Pb-Pb Run 2
$\sqrt{s_{NN}} = 5.02$ TeV

ALICE status report

Chiara Pinto (CERN)
on behalf of the ALICE Collaboration

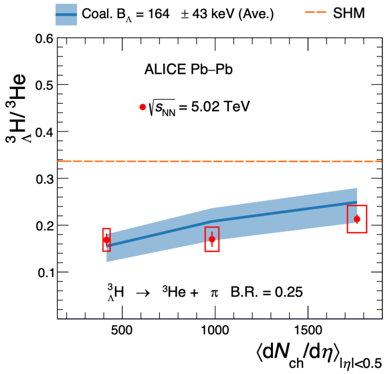
LHCC meeting – open session

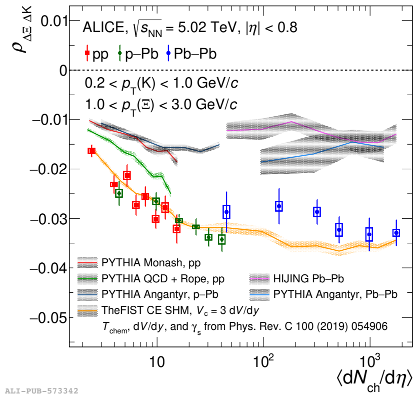
11 September 2024

ALICE status: outline

ALICE 1		ALICE 2	ALICE 2.1	ALICE 3
RUN 1	RUN 2	RUN 3	RUN 4	RUN 5 & 6
2009-2013	2015-2018	2022-2025	2029-2032	from 2035
pp, p-Pb, Pb-Pb	pp, p-Pb, Xe-Xe, Pb-Pb	pp, p-O, O-O, Pb-Pb	pp, p-Pb, Pb-Pb	

Recent physics publications





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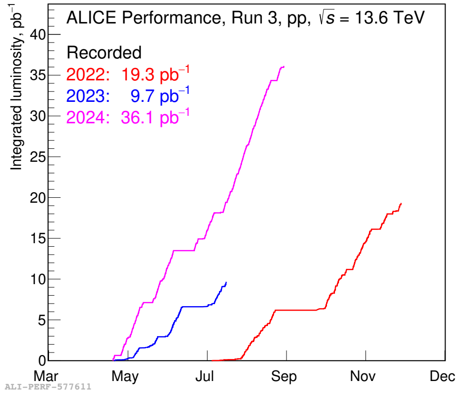
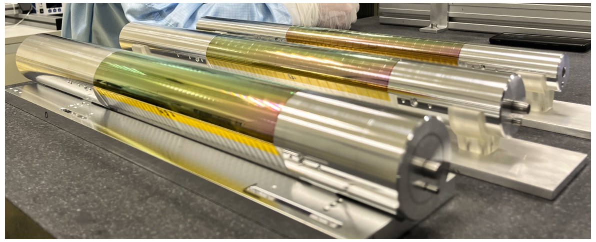
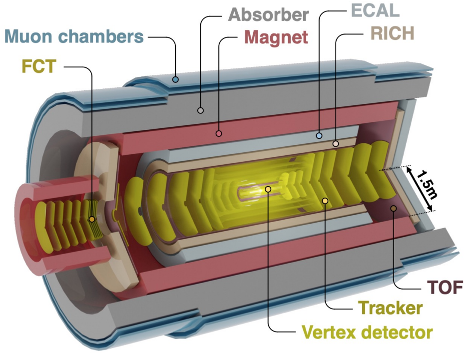


Upgrades and future





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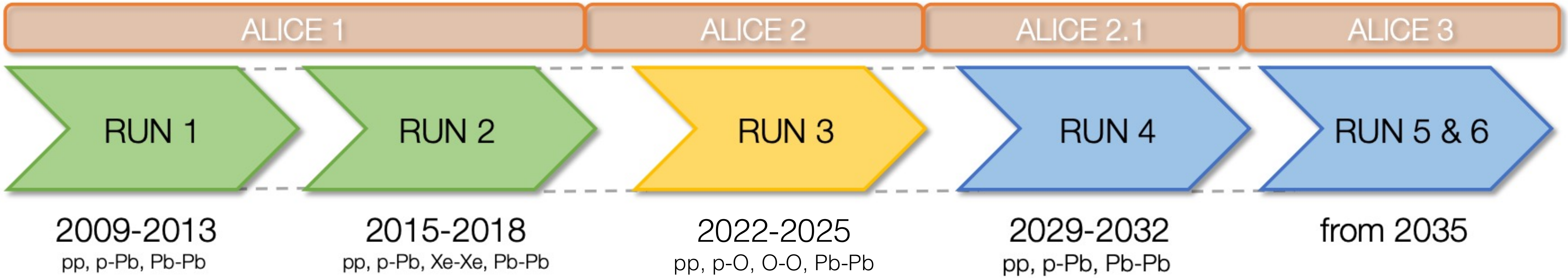

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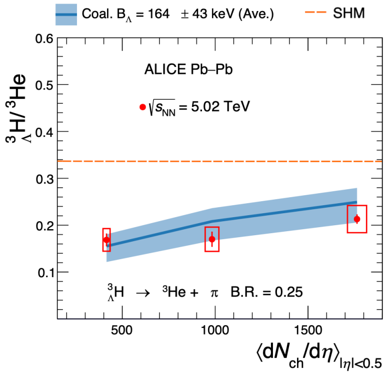

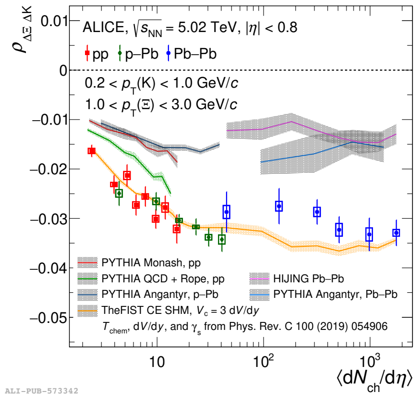

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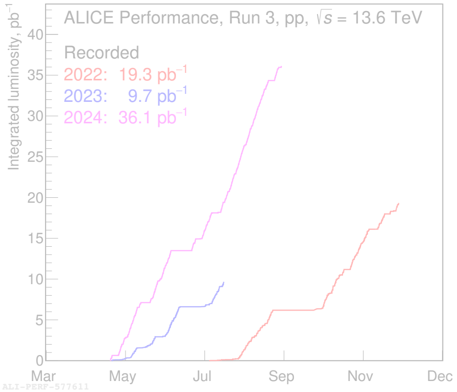

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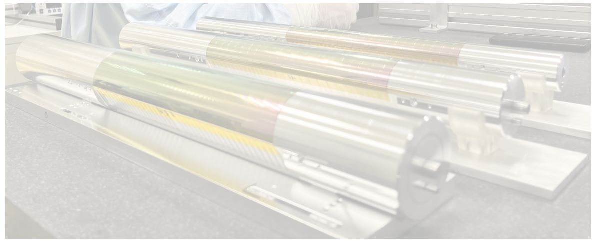

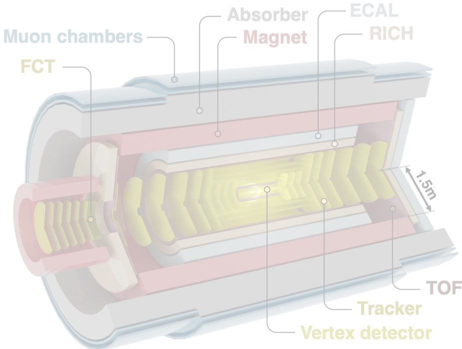

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List of publications since last LHCC meeting

- Measurement of the production and elliptic flow of (anti)nuclei in Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV, arXiv:2405.19826
- Measurement of ${}^{3}_{\Lambda}\mathrm{H}$ production in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, arXiv:2405.19839
- Investigating Lambda baryon production in p–Pb collisions in jets and underlying event using angular correlations, arXiv:2405.19855
- Probing strangeness hadronization with event-by-event production of multistrange hadrons, arXiv:2405.19890
- Measurement of the inclusive isolated-photon production cross section in pp collisions at $\sqrt{s}$ = 13 TeV, arXiv:2407.01165
- Rapidity dependence of antideuteron coalescence in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE, arXiv:2407.10527
- Measurement of beauty production via non-prompt charm hadrons in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, arXiv:2407.10593
- Particle production as a function of charged-particle flattenicity in pp collisions at $\sqrt{s_{\mathrm{NN}}}$ = 13 TeV, arXiv:2407.20037
- Higher order symmetry plane correlations in Pb—Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, arXiv:2409.04238
- J/psi-hadron correlations at midrapidity in pp collisions at $\sqrt{s}$ = 13 TeV, arXiv:2409.04364
- Exploring the nuclear structure with multiparticle azimuthal correlation at the LHC, arXiv:2409.04343
- Multiplicity-dependent jet modification from di-hadron correlations in pp collisions at $\sqrt{s}$ = 13TeV, arXiv:2409.04501

Recently released **public notes**:

- D^0 meson yields as a function of the underlying event activity in pp collisions at $\sqrt{s}$ = 13 TeV: https://cds.cern.ch/record/2901185
- Assessing the speed of sound in Pb–Pb collisions with ALICE: https://cds.cern.ch/record/2904102

New results shown today

Light nucleus measurements

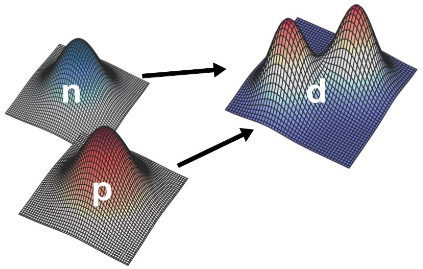
Hadronization models

Statistical models (SHM)

- Hadrons emitted from a system in local chemical equilibrium
- 3 free parameters: V, T_{chem}, μ_B
  – Particle ratios → volume V cancels
  – Baryochemical potential μ_B fixed by $\bar{p}/p$ ratio
  → one remaining parameter T_{chem}
- $dN/dy \propto \exp(-m/T_{\text{chem}})$

  ⇒ Nuclei (large m): large sensitivity to T_{chem}
- Successfully works in central Pb—Pb collisions
- Now also tested **in Xe—Xe**[1]

Coalescence models



- State-of-the-art coalescence models use the *Wigner function formalism* → (anti)nuclei arise from the overlap of the (anti)nucleons phase-space distributions with the Wigner density of the bound state
- Interplay between the nucleus wavefunction and the system size

Andronic et al., Nature 561, 321–330 (2018)
[1] ALICE Collaboration, arXiv:2405.19826

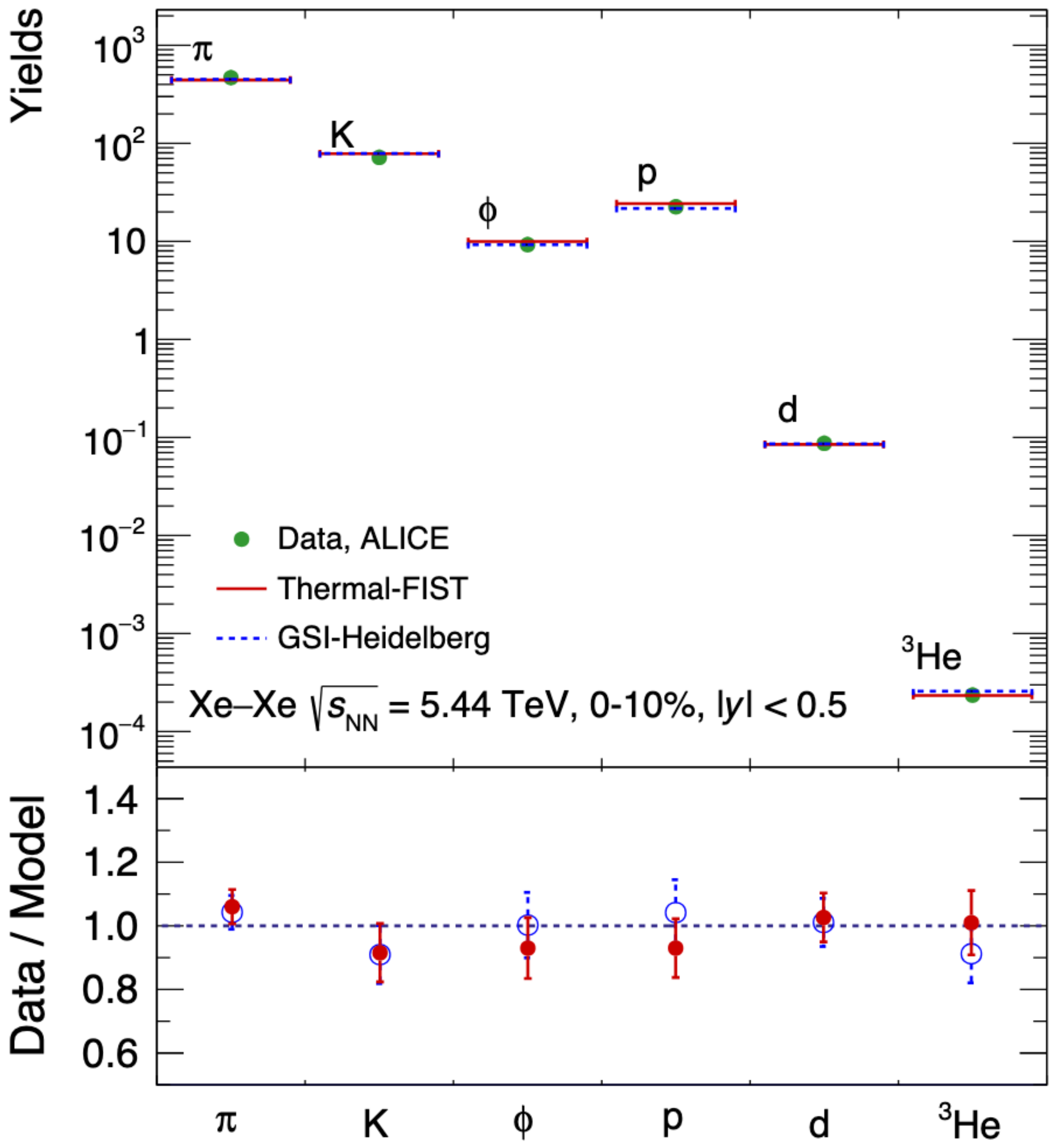
Butler et al., Phys. Rev. 129 (1963) 836
Mahlein et al., EPJC 83, 804 (2023)

Modelling the production of (anti)nuclei

- SHM is tested now also **in Xe—Xe**, by fitting the yields using 2 implementations of the model:
  - GSI-Heidelberg: T_{chem} = (154.2 ± 1.1) MeV, V = (3626 ± 298) fm^3
  - Thermal-FIST: T_{chem}= 156.6 MeV (fixed), V = (2996 ± 102) fm^3

Pb—Pb: T_{chem} = 156.6 ± 1.1 MeV
LatticeQCD[1]: $T_{pseudo\text{-}crit}$ = 156.5 ± 1.5 MeV

T_{chem} is the same in Pb—Pb and Xe—Xe: phase transition temperature



ALICE Collaboration, arXiv:2405.19826
Andronic et al., Nature 561, 321–330 (2018)
[1] HotQCD Coll., Phys.Lett.B 795 (2019) 15

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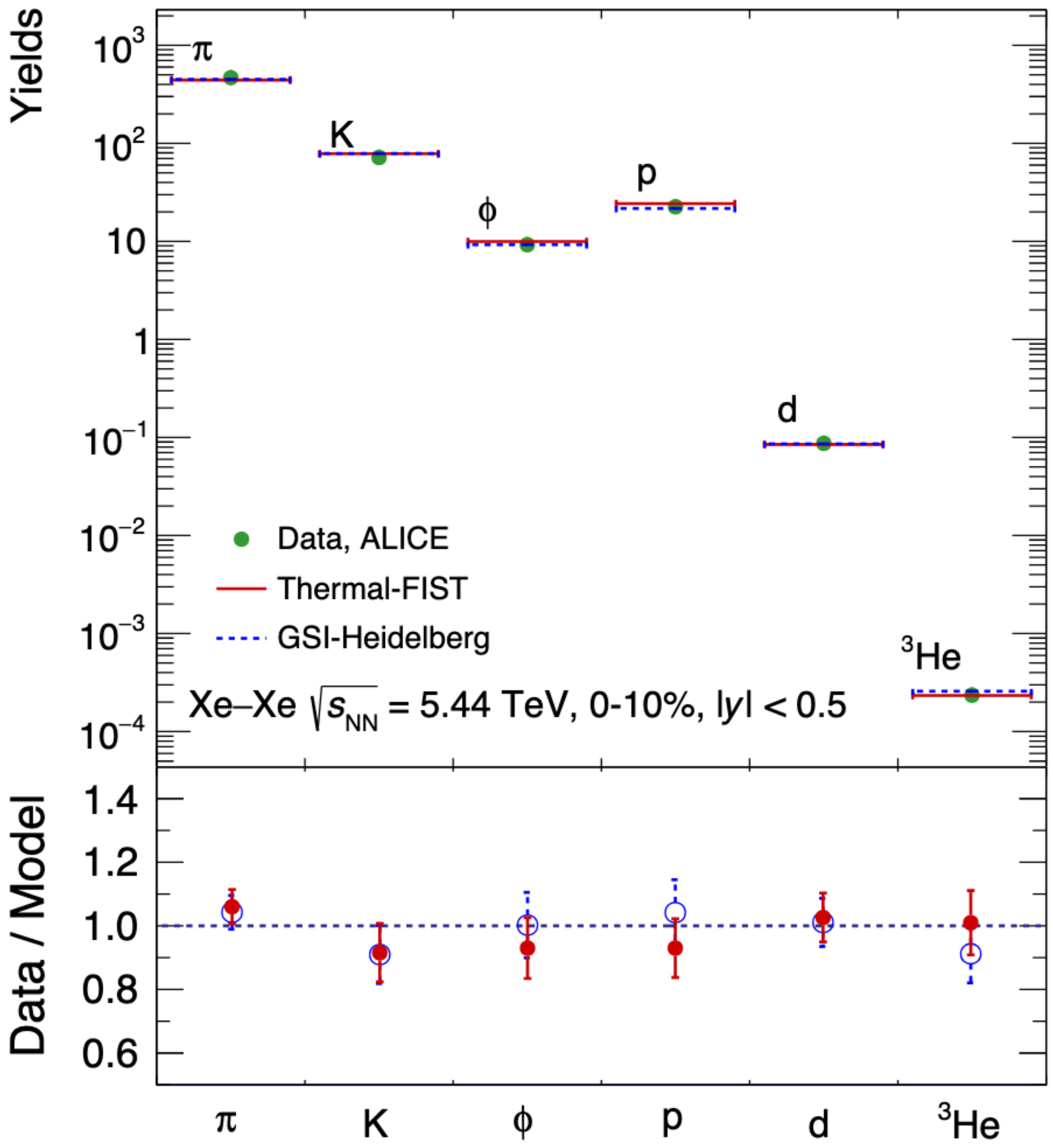
→ SHM works in heavy-ions

