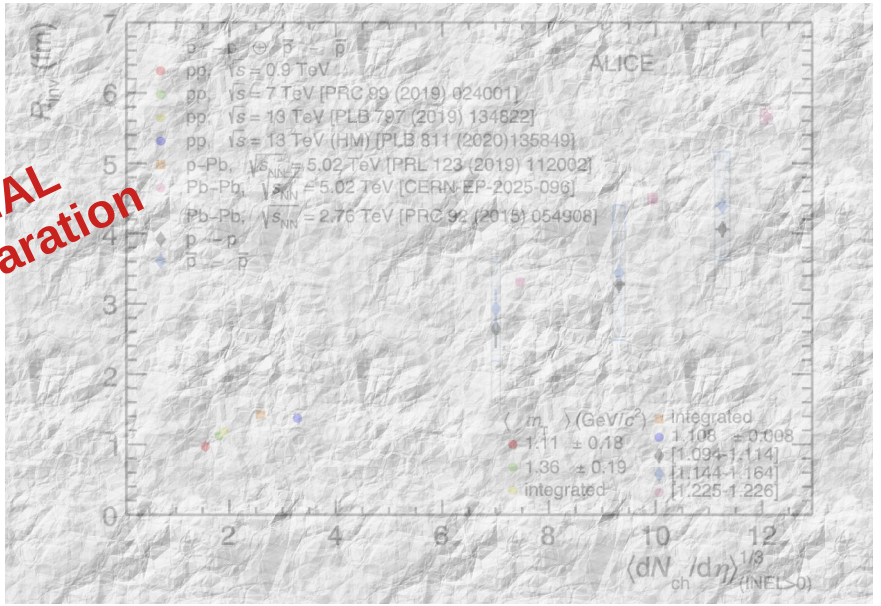
Milestone #15, CF [data prevista completamento: 31-12-2025]=> 50%



ALICE INTERNAL
Paper in preparation

- To do: finalize paper draft (paper proposal approved by the ALICE collaboration)

- First measurement of the proton source size in pp at √s = 900 GeV



- Clear increasing trend observed vs multiplicity → Smaller source at 900 GeV

$\langle m_T \rangle = \sqrt{(\langle k_T \rangle^2 + m_p^2)}$

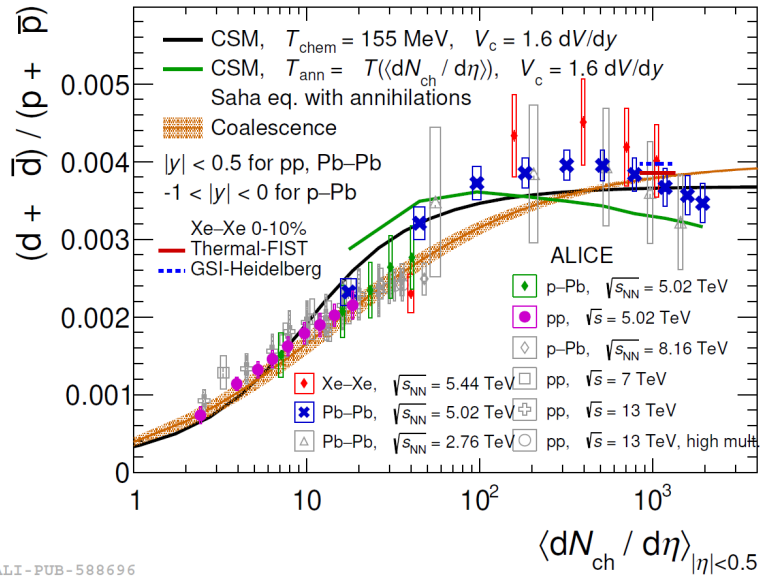
Production of (anti)nuclei: physics motivations

- Multi-baryon bound states (d, ^{3}H, ^{3}He, ^{4}He) including rare (anti)hypernuclei (consisting of nucleons and hyperons, e.g $_\Lambda{}^3$H, $_\Lambda{}^4$H, $_\Lambda{}^4$He) observed in high-energy collisions

- **Shed light on production mechanisms** → need systematic measurements of (anti)nuclei in different collision systems to test production models

  Two competing models:

  - Statistical Hadronization Model (SHM): primordial yields of hadrons (including nuclei) at chemical freeze-out calculated using the hadronic partition function
  - Coalescence model: bound states formed by coalescence if nucleons / hyperons are close in phase-space at the kinetic freeze-out

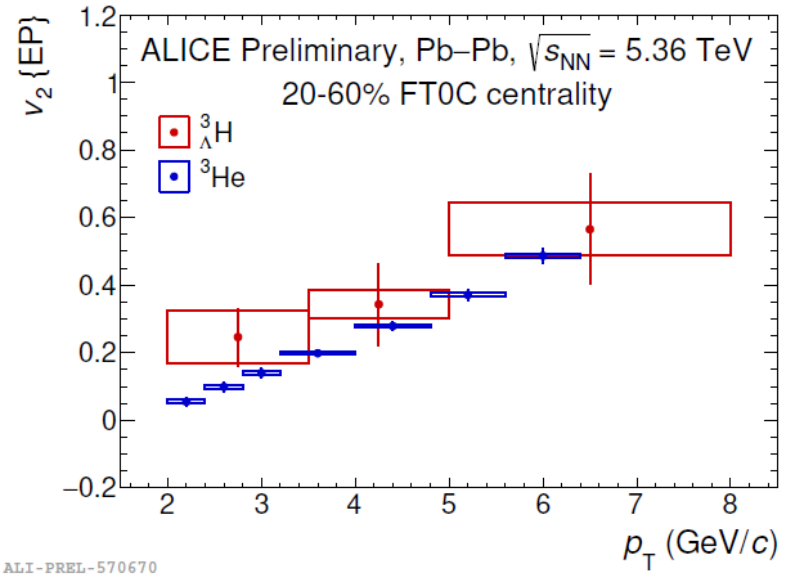


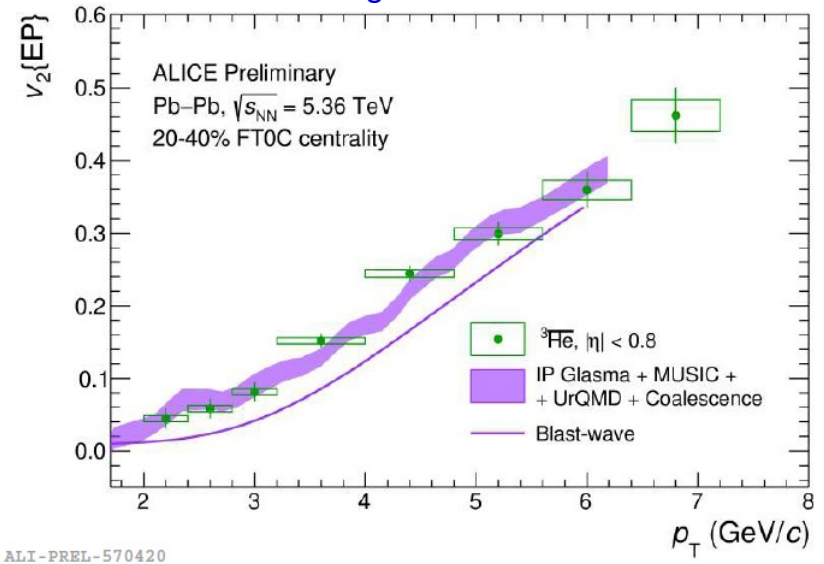
- **Contribute to cosmic-ray physics and dark-matter searches** → modelling the production of anti-nuclei in pp collisions can provide constraints to DM models

Flow of (anti)nuclei in Pb-Pb at 5.36 TeV (Run3) - preliminary

Milestone #11, LF [data prevista completamento: 30-06-2025]=> 100%

- Elliptic flow of (anti)nuclei can be used to test the formation-mechanisms of light nuclei