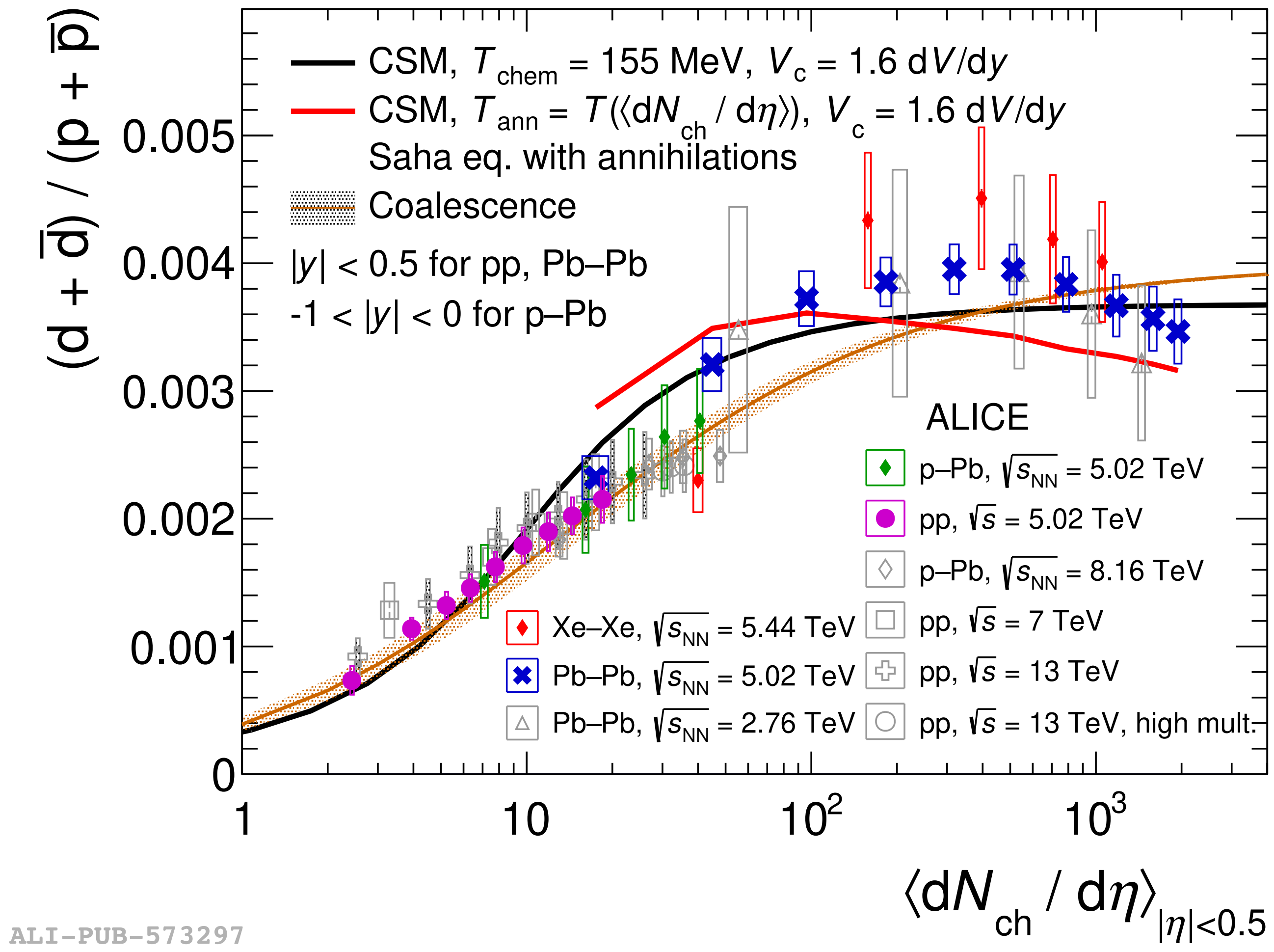
→ *What about small systems?*



ALICE Collaboration, arXiv:2405.19826
Andronic et al., Nature 561, 321–330 (2018)
[1] HotQCD Coll., Phys.Lett.B 795 (2019) 15

Testing production models: yield ratios

ALICE Collaboration, arXiv:2405.19826



- **Canonical statistical model (CSM)** → exact conservation of B, Q and S is required only in the correlation volume (V_c)
- Two implementations of CSM → either with fixed chemical temperature (CSM-I) or with **annihilation** temperature depending on multiplicity[1] (CSM-II)
- Both CSM and **coalescence**[2] predictions qualitatively reproduce the trend and overall yields
- Coalescence model[3] that includes realistic wavefunction describes deuteron yields
- **(Hyper)nuclei** with higher masses (**A≥3**) have larger **discrimination power on models** (hypernuclei weakly bound → *large radius*)

B:baryon number, Q:charge, S: strangeness content

[1] Vovchenko, Koch, PLB 835, 137577 (2022)

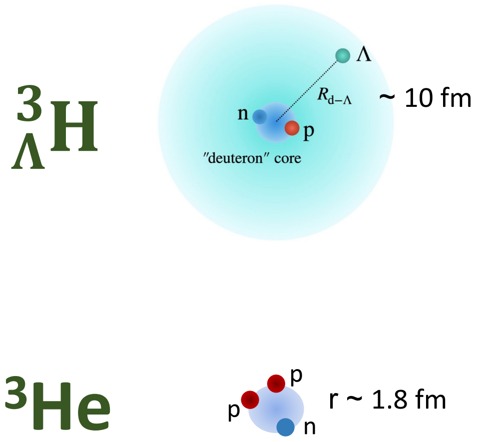
[2] Sun et al., PLB 792 (2019) 132-137

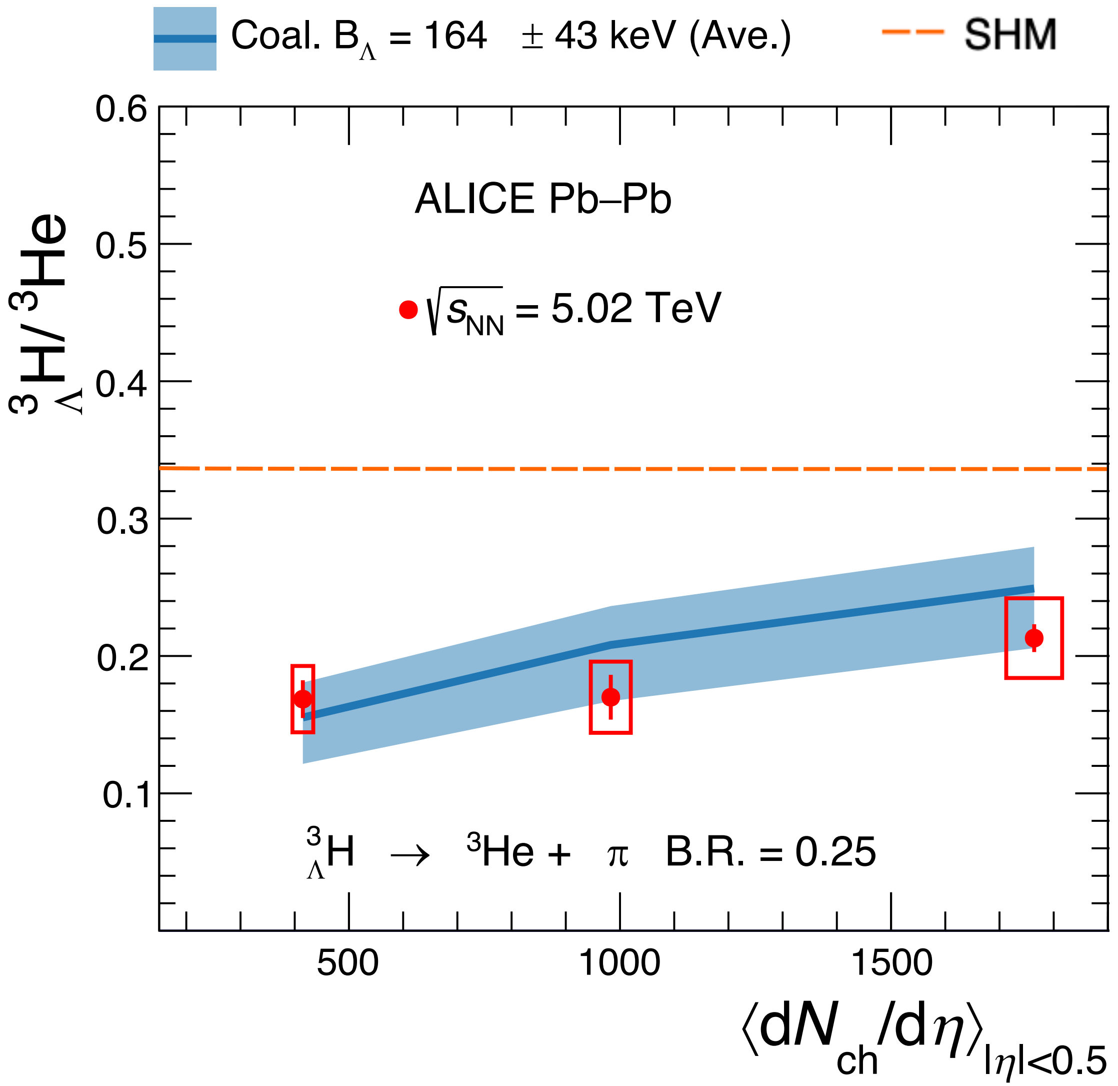
[3] Mahlein et al., EPJC 83, 804 (2023)

Hypertriton in Pb—Pb: test of production models

$^{3}_{\Lambda}H/^{3}He$ ratio allows for testing the production models

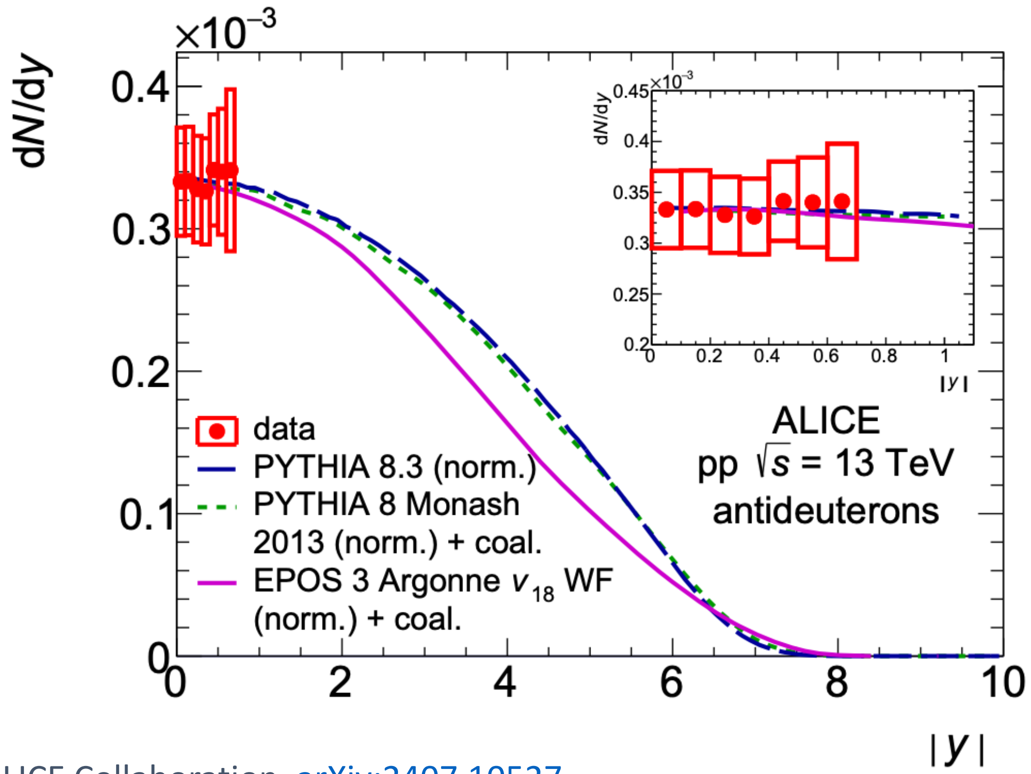
- **SHM** predicts a flat ratio: sensitive to their similar masses ($m_{^{3}_{\Lambda}H}$=2.991 and $m_{^{3}He}$=2.809 GeV/c^2), but insensitive to their size [$r_{^{3}He}$: 1.76 fm, $r_{^{3}_{\Lambda}H\,(d\Lambda)}$: 10 fm ($B_\Lambda \sim$ 0.13 MeV)]
- **coalescence** → interplay between the spatial extension of the nucleus wavefunction and the system size
- better agreement with coalescence



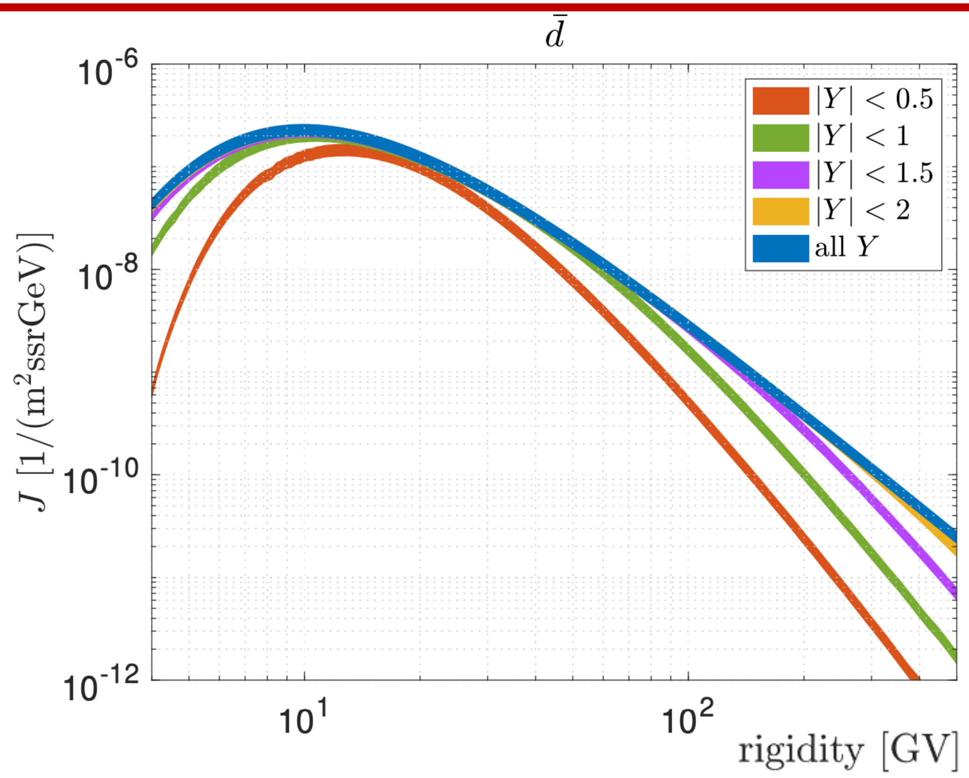


ALICE Collaboration, arXiv:2405.19839

Production of nuclei rapidity-differential with ALICE



ALICE Collaboration, [arXiv:2407.10527](https://arxiv.org/abs/2407.10527)

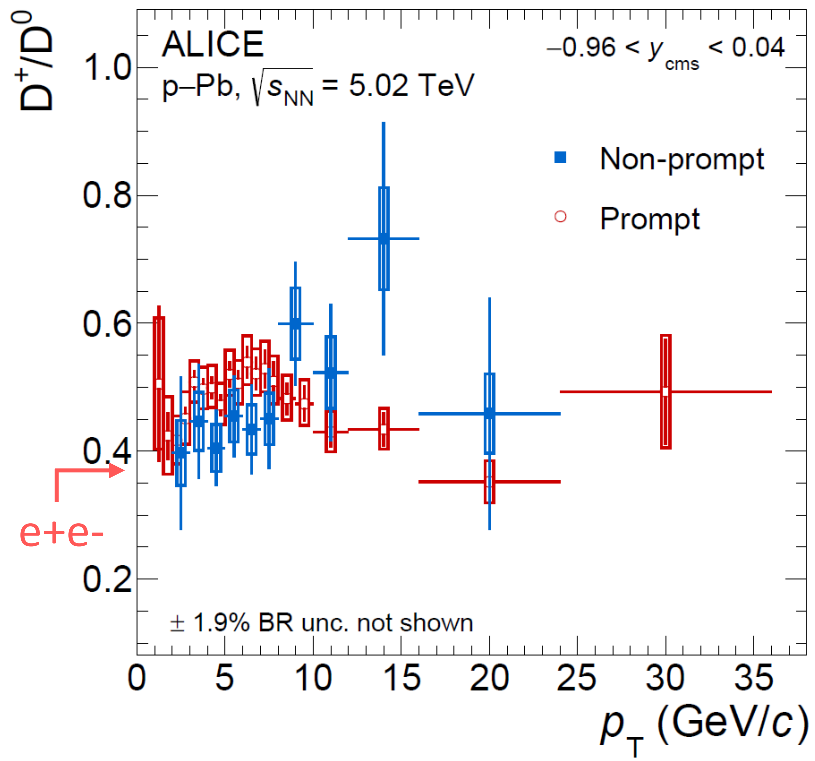


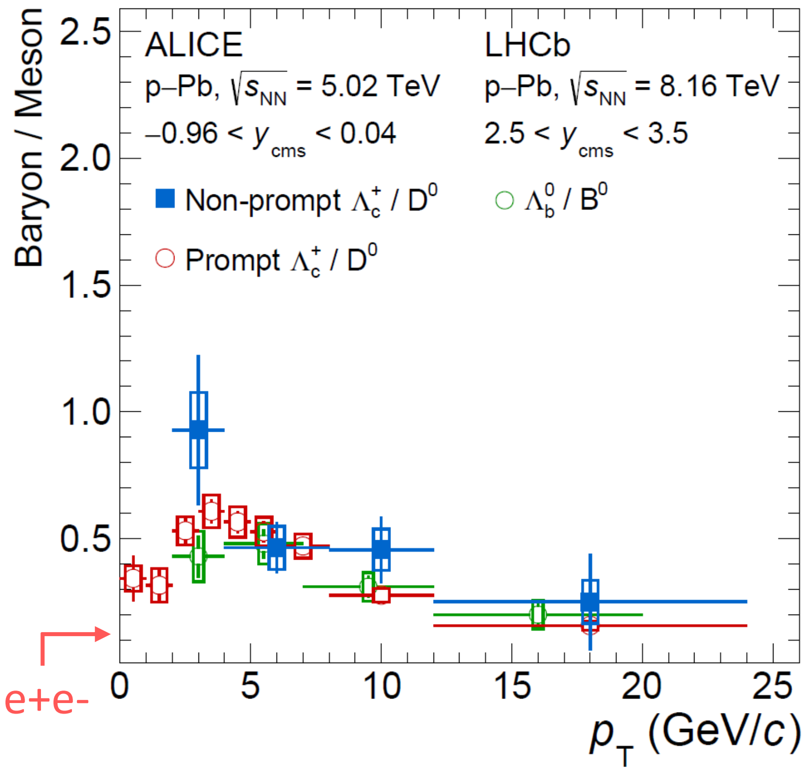
K. Blum, PRC 109 (2024) 3, L031904

- ALICE measurements cover the midrapidity region ($|y|<0.5$), while astrophysical models extrapolate to forward region
- Current acceptance of ALICE detector allows one to measure antideuterons rapidity-differential up to $|y| = 0.7$
- Rapidity and p_T dependence of yields is extrapolated to forward rapidity using a coalescence afterburner on top of Pythia 8.3 and EPOS events
- Model predictions based on ALICE measurements are used as input to calculate antideuteron flux from cosmic rays* → dominant background in dark matter searches → **Most of the antideuteron yield in CR flux comes from $|y|< 1.5$**

Hadronization studies

Non-prompt charm-hadron production in p–Pb





- Fragmentation fractions in beauty sector similar to charm sector
- Baryon enhancement in beauty fragmentation at low p_T (compared to e+e-)

ALICE Collaboration, arXiv:2407.10593

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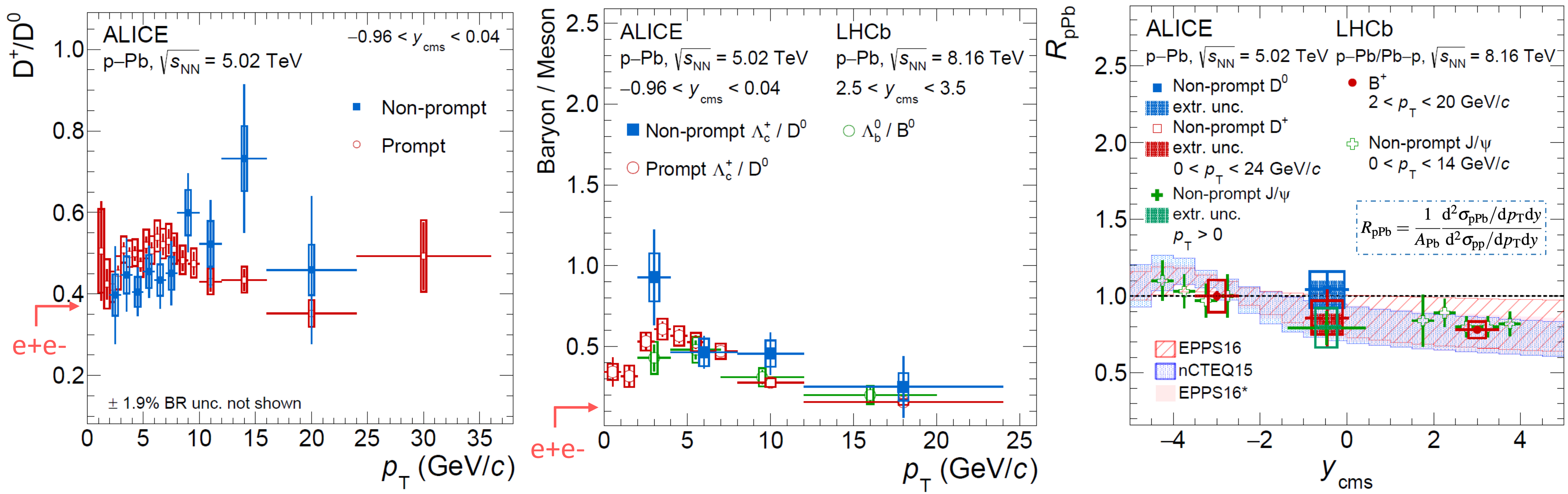
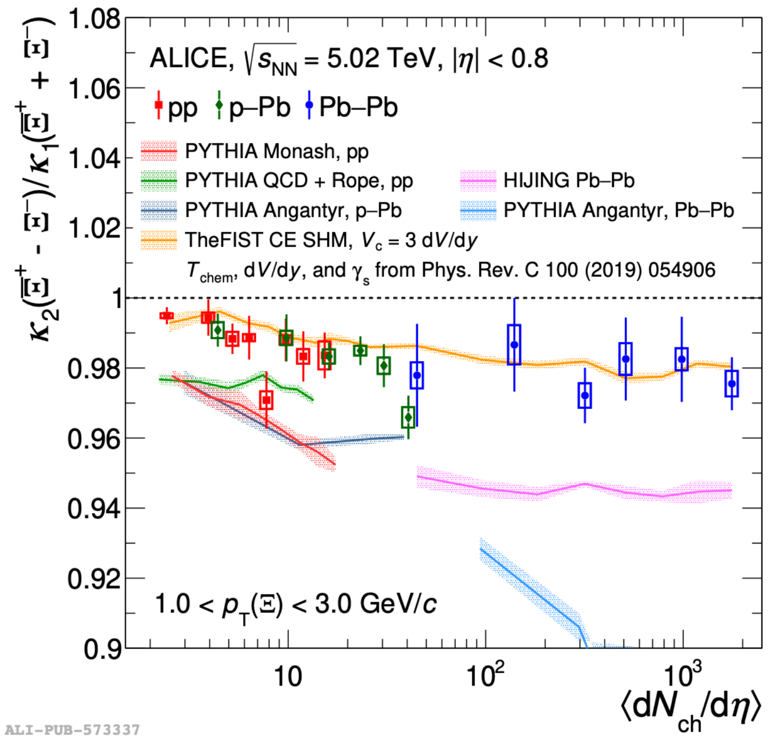


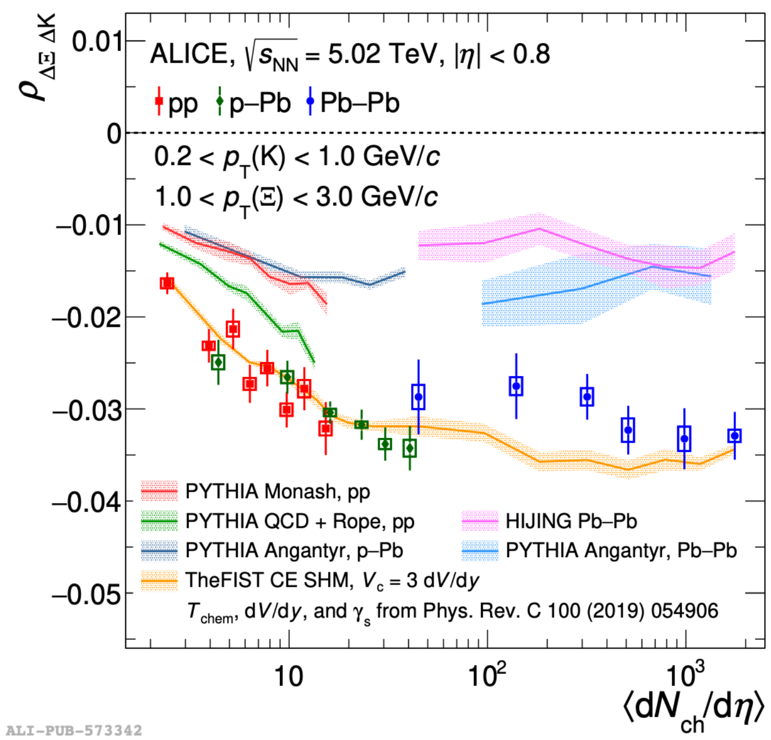
- Fragmentation fractions in beauty sector similar to charm sector
- Baryon enhancement in beauty fragmentation at low p_{T} (compared to e+e-)
- The p_{T}-integrated R_{pPb} of non-prompt D mesons is compatible with unity
  - ➢ In agreement with non-prompt J/ψ at central and forward rapidity and B^{+} production at forward rapidity
- **No significant impact of CNM effects is observed for beauty within the current uncertainties**

ALICE Collaboration, arXiv:2407.10593

Event-by-event production of multistrange hadrons

ALICE Collaboration, arXiv:2405.19890



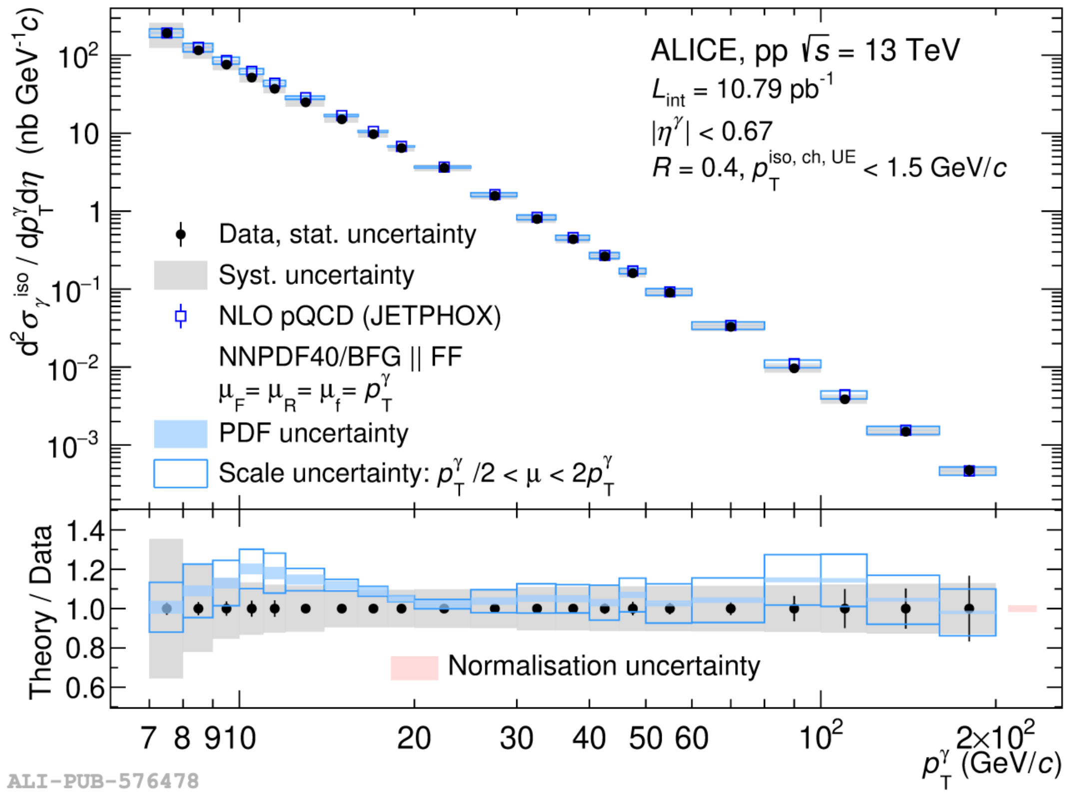


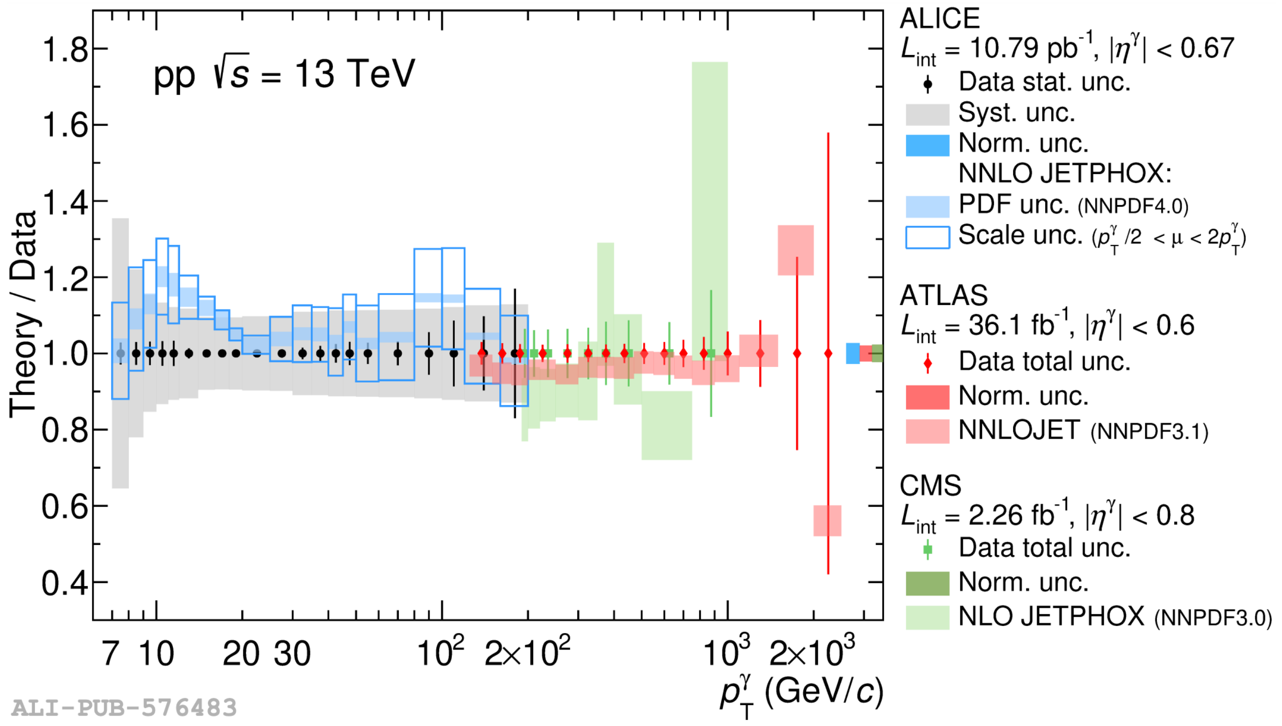
- *string fragmentation*: quantum numbers conserved locally for $q\bar{q}$ formation
- *CSM*: conservation laws hold over a finite correlation volume

- Normalized second order cumulant of net-Ξ and the correlation between net-Ξ and net-K vs. multiplicity have a great discrimination power among models: effect of **quantum number conservation**
- Large correlation volume fitted with SHM: $V_C = 3.19 \pm 0.14$ dV/dy → **large V_C regulates the strangeness conservation**

  → **within SHM correlations are formed at earlier times than predicted by string fragmentation**
- **Data favor SHM:** Thermal-FIST model includes long-range correlations due to strangeness conservation and correlations between hadrons with same-sign strange quantum numbers, unlike string fragmentation framework

Isolated-photon production in pp collisions





- Production cross section of inclusive isolated-photons measured with **EMCal+ITS+TPC**
- Taking advantage of the **full calorimeter acceptance** and using **only charged particles in the isolation cone** the measurement is extended to **lower isolated-photon p_T** (=7 GeV/c)
- Good agreement with previous similar measurements by **ATLAS and CMS** and with **NLO pQCD** calculations (<1σ)
- Comparison of ratio to predictions using **same isolation criteria**

ALICE Collaboration, arXiv:2407.01165

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RUN 5 & 6
from 2035

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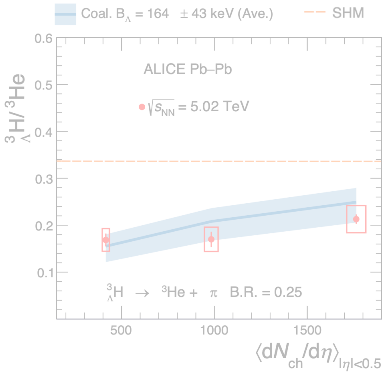

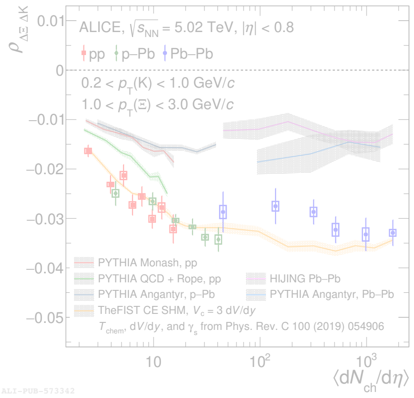

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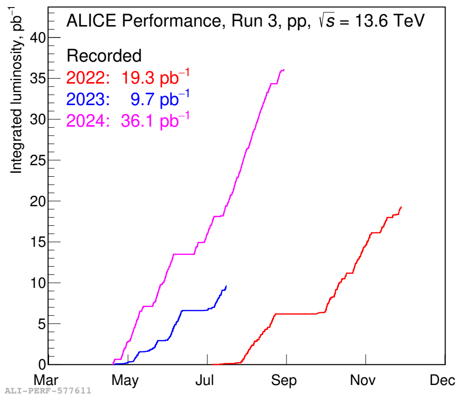
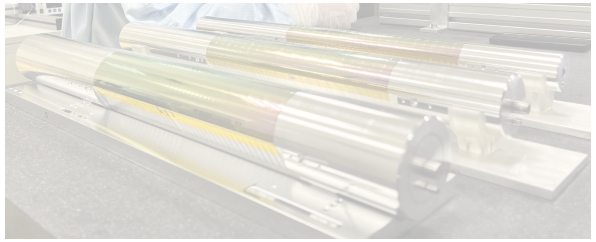
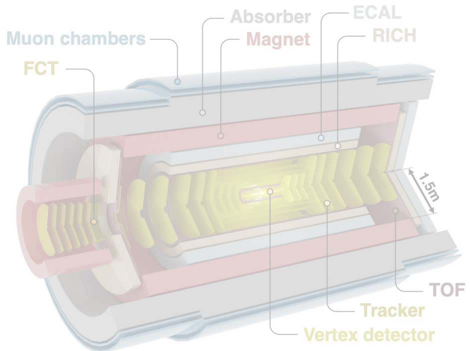


Upgrades and future



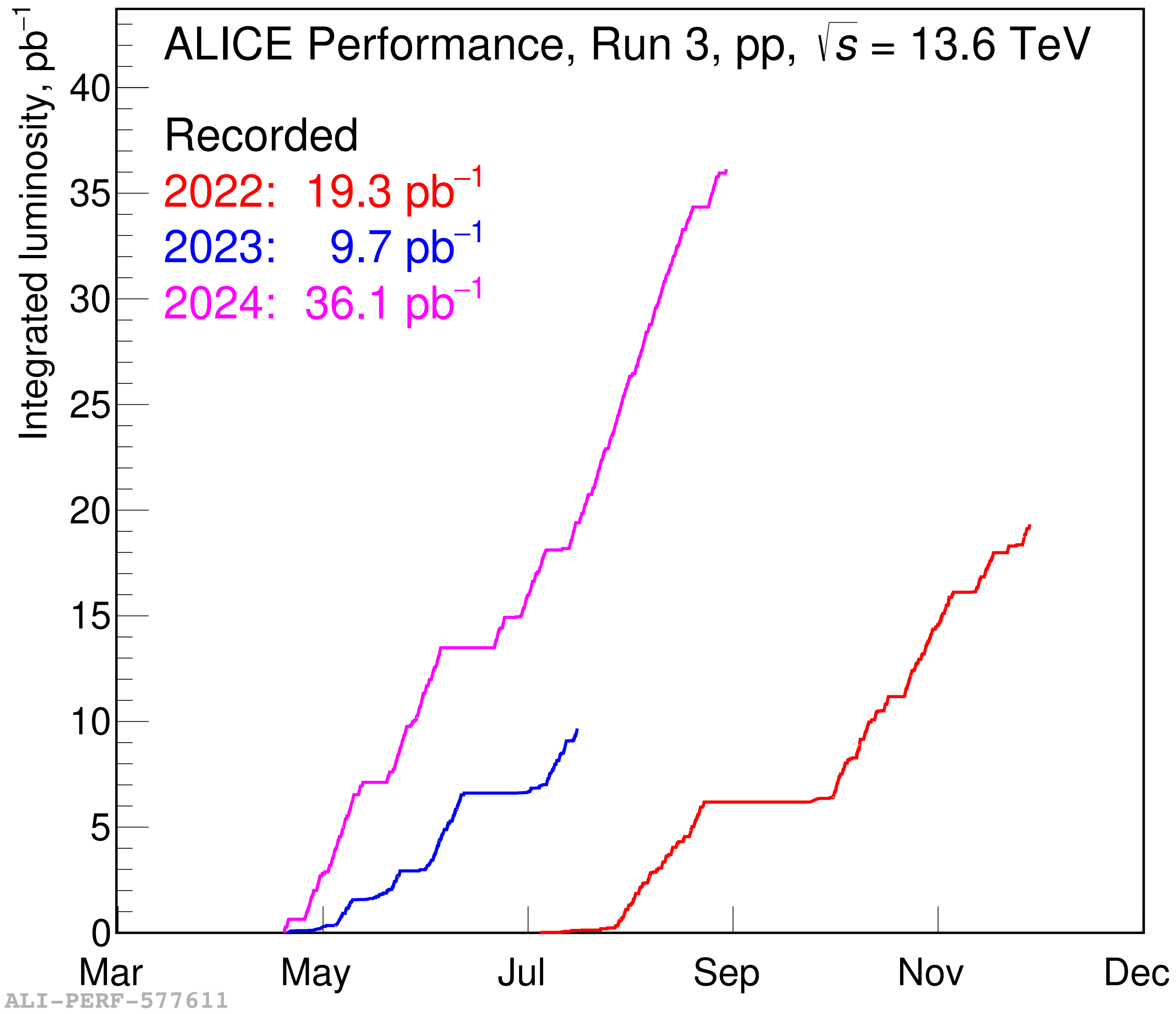


Run 3: status of ongoing data taking

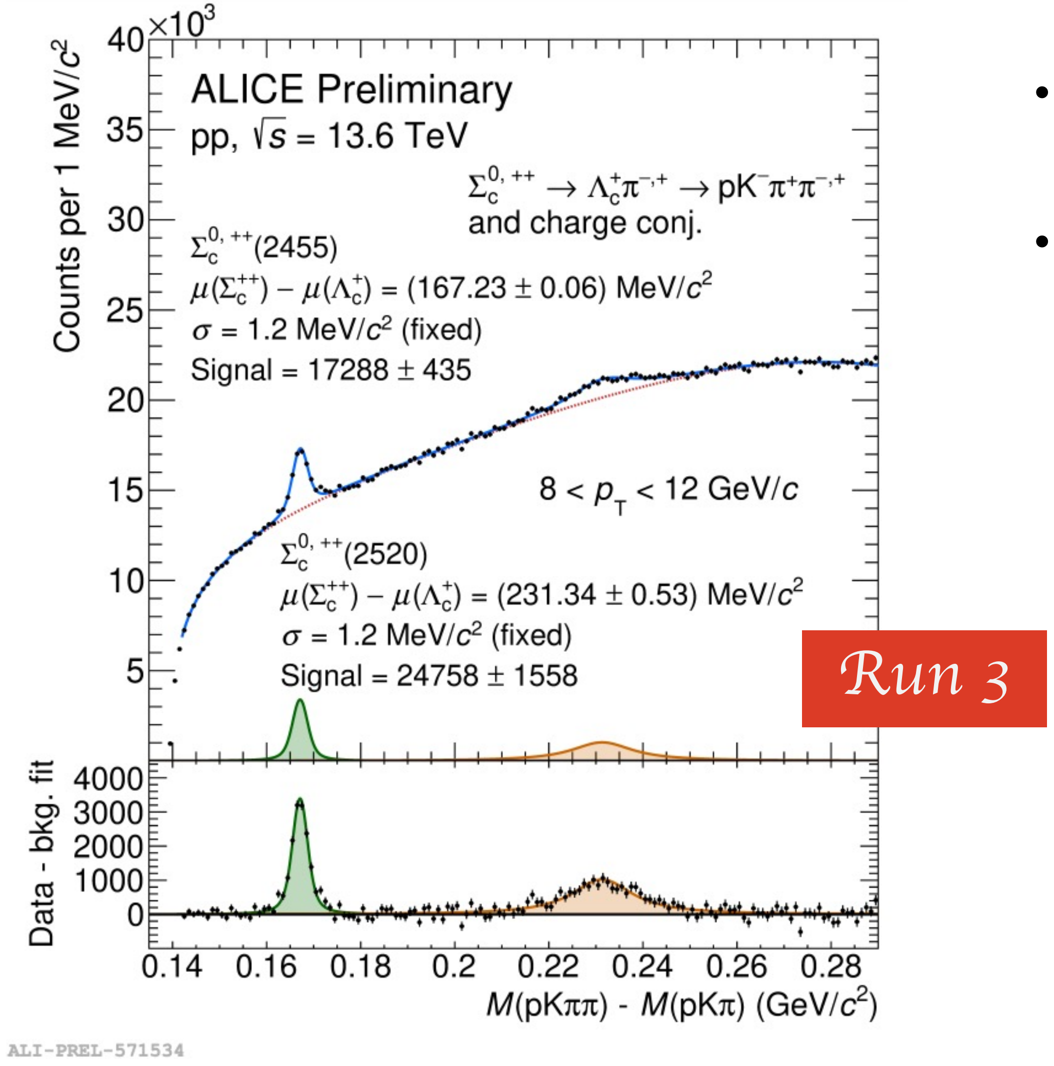
Total recorded $\mathcal{L}$ in 2024: ~ 36 pb^{-1}
Total delivered $\mathcal{L}$ in 2024: ~ 40 pb^{-1}
→ **~ 90% efficiency**