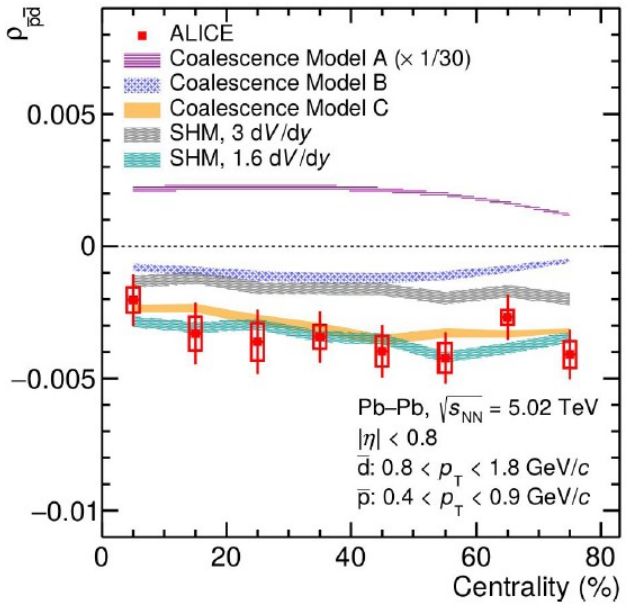
- Preliminary results approved for Quark Matter 2025
- Proposal of publication approved by the ALICE Collaboration In June
- Draft preparation ongoing

- ^{3}He flow measured in Run3: more precise and more differential measurement wrt the existing results from Run2
  - Results compatible with $^3_\Lambda$He flow (first ever measurement of the $^3_\Lambda$He elliptic flow)
  - Data described by hybrid model using hydro + coalescence

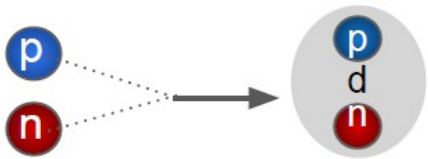
Antideuteron-net-Λ correlations in Pb-Pb at 5.02 TeV (Run2) - publication

Milestone #14, CF [data prevista completamento: 31-12-2025]=> 50%

- ✔ Disentangle thermal production vs coalescence using event-by-event fluctuation observables
- ✔ **Antideuteron–antiproton correlation** has two possible sources of correlation:
  - (1) baryon number conservation
  - (2) coalescence



ALICE, Phys. Rev. Lett. 131, (2023) 041901



Cumulants

$\kappa_1 = \langle n \rangle$ Mean value

$\kappa_2 = \langle (n - \langle n \rangle)^2 \rangle$ (Co)variance

$\rho_{ab} = \langle (n_a - \langle n_a \rangle)(n_b - \langle n_b \rangle) \rangle / \sqrt{\kappa_{2a}\kappa_{2b}}$

Pearson coefficient: sensitive to correlations between (net) particles of species a and b originating from quantum numbers conservation

- ✔ **Statistical hadronization model** can describe the data but only with a relatively smaller correlation volume (1.6 dV/dy) than other hadrons (3 dV/dy)
- ✔ **Model C** that incorporate deuteron production from the coalescence with V_c = 3 dV/dy gives more consistent picture with other hadrons

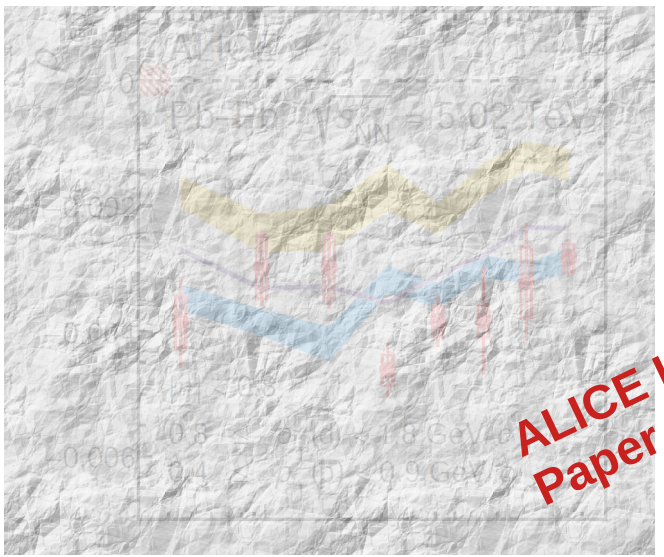
V_c = correlation volume -> volume in which charges are conserved (expressed in units of rapidity)