- DAQ efficiency is > 95% (vs. last year ~80%)
- Remaining 5% loss due to hardware failures, e.g. leak in L3 cooling

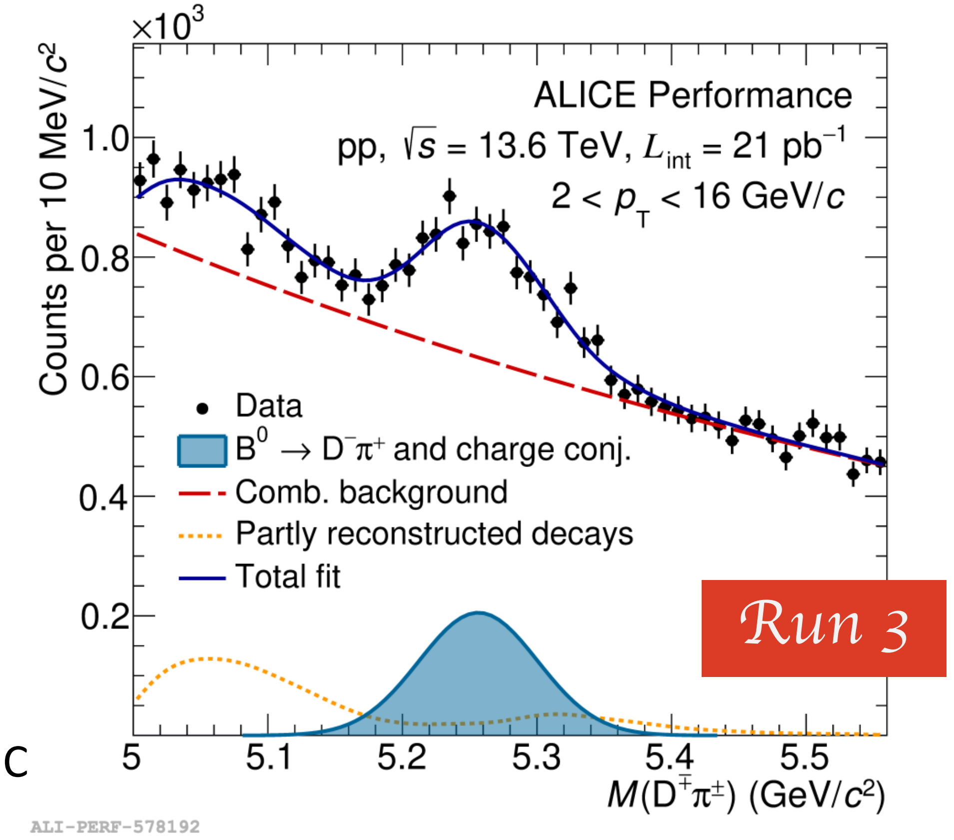
- All the data are processed by the Offline Trigger selection
  - Full data volume calibrated and reconstructed (~7-12 PB/week)
  - Analysis Level selections to trigger on interesting chunks of data
  - 4-6 weeks processing to reduce the data volume to ~4% of the original size



News from Heavy Flavor from Run 3



- With Run 3 pp data **full reconstruction of B meson** is possible for the first time with ALICE thanks to analysis-level trigger selections
- Extending similar measurements of CMS and ATLAS down to low p_T at midrapidity



- $\Sigma_c^{0,++}$(2520) production is measured in Run 3 for the first time at the LHC
  - Important input to constrain the production models

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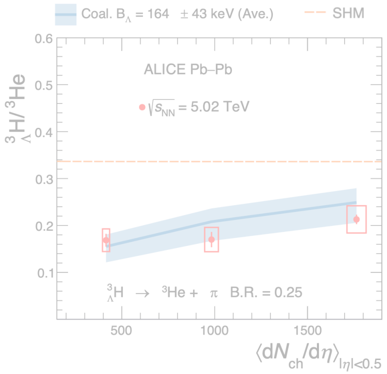

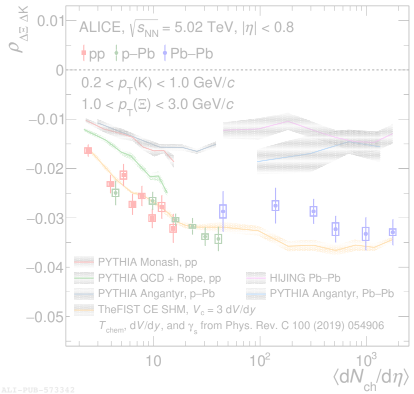

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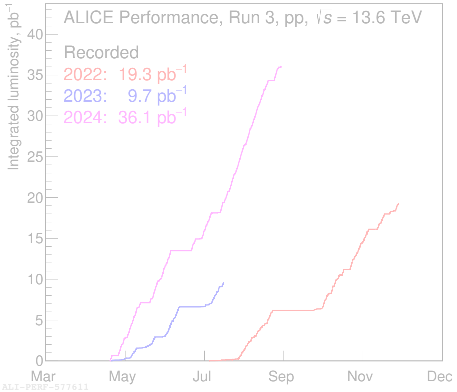
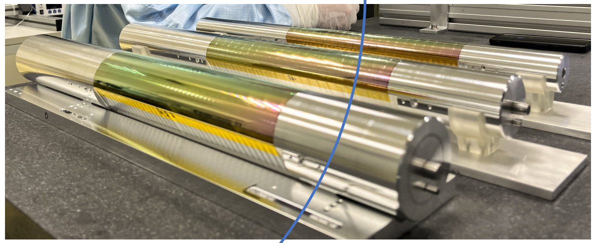
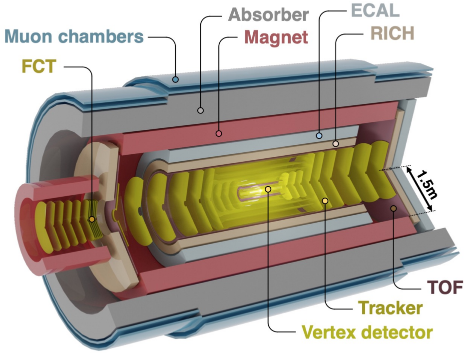


Upgrades and future

FoCal & ITS3





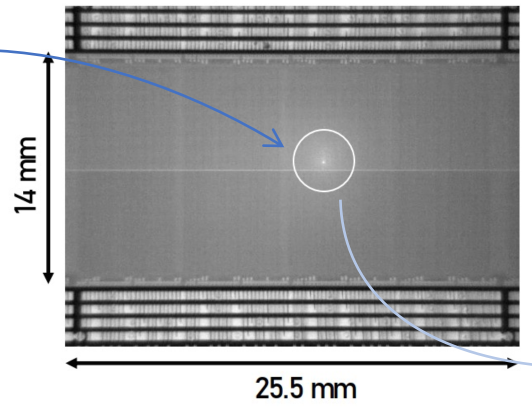
ALICE 3

ALICE upgrade projects: ITS3

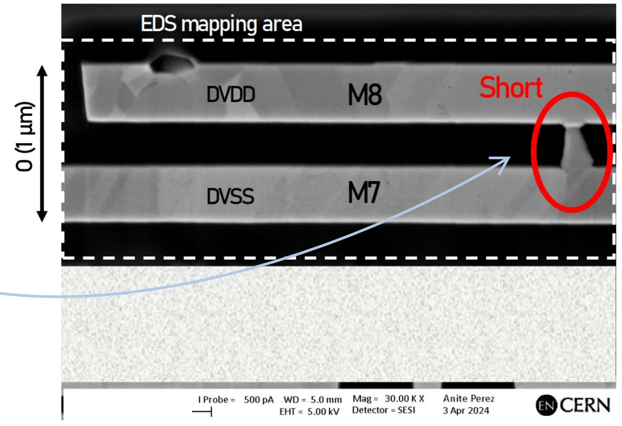
MOSS (Monolithic Stitched Sensor ER1 prototype) yield loss investigation

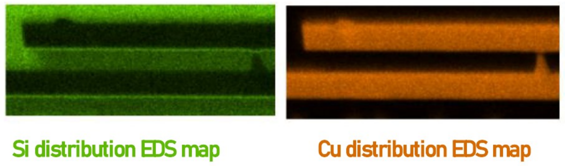
- Overcurrents on first powering (visible as hot spots in IR camera images) now established as shorts between the two top metal layers
- Will be fixed by foundry for next ER2 submission

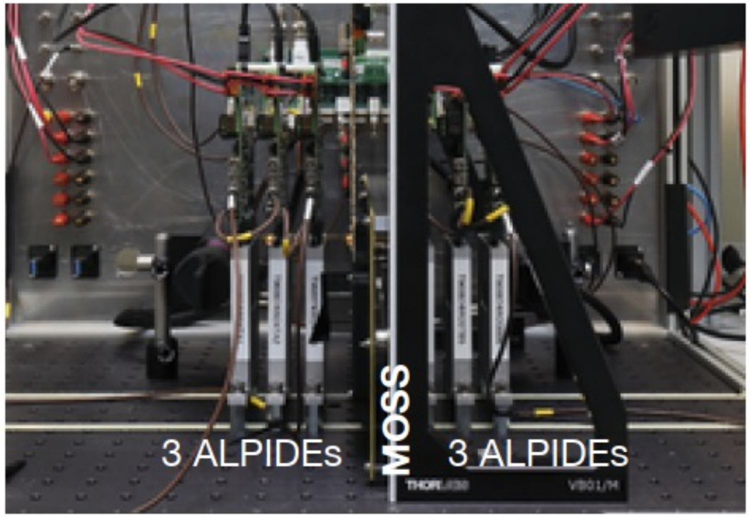
IR camera image



Focused Ion Beam + SEM
CERN-MME-MM





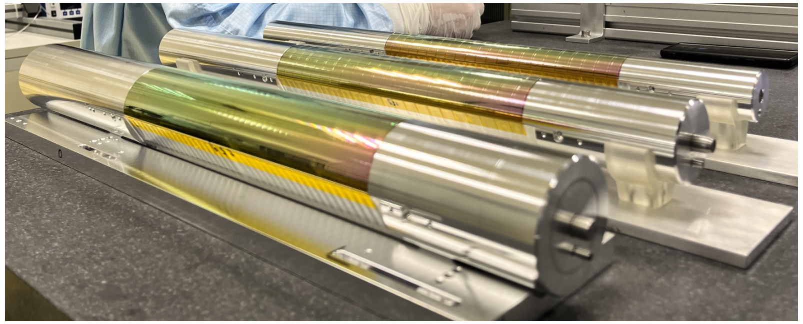


ER1 testbeams

- Intense campaign in 2024
- Irradiation and operating point studies
- Data processing in progress, results relevant to select pixel variants for ER2

Electromechanical integration

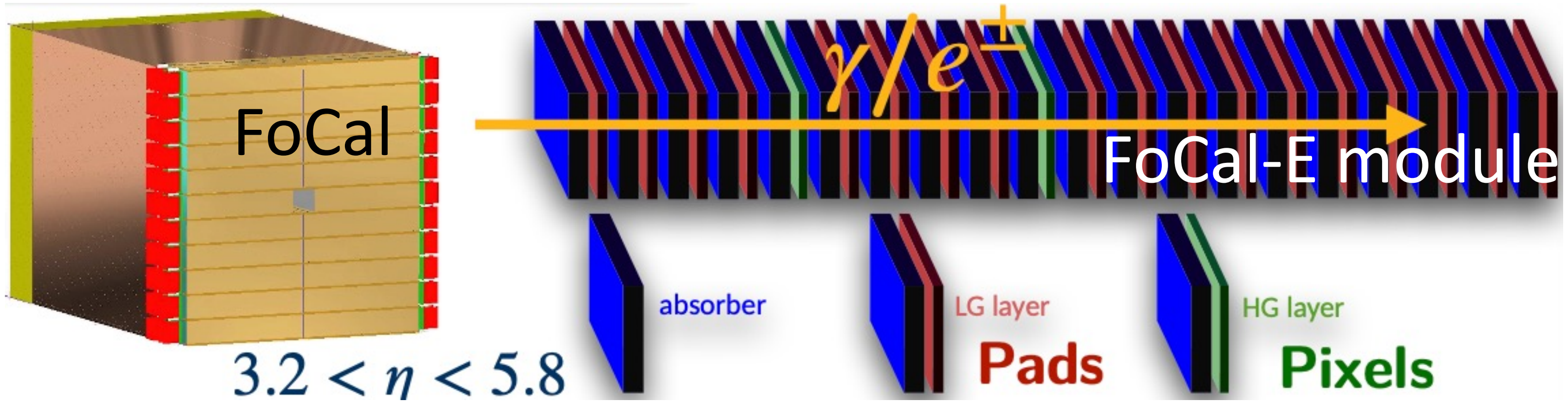
- Successful 3-layers assemblies of pad wafers with dummy FPCs

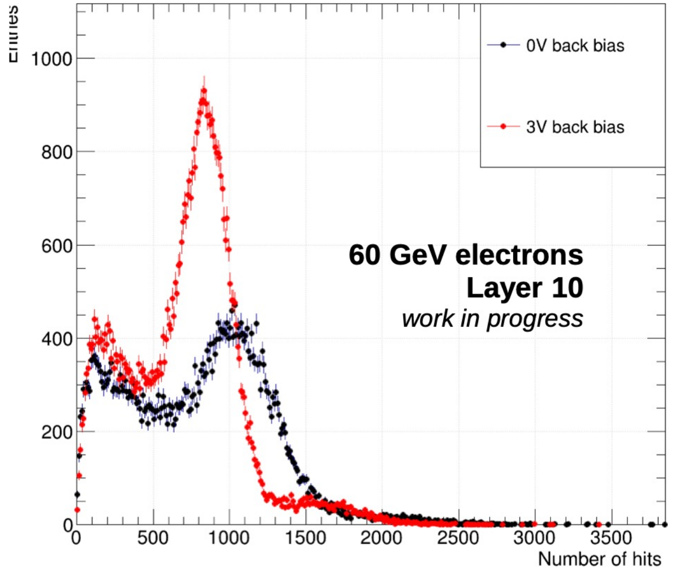


ITS3 TDR

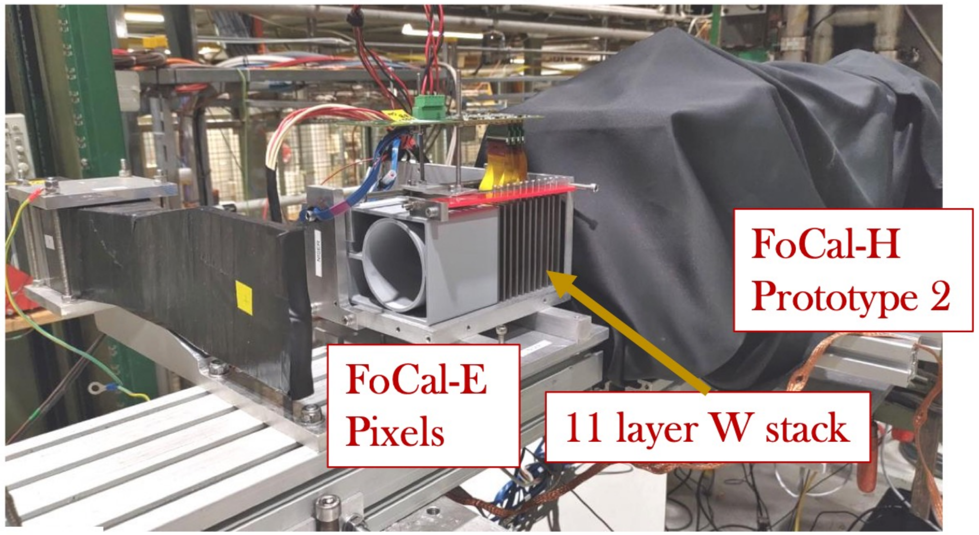
ALICE upgrade projects: FoCal

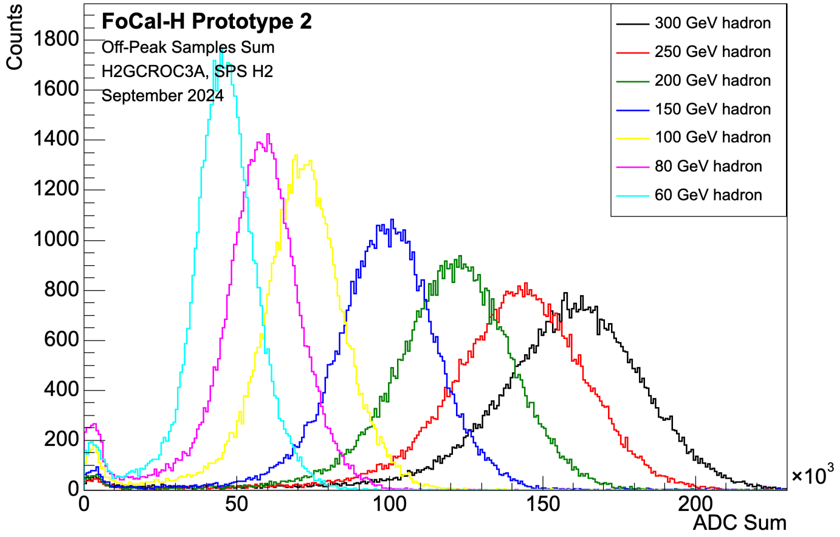
[FoCal TDR](#)