Antideuteron-net-Λ correlations in Pb-Pb at 5.02 TeV (Run2) - publication

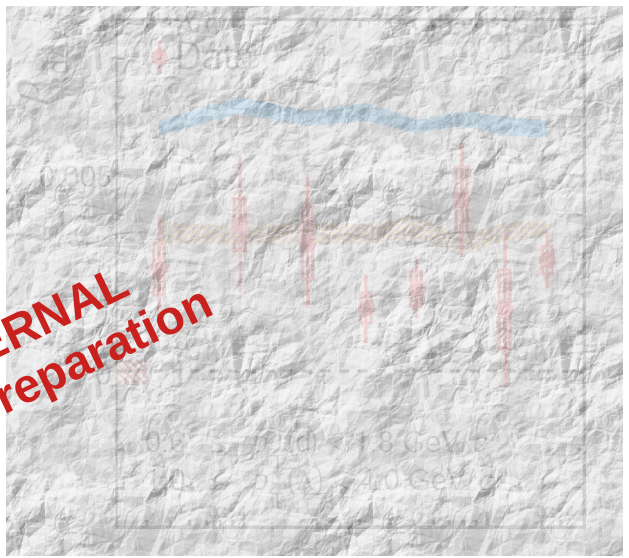
Milestone #14, CF [data prevista completamento: 31-12-2025]=> 50%

- Disentangle thermal production vs coalescence using event-by-event fluctuation observables
- **Antideuteron–antiproton correlation** has two possible sources of correlation:
  (1) baryon number conservation
  (2) coalescence
- **Antideuteron–(net)Λ** only sensitive to baryon number conservation (deuterons are not produced from the coalescence of Λ barion)

V_c = 3.0 dV/dy w/ coal.
V_c = 3.0 dV/dy w/o coal.
V_c = 1.6 dV/dy



ALICE INTERNAL
Paper in preparation



- **Antideuteron–(net)Λ correlation** consistent with Thermal-FIST with V_c = 3 dV/dy (w/ and w/o coalescence)
- **Antideuteron–antiproton correlation** consistent with Thermal-FIST with V_c = 3 dV/dy **only when coalescence is included**
- Status: paper proposal approved by the ALICE Collaboration. Draft under internal review

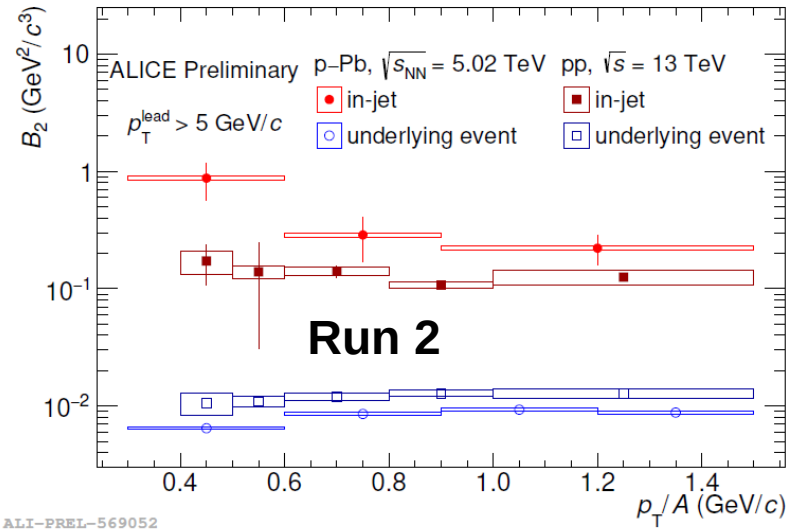
Production of anti-nuclei in- and out-of-jet in pp collisions at 13.6 TeV (Run3) - preliminary