Test Beam setup 4-11 September 2024



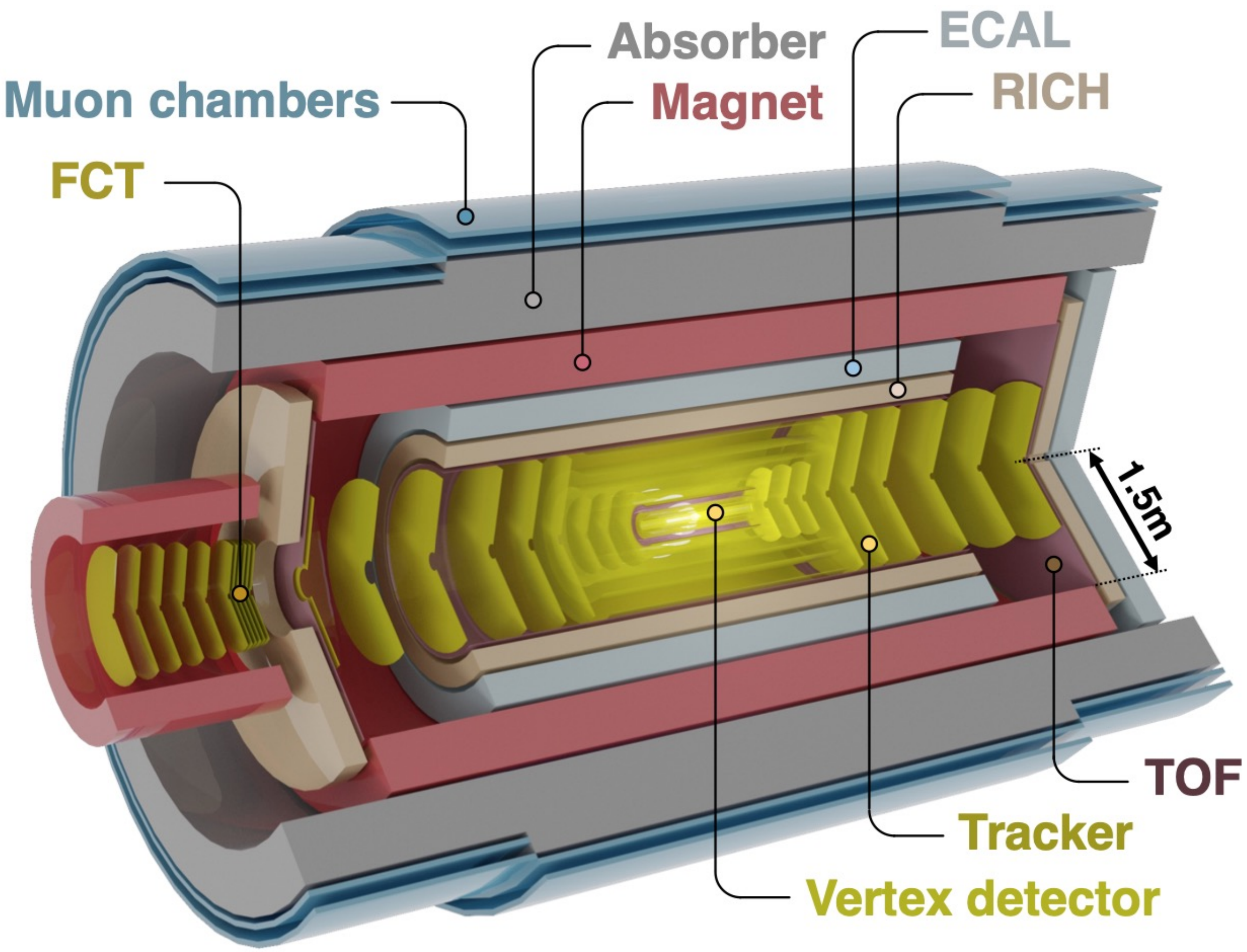


Testing ALPIDE pixel planes in back-biased mode
→ lower occupancy

FoCal-H raw signal with H2GCROC board (CMS)

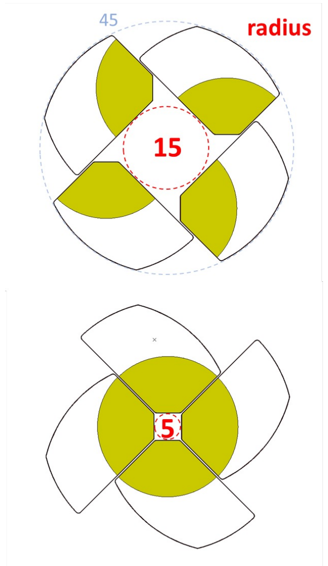
ALICE upgrade projects: ALICE 3

- **Novel detector concept**
  - Compact and lightweight all-silicon tracker
  - Retractable vertex detector with R_{min}= 5 mm
  - Extensive particle identification
  - Large acceptance $|\eta|$<4
  - Superconducting solenoid, B=2T
  - Continuous read-out and online processing
- **Sensor R&D ongoing**
  - Test-beams for MID, RICH, TOF in October
- **Scoping Document** submitted to LHCC referees - first discussion this week

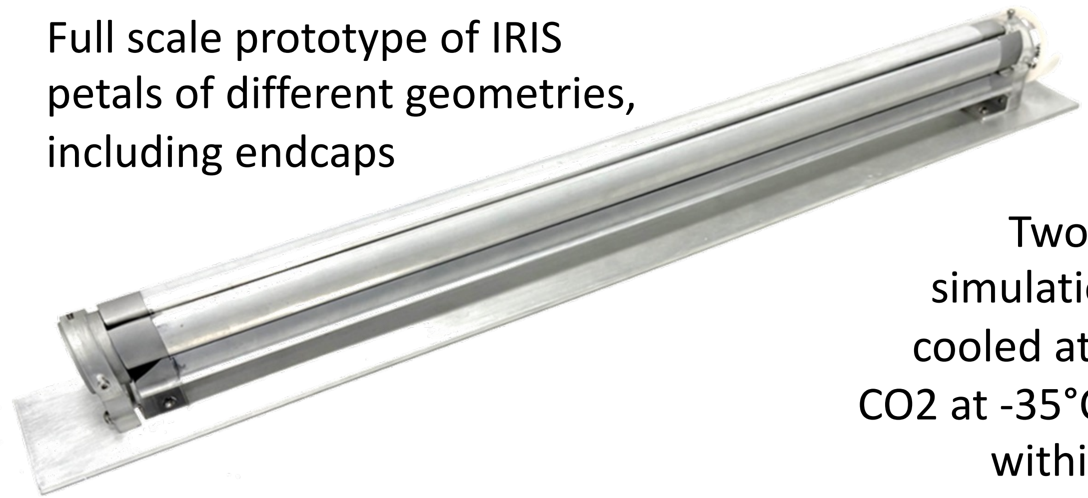


ALICE 3 LOI: arXiv:2211.02491

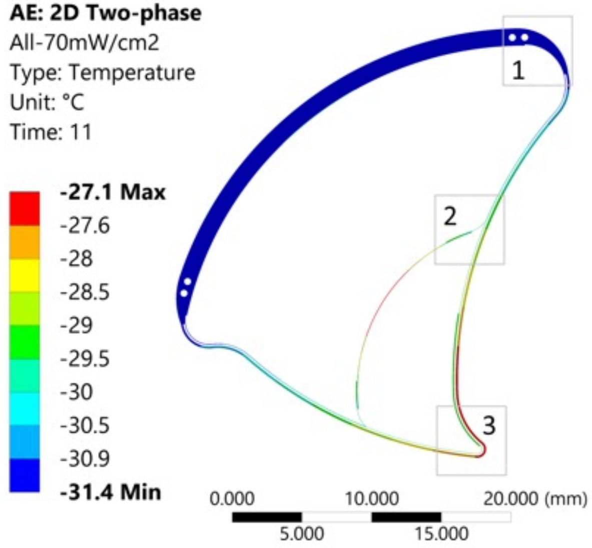
ALICE upgrade projects: R&D for Vertex detector

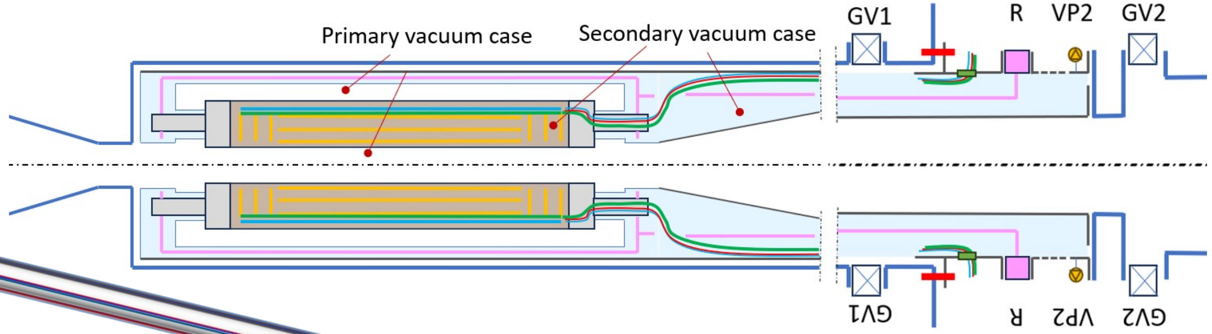


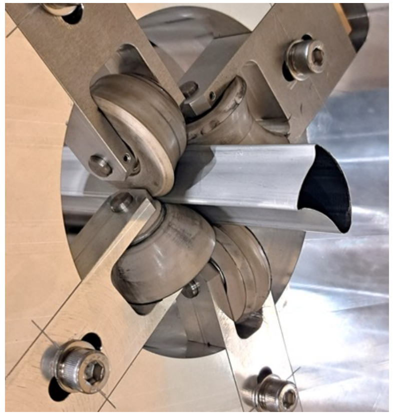
Full scale prototype of IRIS petals of different geometries, including endcaps

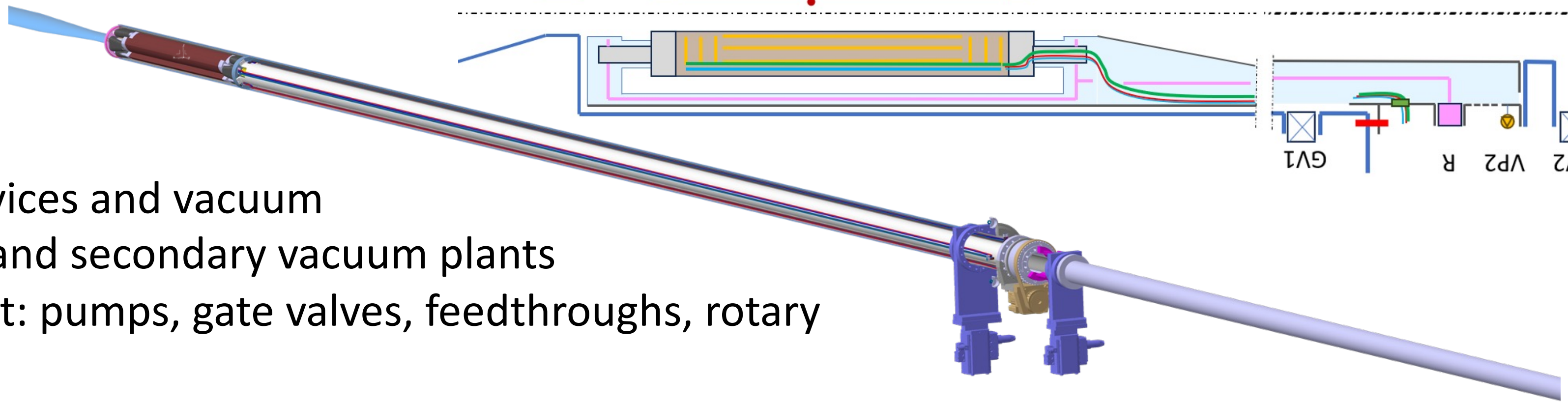


Two-phase CO2 cooling simulations: sensors can be cooled at -29°C with an inlet CO2 at -35°C, and a ΔT of 1-2°C within the single sensor







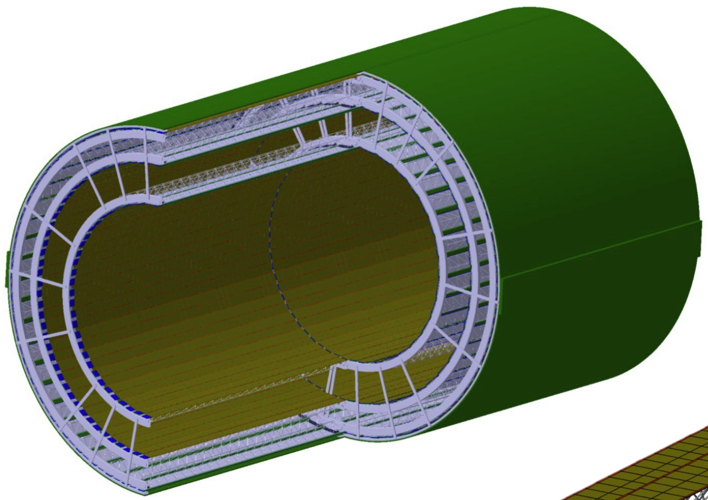


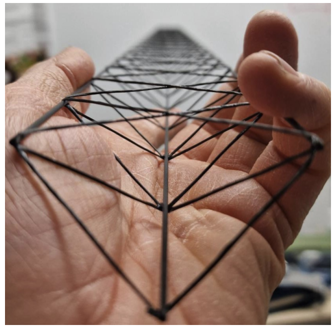
Integrations of services and vacuum
Design of primary and secondary vacuum plants
Study of equipment: pumps, gate valves, feedthroughs, rotary systems

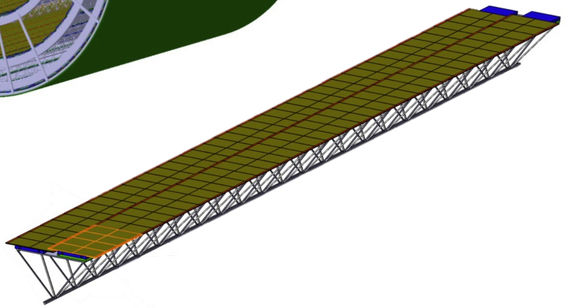
ALICE upgrade projects: R&D for Outer Tracker

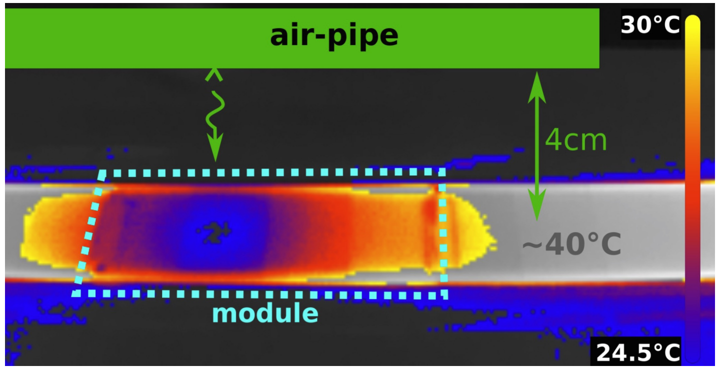
OT barrel and stave design:

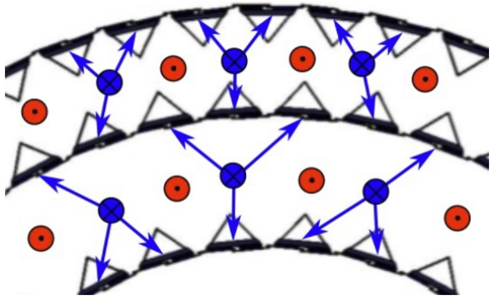
- detailed design of end and middle wheels including connections
- minimized gaps between barrels
- stave mock-ups using industrialized manufacturing process of carbon frame

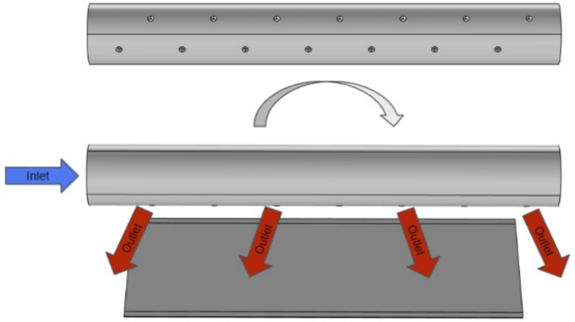












Air cooling studies:

- cooling pipes with micro-holes to inject cold air in front of sensors, Comsol simulations
- optimisation of pipe outlets and integration
- supply and removal of air
- vibration measurements

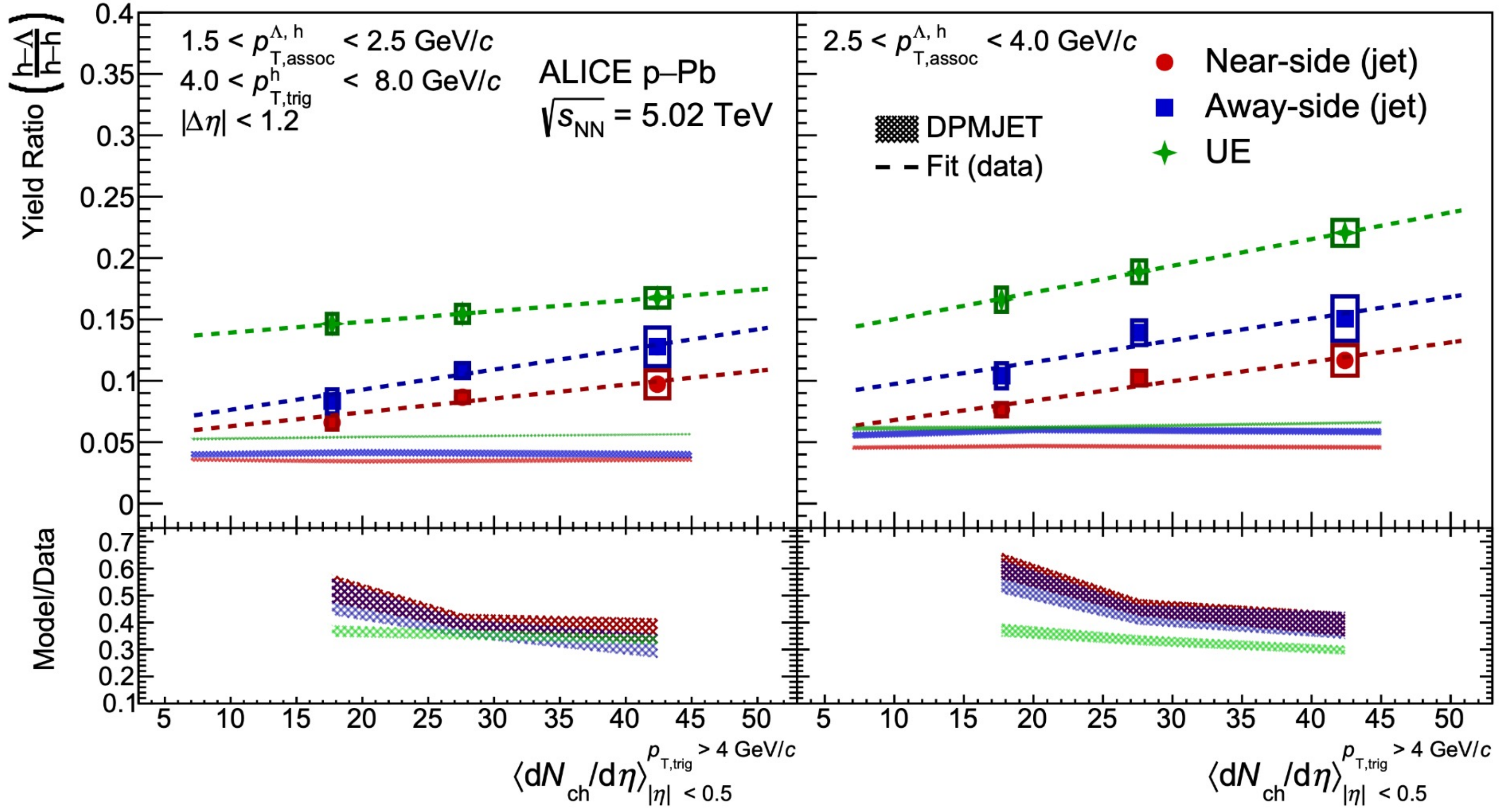
Summary

- **12 publications and 2 public notes** have been released since last LHCC meeting
  - 14 more publications are on preparation for Hard Probes conference (22-27 September)
- **Run 3 data taking** is proceeding steadily, collecting pp data with a luminosity **efficiency of ~90%**
  - Preparation for the upcoming **Pb—Pb runs** at the end of the year
- Large **upgrade program** foreseen for LS3 and 4
  - For **ALICE 3** discussion on scoping document is in progress, as well as intense R&D activities

Thank You...

Spares

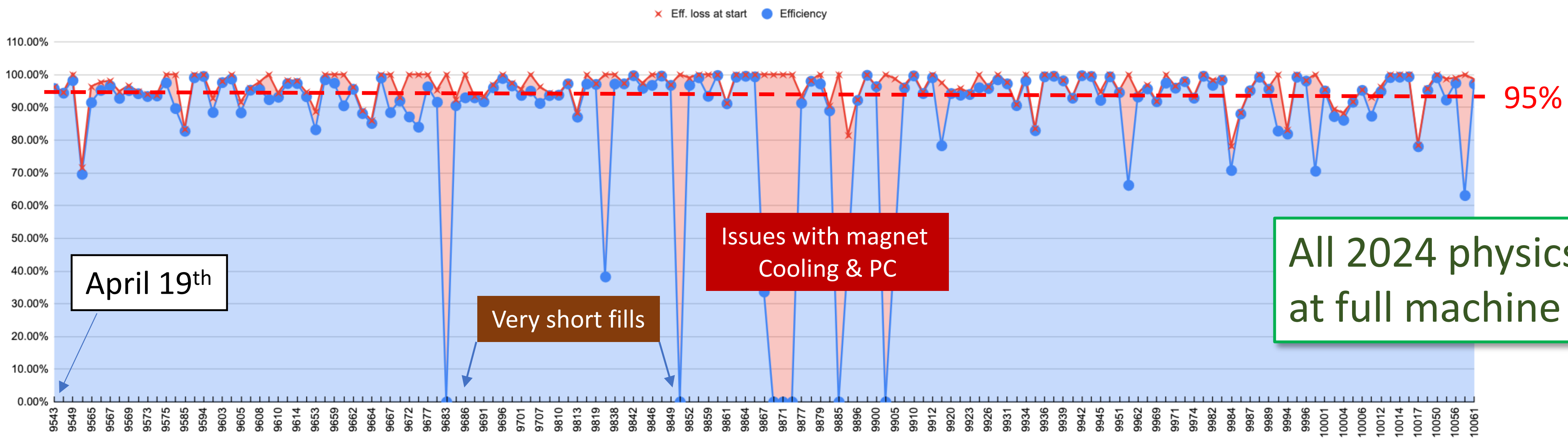
(h-Λ)/(h-h) (≃Λ/π) ratios in jet and UE vs. multiplicity



- Underlying event **(h-Λ)/(h-h)** ratios are higher than all other regions → **strangeness <u>production</u> mostly coming from UE!**
- Near and away-side jet **(h-Λ)/(h-h)** ratios increase with multiplicity → **strangeness <u>enhancement</u> in the jets?**
- DPMJET also predicts UE *<u>produces</u>* the most strangeness, cannot describe *<u>enhancement</u>* in any of the regions

ALICE Collaboration, arXiv:2405.19855

Data taking efficiency: all physics fills



All 2024 physics fills at full machine

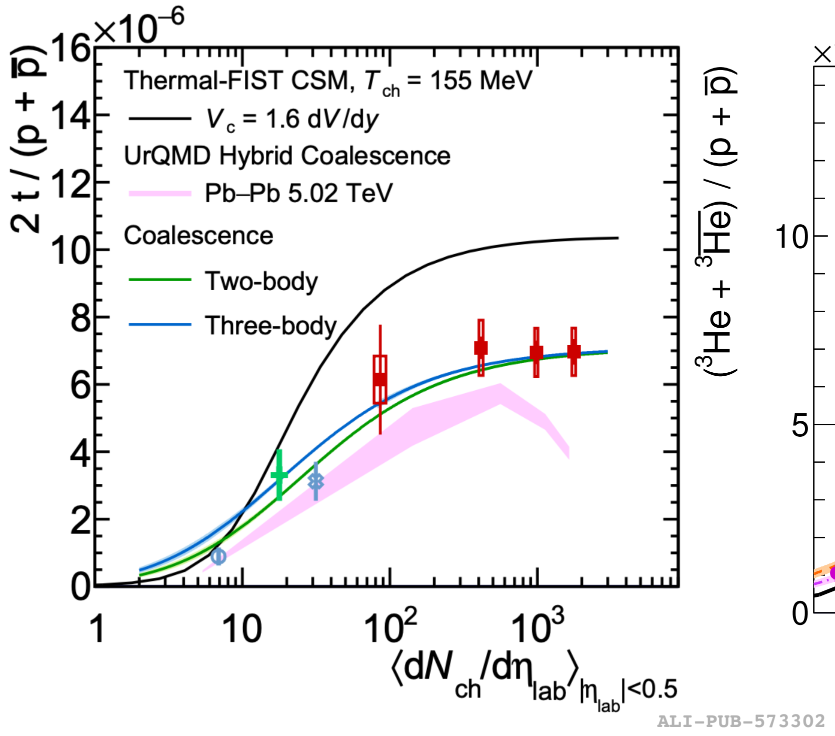
Data taking operations significantly more reliable compared to 2023

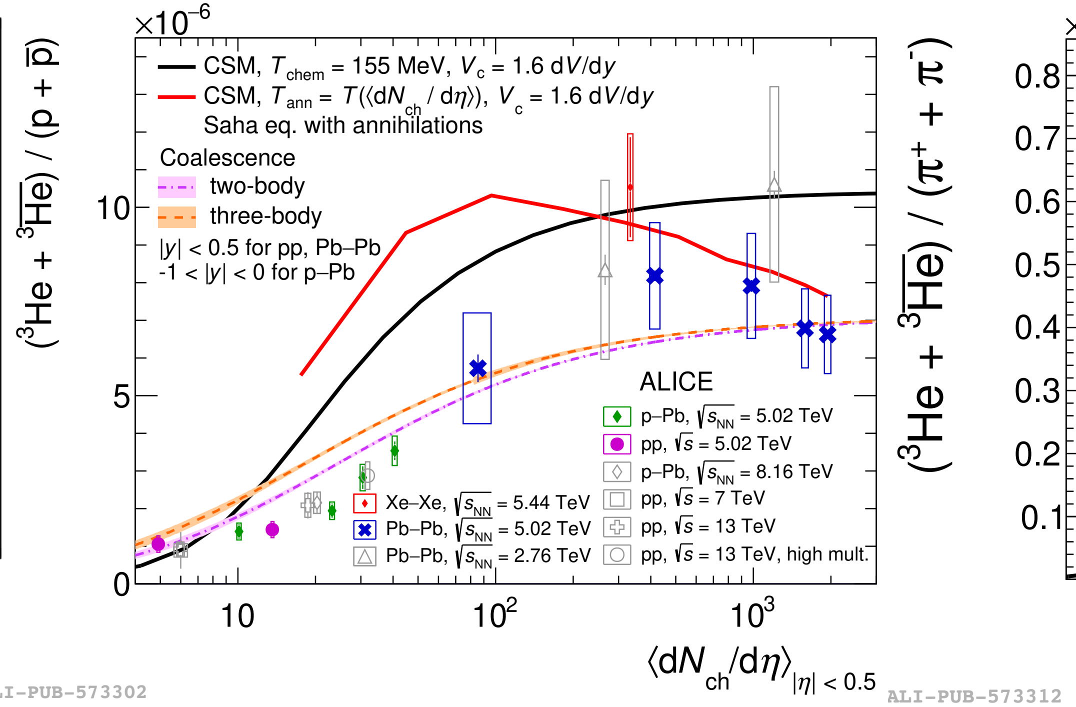
- Efficiency typically clustering around 95%
- Only rare issues with longer downtime (e.g. magnet issues)

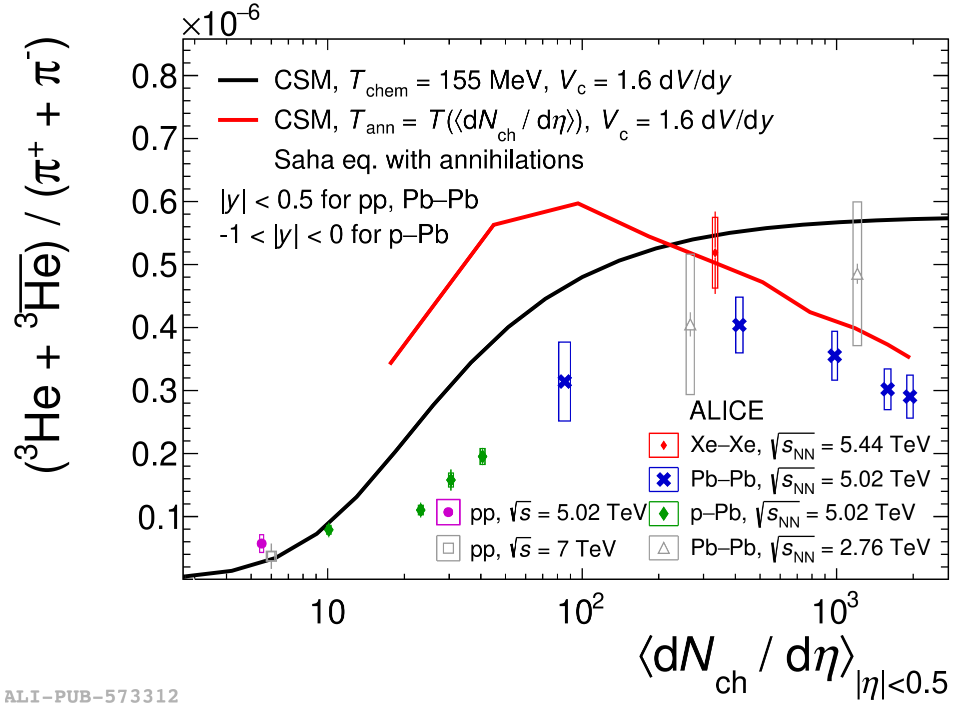
Typical weekly figures:

- Recorded luminosity: ~3 pb-1
- Data size on disk: ~10 PB

Testing production models with A=3







- Measurements of yields of nuclei with A=3 challenge the models
- Neither of the CSM models or **coalescence** predictions reproduce the trend of the ratios, but qualitatively reproduce the overall yields
- As for d/π and d/p ratios, CSM-II at high multiplicity catches the decreasing trend

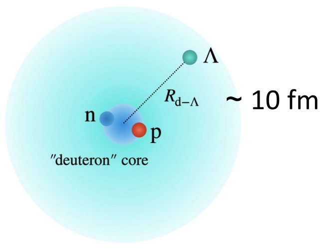
ALICE Collaboration, PRL 131 (2023) 041901
Vovchenko, Koch, PLB 835, 137577 (2022)
ALICE Collaboration, PRC 107 (2023) 064904
Sun, Ko, Doenigus, PLB 792 (2019) 132-137
ALICE Collaboration, arXiv:2405.19826

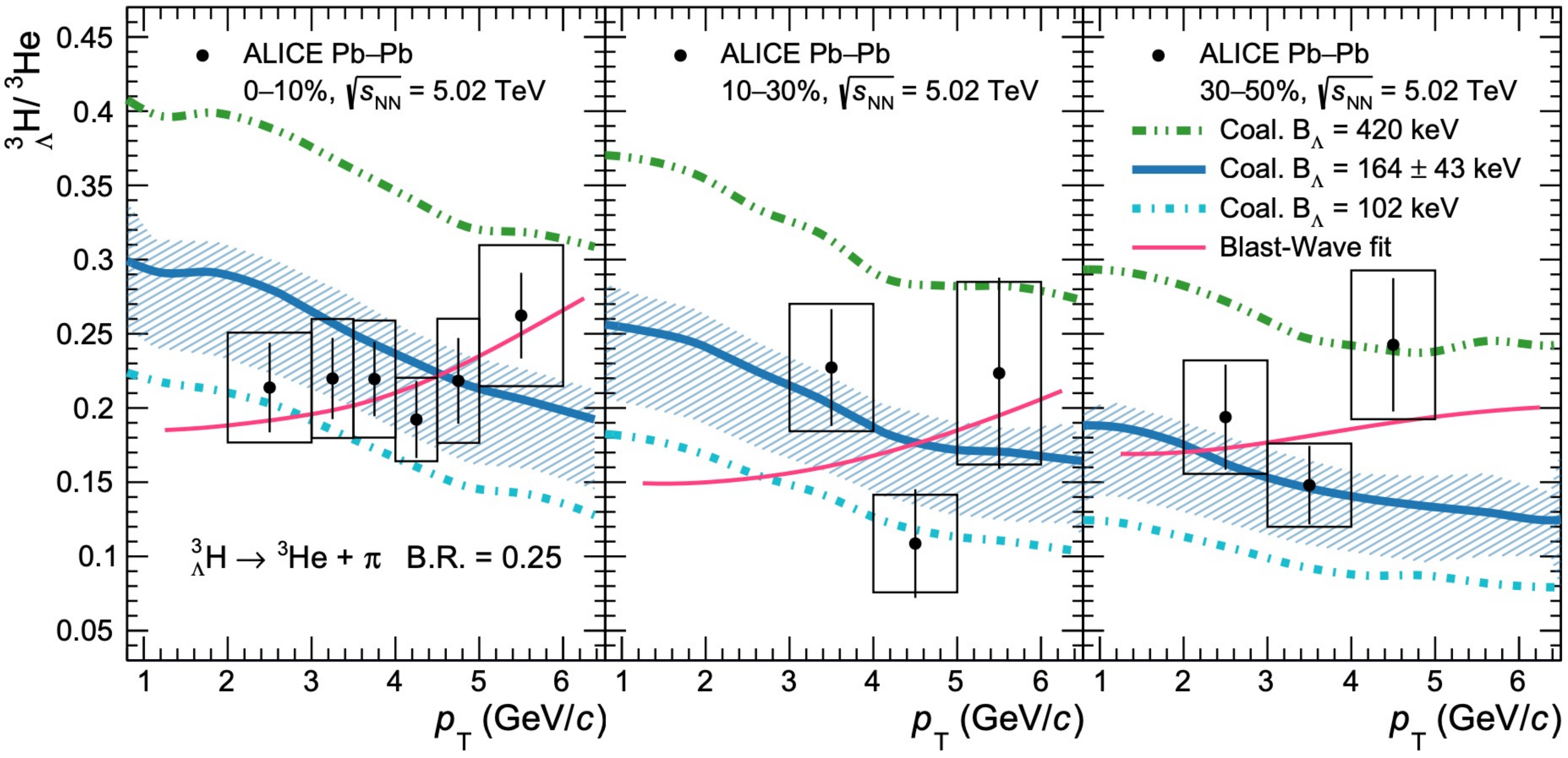
Hypertriton in Pb—Pb: test of production models

- $^{3}_{\Lambda}\mathrm{H}/^{3}\mathrm{He}$ ratio allows for testing the production models

vs. p_T
- Radial flow picture (Blast-Wave): higher mass states have a harder momentum spectrum
- Coalescence: at large momentum smaller source radius, hence the state with the larger wave-function will get suppressed

$^{3}_{\Lambda}\mathrm{H}$

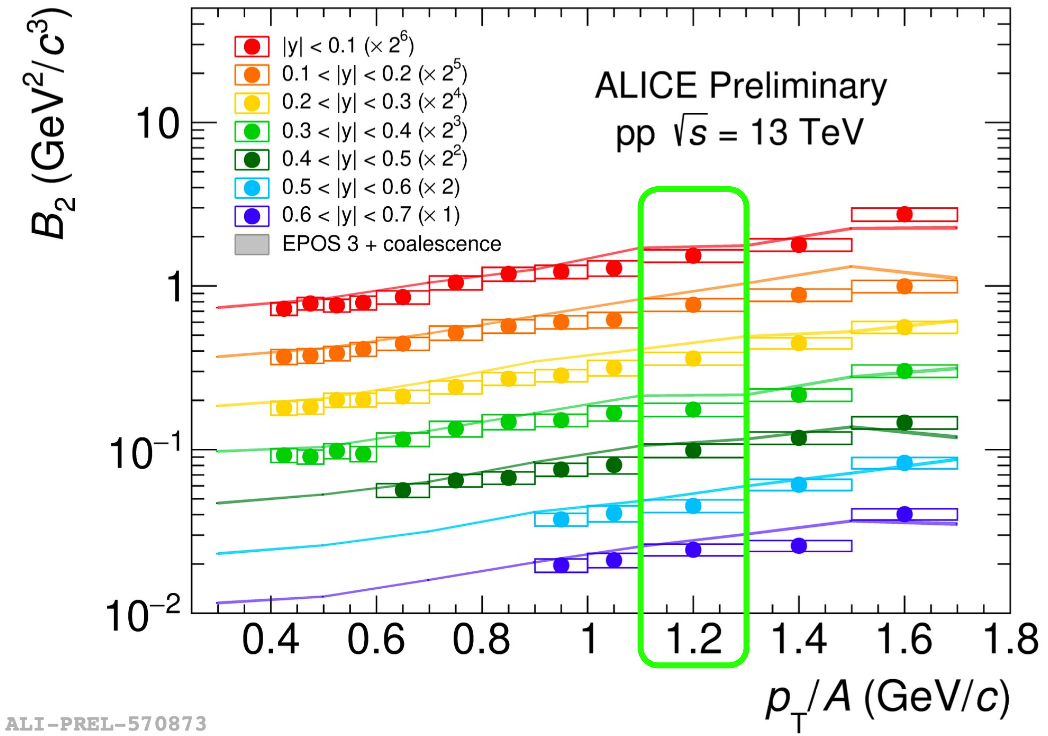




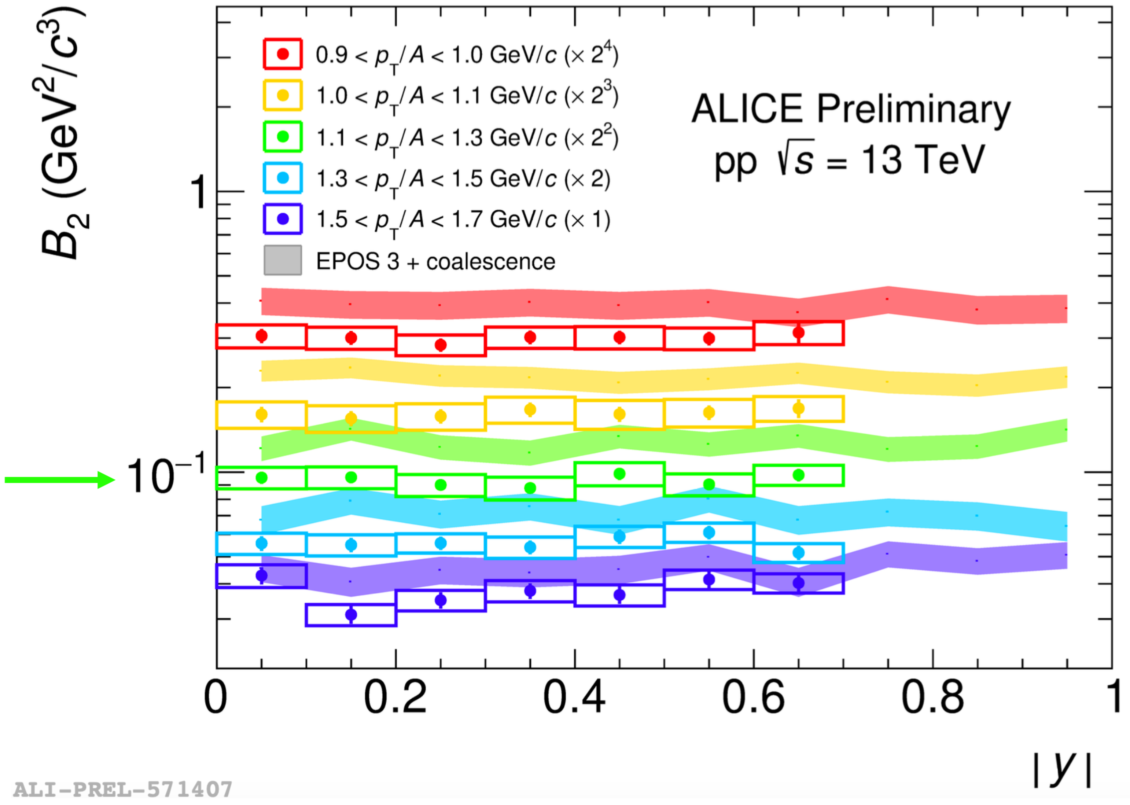
$r_{0,\text{ low pT}}$ ~ 6 fm → $r_{0,\text{ high pT}}$ ~ 3 fm