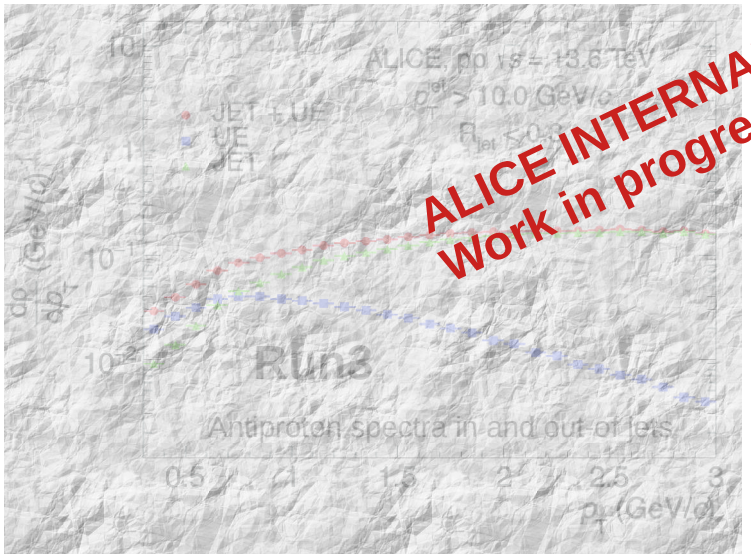
Milestone #10, LF [data prevista completamento: 31-12-2025]=> 50%

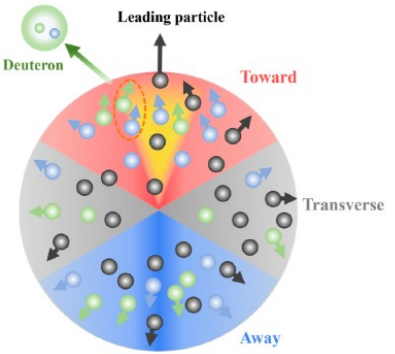
- Goal: measure coalescence parameter of anti-deuterons in jets and out-of-jets

$$B_2 = \left(\frac{3}{2\pi p_{\mathrm{T}}^{\mathrm{d}}}\frac{\mathrm{d}^2N_{\mathrm{d}}}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}^{\mathrm{d}}}\right) \Big/ \left(\frac{3}{2\pi p_{\mathrm{T}}^{\mathrm{p}}}\frac{\mathrm{d}^2N_{\mathrm{p}}}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}^{\mathrm{p}}}\right)^2$$

→ proportional to coalescence probability







Status and outlook:

- antideuteron and antiproton spectra provided in and out-of jets (corrected by acceptance and efficiency)
- Compute B_2 and finalize systematic uncertainties

- Significant difference observed between B_2^{JET} and B_2^{UE} in Run2

Summary and final considerations

Milestone #1, HF [data prevista completamento: 31-12-2025]=> 100%
Milestone #2, HF [data prevista completamento: 30-06-2025]=> 100%
Milestone #3, HF [data prevista completamento: 31-12-2025]=> 50%
Milestone #4, HF [data prevista completamento: 30-09-2025]=> 100%
Milestone #5, DQ [data prevista completamento: 30-06-2025]=> 100%
Milestone #6, DQ [data prevista completamento: 31-12-2025]=> 100%
Milestone #7, DQ [data prevista completamento: 30-06-2025]=> 100%
Milestone #8, DQ [data prevista completamento: 30-06-2025]=> 100%
Milestone #9, LF [data prevista completamento: 31-12-2025]=> 50%
Milestone #10, LF [data prevista completamento: 31-12-2025]=> 50%
Milestone #11, LF [data prevista completamento: 30-06-2025]=> 100%
Milestone #12, LF [data prevista completamento: 31-12-2025]=> 30%
Milestone #13, LF [data prevista completamento: 31-12-2025]=> 50%
Milestone #14, CF [data prevista completamento: 31-12-2025]=> 50%
Milestone #15, CF [data prevista completamento: 31-12-2025]=> 50%
Milestone #16, CF [data prevista completamento: 31-12-2025]=> 100%
Milestone #17, Lumi [data prevista completamento: 31-12-2025]=> 50%

- ✔ All milestones well on track, most of them based on Run3 data (14/17)
- ✔ 9 out of 17 milestones already completed
- ✔ Pending milestones expected to be finalized by the end of the year (no critical case)

List of milestones for 2026

- PWG-HF and PWG-DQ:

HF	1	31/12/2026	Invio per la pubblicazione della misura del flusso ellittico di adroni con charm in collisioni Pb-Pb semi-centrali
HF	2	31/12/2026	Invio per la pubblicazione della misura di correlazioni angolari tra adroni con charm e particelle cariche in collisioni protone-protone con dati del Run 3
HF	3	31/12/2026	Invio per la pubblicazione della misura della produzione di adroni con charm in stati eccitati
HF	4	30/6/2026	Misura preliminare della dipendenza dalla centralità del flusso ellittico di adroni con charm con dati Pb-Pb 2023+2024
DQ	5	31/12/2026	Invio a rivista per la pubblicazione dell'analisi del rapporto di Psi(2S)/Jpsi a rapidità in avanti in collisioni pp a 13.6 TeV
DQ	6	31/12/2026	Invio a rivista per la pubblicazione dell'analisi della polarizzazione delle J/psi da fotoproduzione in collisioni Pb-Pb periferiche a 5.02 TeV per nucleone
DQ	7	30/6/2026	Risultati preliminari sulla frazione corretta di J/psi da beauty a rapidità centrale in collisioni protone-protone a 13.6 TeV
DQ	8	31/12/2026	Invio a rivista per la pubblicazione dell'analisi di produzione di prompt e non-prompt J/psi in jets a rapidità centrale in collisioni protone-protone a 13 TeV

List of milestones for 2026

- PWG-LF, PWG-CF and luminosity PAG

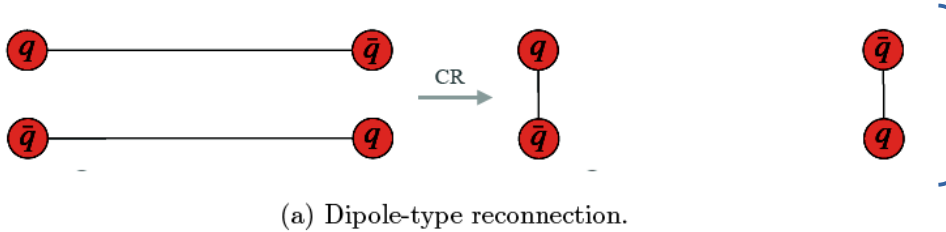
LF	9	31/12/2026	Invio a rivista dell'analisi sugli spettri π-K-p in pp @ 13.6 TeV
LF	10	31/12/2026	Invio a rivista/pubblicazione su rivista dell'analisi sulla produzione di barione Sigma- in collisioni pp e p-Pb a 5.02 TeV
LF	11	31/12/2026	Invio a rivista dell'analisi sulla produzione di barioni strani in funzione della molteplicita' di particelle cariche in collisioni pp a 5.02 TeV
CF	12	31/12/2026	Invio per la pubblicazione della misura dei cumulanti di ordine elevato del numero netto di protoni in collisioni pp a 13 TeV
Lumi	13	31/12/2026	Risultati preliminari vdM scans del 2024

Thank you!

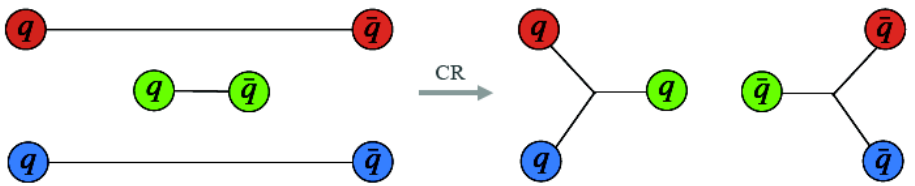
BACK-UP

Hadronization in PYTHIA

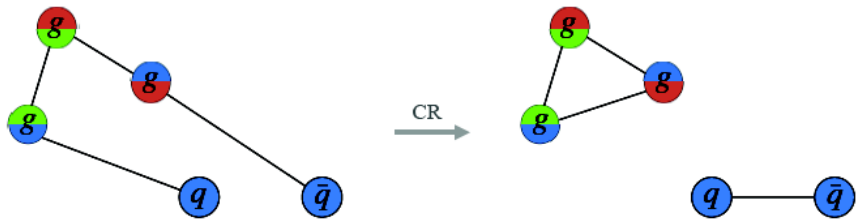
[Altmann et al.,https://arxiv.org/pdf/2405.19137]



(a) Dipole-type reconnection.



(b) Junction reconnection.



(c) Gluon-loop formation.