ALICE Collaboration, arXiv:2405.19839

B_2 vs rapidity with ALICE

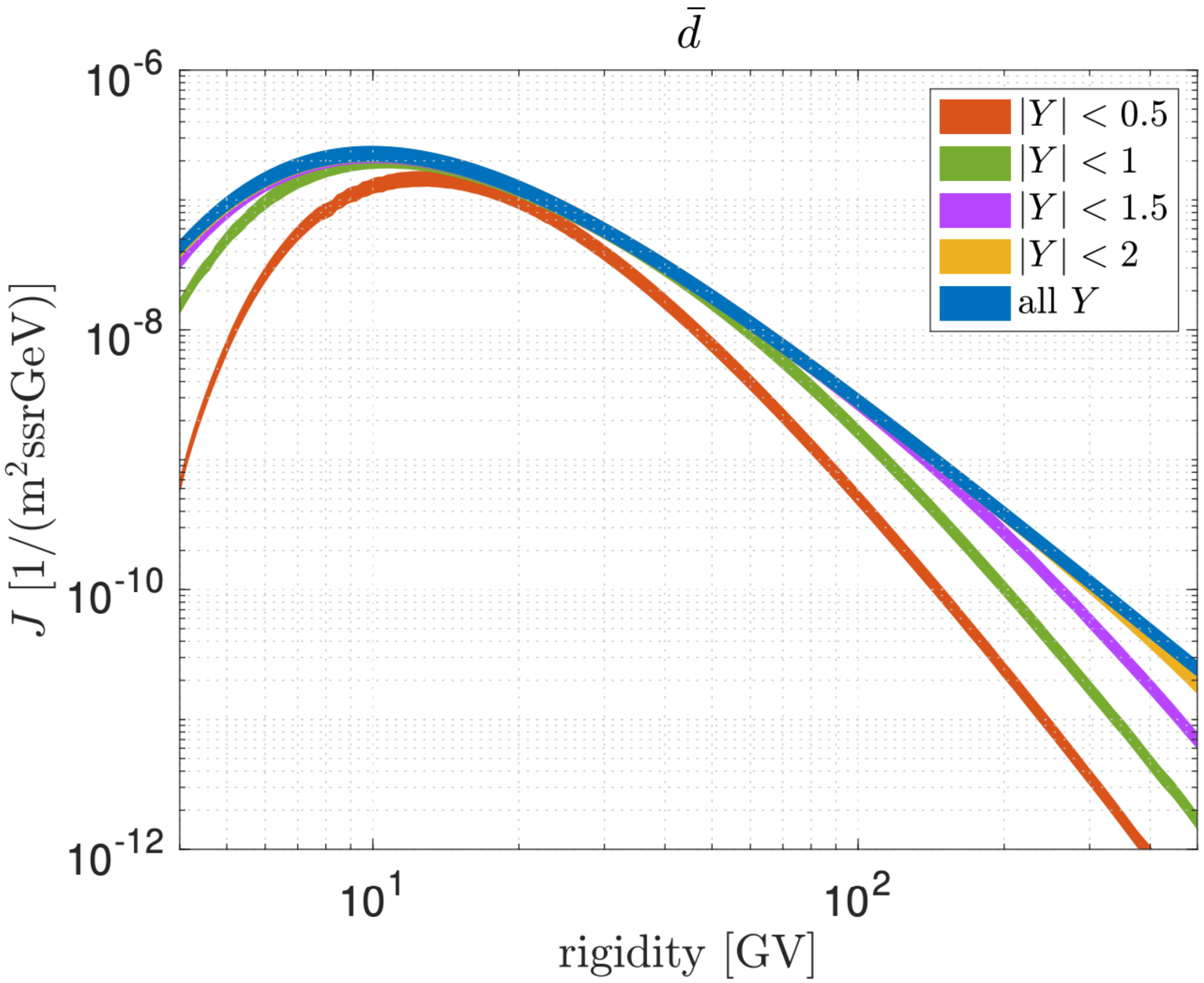


- ALICE measurements cover the midrapidity region (|y|<0.5), while astrophysical models extrapolate to forward region
- Current acceptance of ALICE detector allows one to extend the measurement of antinuclei up to |y| = 0.7



- Rapidity and p_T dependence of B_2 is extrapolated to forward rapidity using coalescence model + Pythia 8.3 and EPOS as event generators

Flux of antinuclei in CRs



- Model predictions based on ALICE measurements are used as input to calculate antideuteron flux from cosmic rays* → dominant background in dark matter searches
- **Most of the antideuteron yield from |y|< 1.5,** in reach with:
  - → future ALICE3[1] detector acceptance ($|y| \lesssim 4$)
  - → LHCb experiment with fixed target
  - → CMS in Run4
- Extrapolation to **lower energies** (~GeV) is needed for astrophysical models

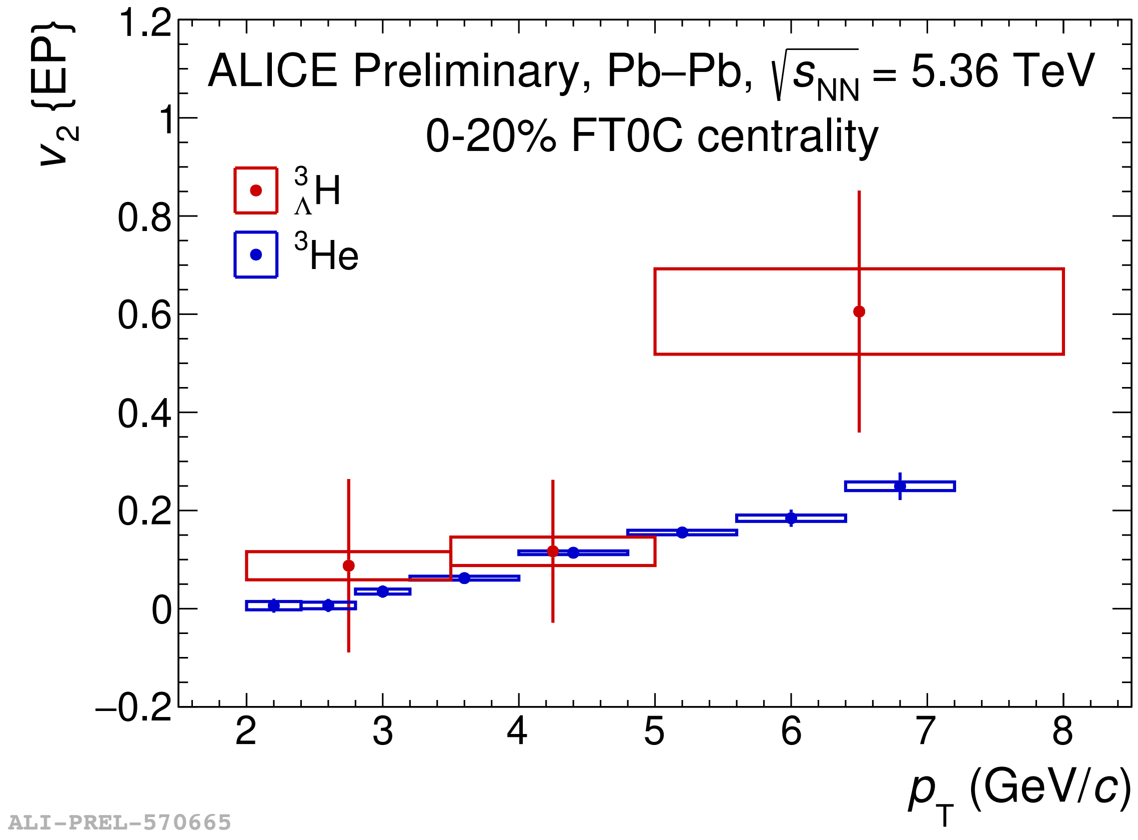
* K. Blum, Phys. Rev. D 96, 103021 (2017)

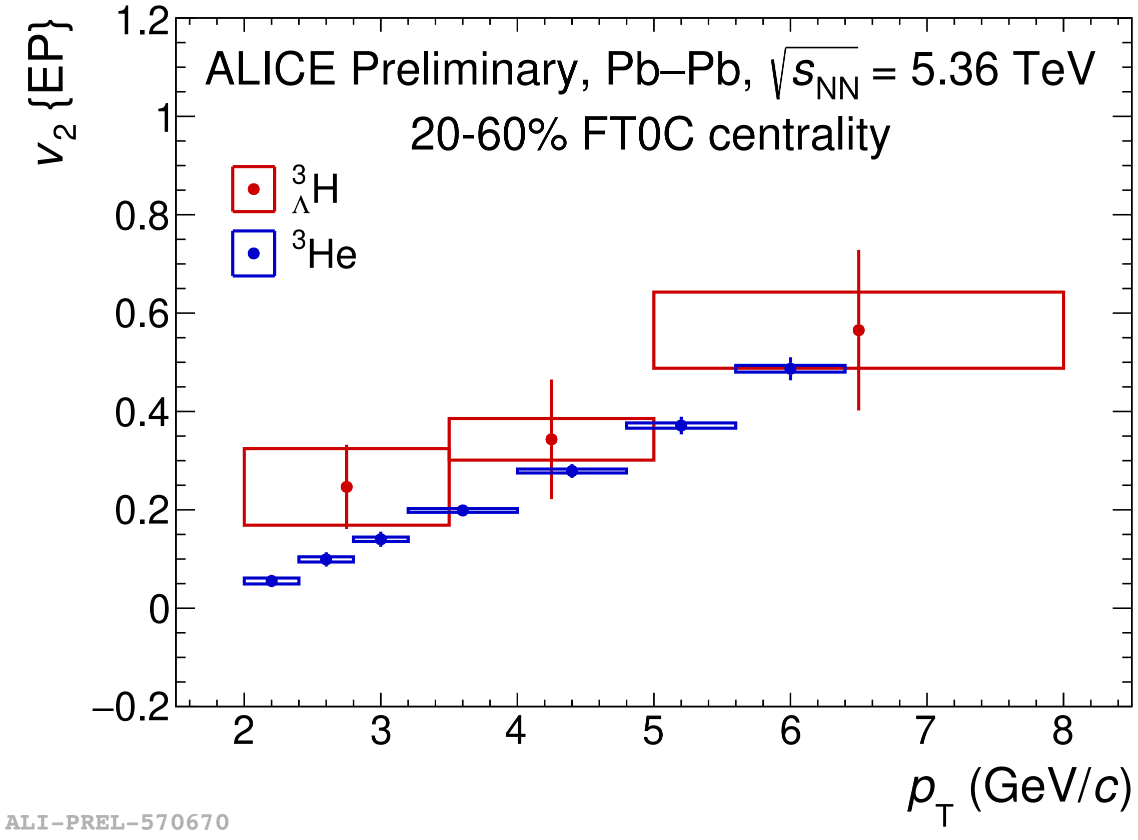
1 ALICE Collaboration, arXiv:2211.02491

K. Blum, arXiv:2306.13165

Elliptic flow of hypertriton measured by ALICE

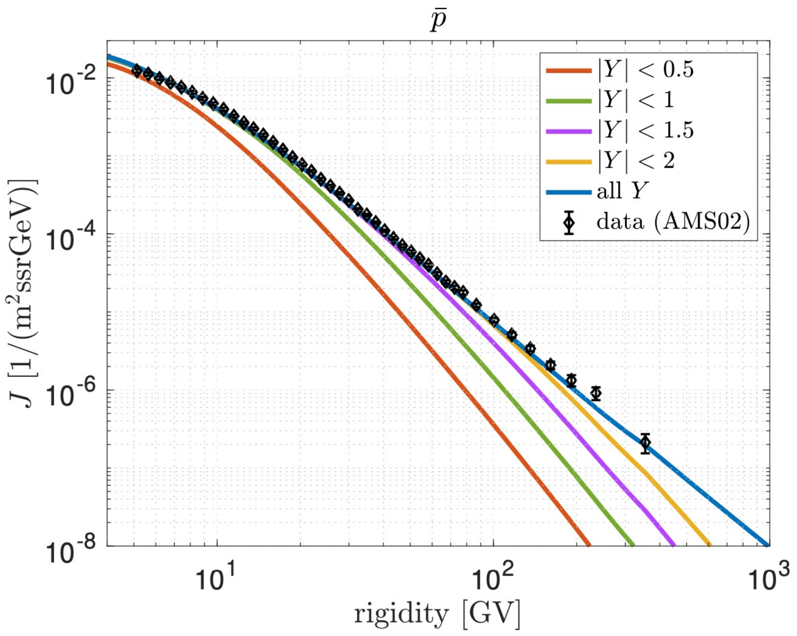
- ALICE delivered the first experimental measurement of hypertriton elliptic flow!
- Compatible with ^{3}He v_2, due to their similar masses
- Large uncertainties

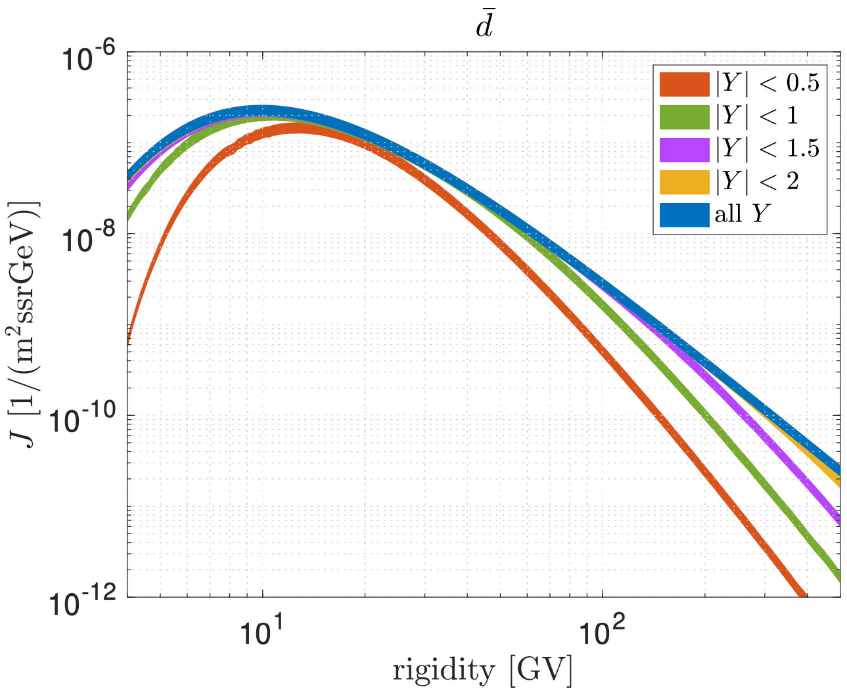


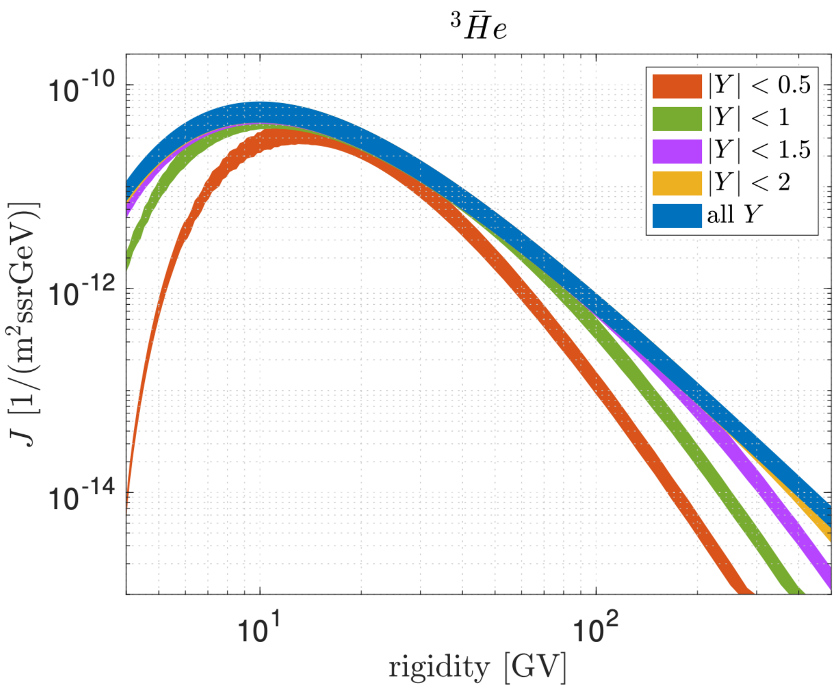


chiara.pinto@cern.ch

Flux of antinuclei in CRs

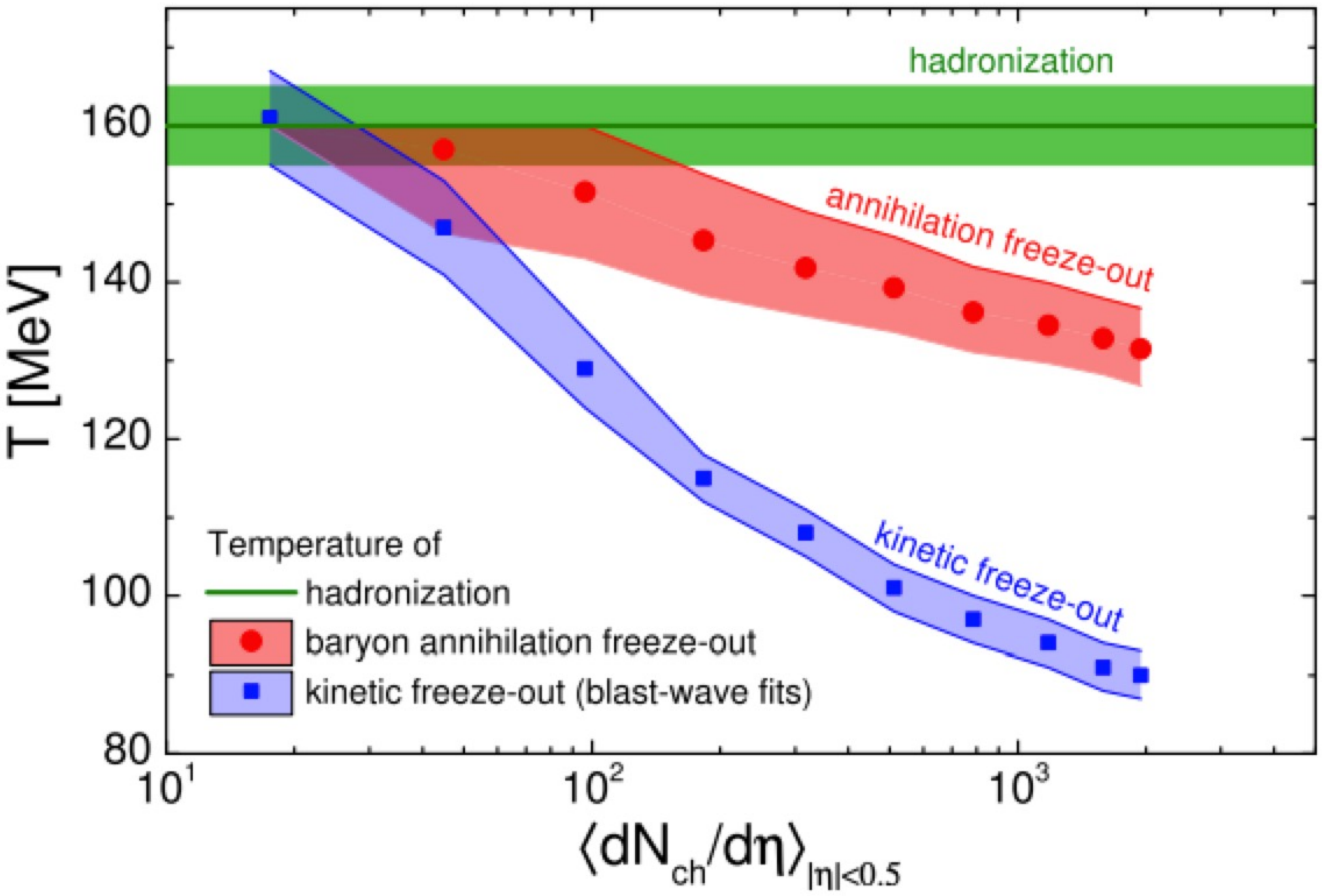






- K. Blum, Phys. Rev. D 96, 103021 (2017)
- K. Blum, arXiv:2306.13165
- M. Aguilar et al. (AMS02 Coll.), PRL 117, 091103 (2016)

CSM-II



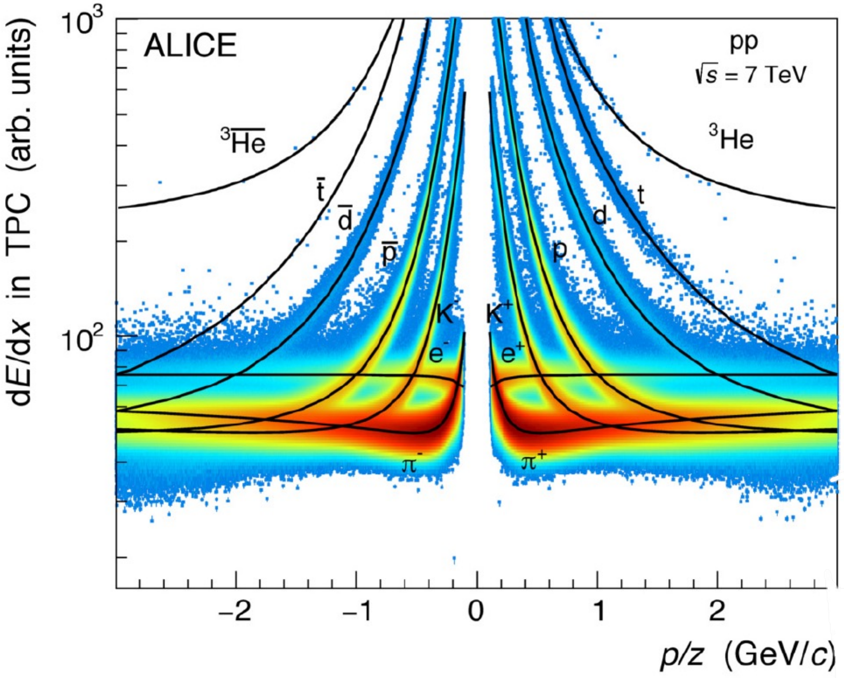
- Correlation volume fixed to 1.6 dV/dy
- Needed to describe the net-deuteron number fluctuations in PbPb collisions.
- Smaller than that of net-proton number fluctuations (3-5)dV/dy
- Temperature of annihilation depends on multiplicity

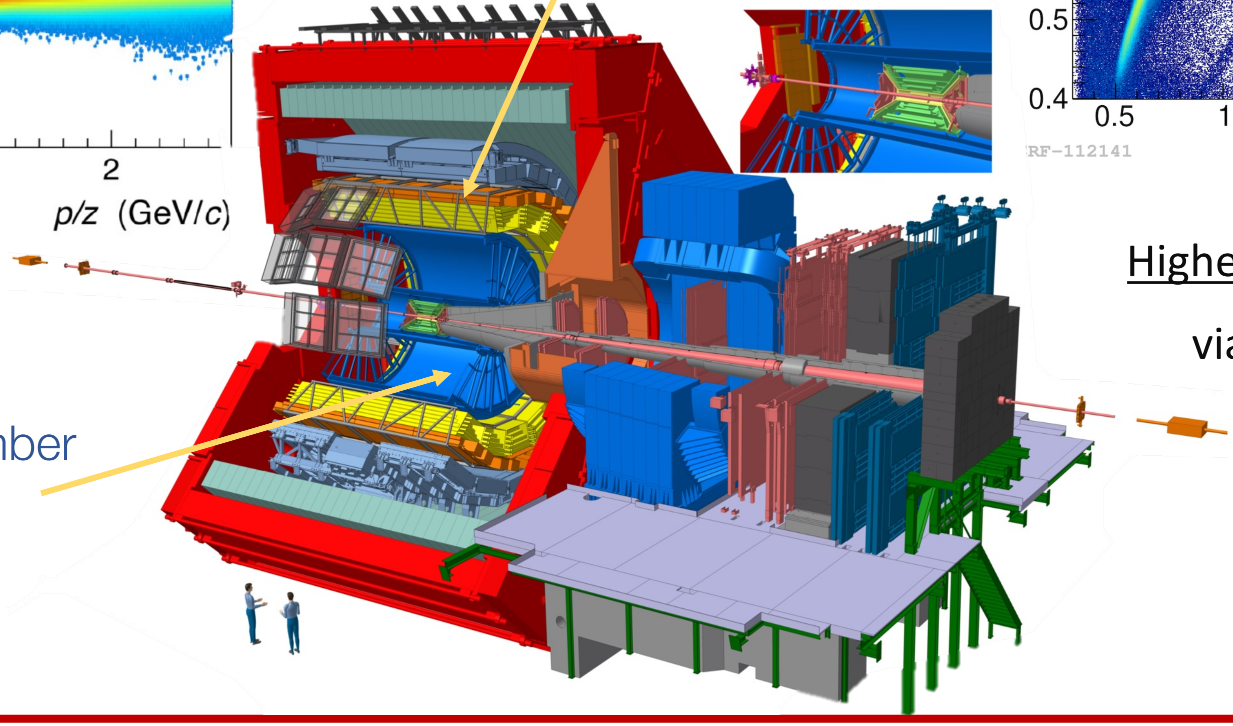
PLB 835, 137577 (2022)

For each multiplicity, the hadronic phase starts with hadronization at 160 MeV and expands in the state of partial chemical equilibrium which includes baryon annihilation reactions to reach chemical equilibrium at annihilation temperature

Identification of nuclei with ALICE

Low *p* region (below 1 GeV/*c*) → PID via d*E*/dx measurements in TPC





Time Of Flight

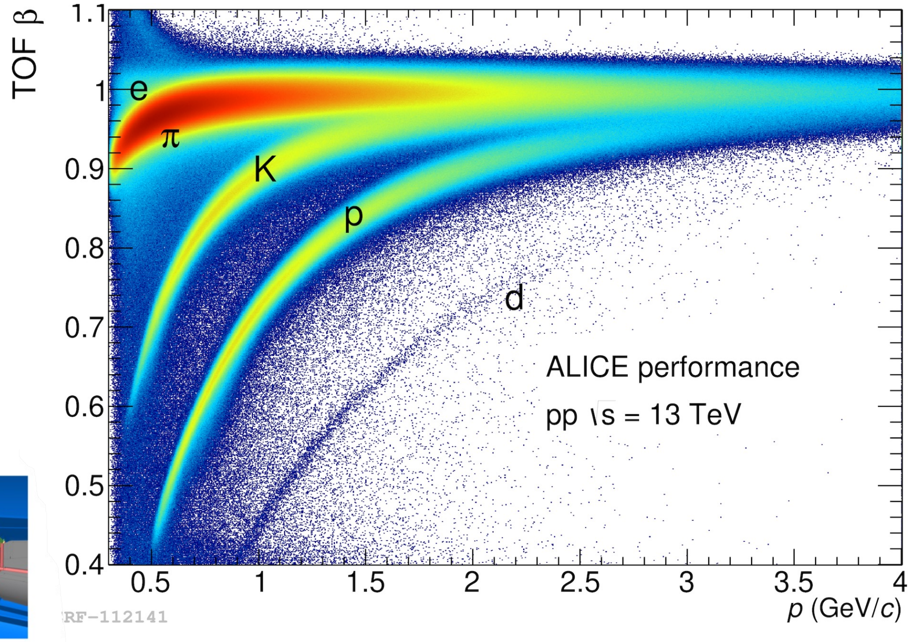
PID via β

σ_{PID} ~ 70 ps

Time Projection Chamber

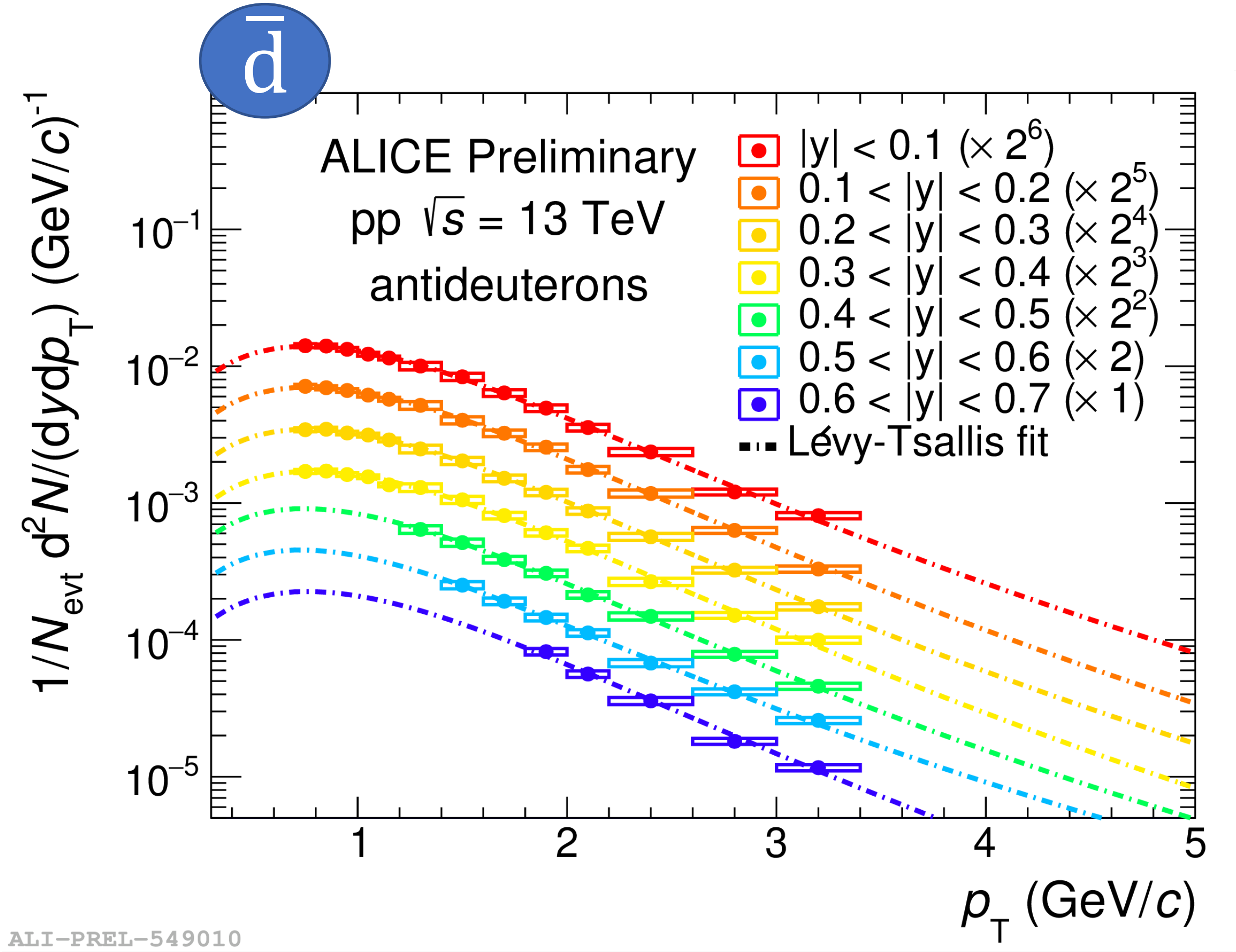
tracking, PID via d*E*/dx

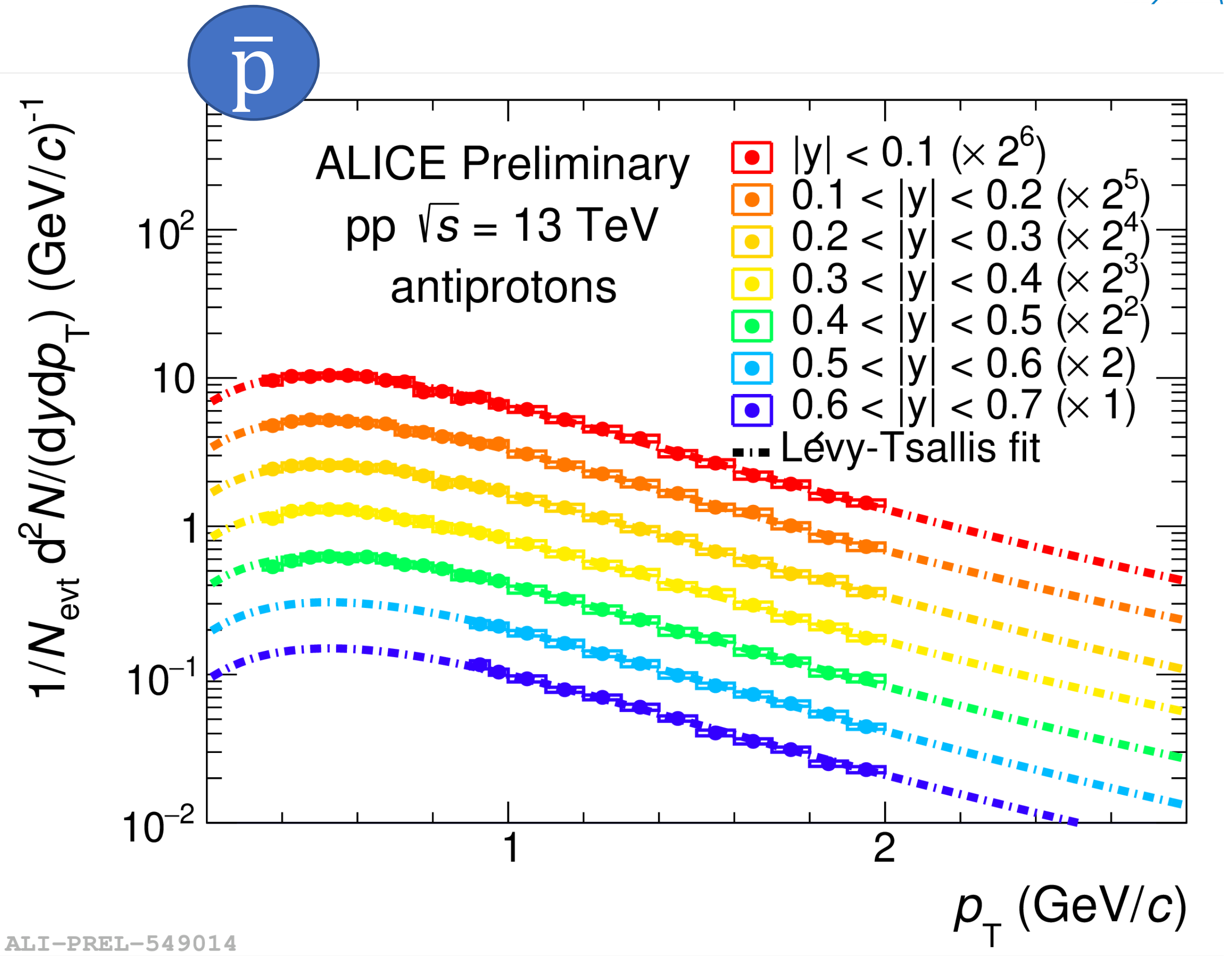
$\sigma_{dE/dx}$ ~ 6%



Higher *p* region (above 1 GeV/*c*) → PID via velocity β measurements in TOF

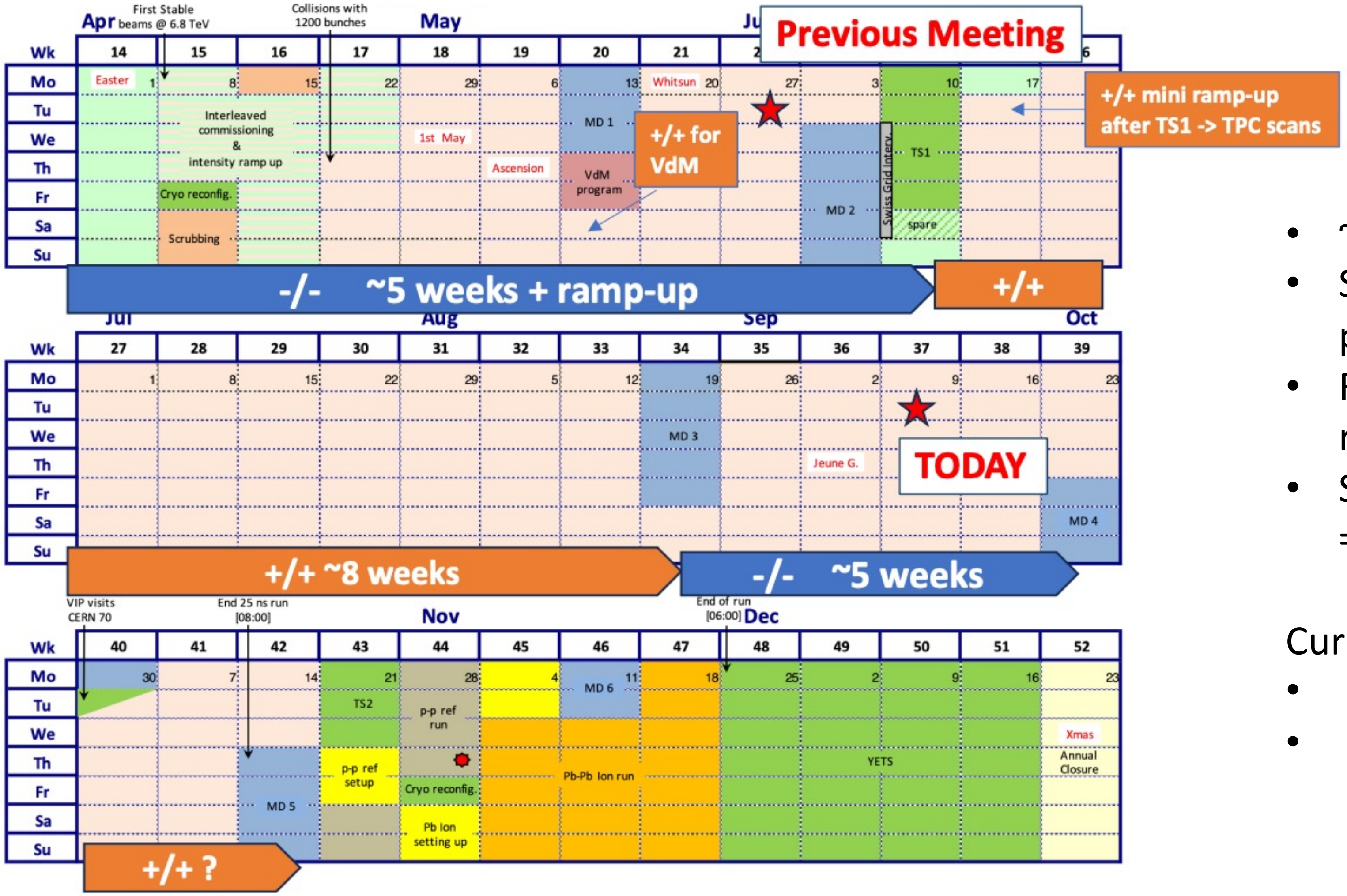
Spectra as a function of rapidity





- Current acceptance of ALICE detector allows to extend the measurement of antinuclei up to $y = 0.7$
- All rapidity classes show a common trend with y, for both species (ratio to $|y| < 0.1$ is ~1)

Run 3: status of ongoing data taking



- ~140d of pp collisions in total
- Since last LHCC meeting: pp physics production
- Regular inversion of magnets polarity to reduce systematic effects
- Short test at high rate after TS1
  => Rate scans for TPC distortion corrections

Current statistics:

- -/- ~15 pb^{-1}
- +/+ ~21 pb^{-1}