- ✔ Color Reconnection among partons belonging to different MPIs → In the **Leading Color** (CR-LC) limit (Monash 2013, default tune) **only "dipole" string configurations are allowed**
  - characterized by two endpoints, typically a colour and an anti-colour charge endpoint (can have any number of intermediate gluons between them which form "kinks" on the string)
- ✔ Color Reconnection **beyond Leading Color** (CR-BLC): alternative string configurations allowed
  - **Junctions provide a new mechanisms to produce baryons** (in the LC approximation baryons are only produced via diquark creation next to a heavy-flavour endpoint)

Baryon formation in current state of art models

- ✔ **Quark (re-)combination mechanism (QCM)** [QCM: Song et al., EPJC (2018) 78: 344]
  - Coalescence of charm quark and light flavour quarks close in “phase-space)”
  - Thermal weights for describing relative production of vector and scalar mesons

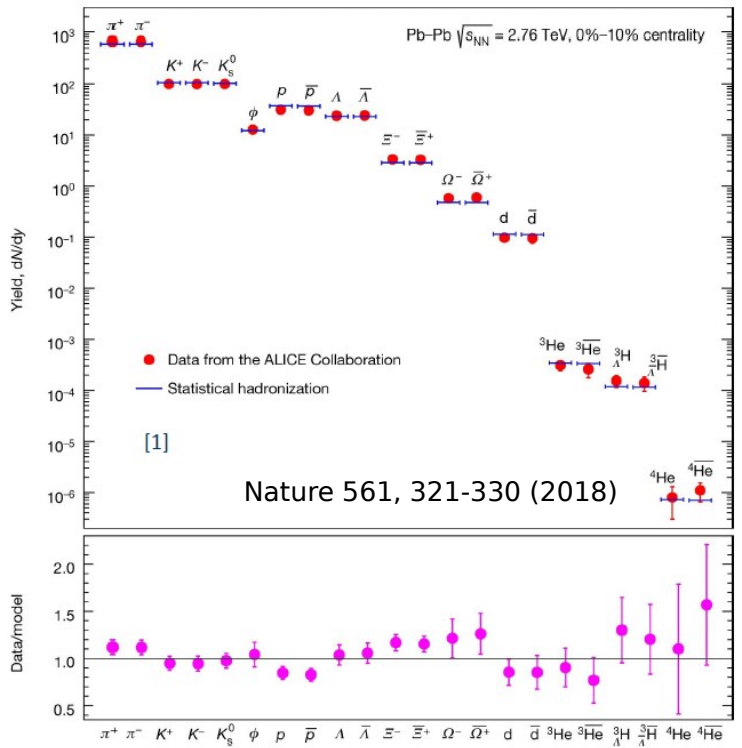
- ✔ **SHM + Relativistic Quark Model** [He et al., PLB 795 (2019) 117-121]
  - Hadrons formed according to thermal weights driven by mass at the freezout temperature estimated from Pb-Pb fits (156.6 MeV)
  - Significant feed-down from excited charm baryon states beyond those listed in the PDG: additional 18 Λ_c, 42 Σ_c, 62 Ξ_c, 2 Ω_c (in the PDG: 5 Λ_c, 3 Σ_c, 8 Ξ_c, 34 Ω_c)

- ✔ **Catania** [Greco et al., PLB 821, 136622]
  - Thermalised systems of light flavour quarks and gluons
  - Charm quark hadronization via fragmentation + recombination with light flavour quarks from the bulk

- ✔ **POWLANG** [Beraudo et al., arXiv:2306.02152]
  - Expanding fireball assumed in pp collisions
  - Hadronisation via recombination with light quarks
  - Charm baryon formation enhanced thanks to diquark excitations

Hadron production in heavy-ion collisions

- Identified hadrons (including strange hadrons) in heavy-ion collisions are produced in apparent ***chemical*** and ***thermal*** equilibrium → **"*macroscopic*" description of the system**
  - ***Statistical Hadronization Model*** to reproduce **hadron abundances**



- Production of light-flavour hadrons well described by Statistical Hadronization Model (SHM) fit over ~9 orders of magnitude (*Grand Canonical ensemble formulation*)
- Hadron yields can be described as emerging from a hot Hadron-Resonance Gas in thermal equilibrium
  - **At LHC: $\mu_B \sim 0$, $T_{ch} \sim 156$ MeV**
- Precise determination of the parameters thanks to the wide variety of particle yields available with good experimental precision